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ON YET ANOTHER MARGINAL NOTE OF FERMAT

R. Sridharan

Chennai Mathematical Institute, H1, SIPCOT IT Park, Padur Post, Siruseri - 603 103

Abstract

The aim of this article is to highlight a remarkable claim of Fermat made by him in his copy of Diophantus, that there is no Pythagorean triangle, whose area is a (rational) square, thereby settling in the negative, a question raised by Backet.

We include a proof of an equivalent statement that there do not exist three squares of integers in a nontrivial arithmetic progression, whose common difference is a square. We also show how the classical result (stated by Fermat, but proved by Euler) that there do no exist four rational squares in a nontrivial arthmetic progression is equivalent to a curious geometric property of rational triangles, which in turn is motivated by a result of Kummer.

Key words : Pythagorean triangles, squares in arithmetic progression, rational triangles and quadrilaterals.

INTRODUCTION

There have been great personages who are sometimes remembered by the future generations, not by the remarkable things they had achieved during their life time, but by their lapses. As the Bard puts it rather cynically, "The good (that men do is) oft interred with their bones". Let us take, as typical example, the work of the mathematician Fermat (1601-1665), whose name has recently caught the attention of the public in connection with a theorem (which he stated but di not prove)- the so called "Fermat's Last Theorem". It was merely an incidental and a rather hasty claim made by Fermat in the margin of his copy of Diophantus (edited by Bachet) and the claim had to wait for three centuries and more before it could reach the safe heaven of accepted mathematical truths. Fermat, has however every right to be among the immortals of mathematics for several other reasons. He was for instance the pioneer in the subject of Number theory, made remarkable contributions, and has rightly been regarded as the originator of modern Number theory. Our main aim in this article is to discuss yet another marginal note of Fermat in his copy of Diophantus, a remarkable statement, answering a question raised by Bachet in his edition of Diophantus. This time, however, Fermat in fact had a proof, using his method of "infinite descent". Incidentally, Fermat seems to have been justly proud of this method. Indeed, in a very brief summary of his work on Number theory which he sent to Huygens, Fermat refers to it as "a most singular method", and adds "though it is harder to apply it to prove affirmative statements like 'Any prime of the form $4n+1$ is a sum is a sum of two squares' ".

In this article we not only present Fermat's proof of Bachet's' question but include some history and discuss some related problems. I would like to point out that there is an excellent recent book on this result of Fermat by Catherine Goldstein [1], which includes an extensive history.

ACKNOWLEDGMENTS

I am very grateful to the referee for critically going through the article and making useful suggestions. This article, which owes much to the deep erudition found in the book of A. Weil [11], is based on a lecture given in the "Conference on Mathematics Education" held in Delhi during December 19-22, 2007 organised by NBHM, NCERT, IGNOU, HBCSE and NCTE. I thank Professor M.S. Raghunathan and R. Bhatia for inviting me to give a lecture and to V. Balaji and K.R. Nagarajan for their encouragement. I would particularly like to express my warm thanks to Dr. K. Subramaniam of the Homi Bhabha Centre at whose suggestion the above mentioned lecture was written up as the present article. I thank Santanu for the meticulous care he took to being the manuscript to its present form and Sripathy, who as ever, came with ready help. And last not least,

Dedicated to the memory of C. Musili who had no complains against the past and was ever hopeful for the future *"Horas non numero nisi serenas"* (I number none but shining hours).

*Corresponding Author: rsridhar@cmi.ac.in

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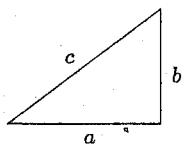
2. Pythagorean Triangles

The result of Fermat that we shall discuss is the following:

Theorem 1. *The area of a Pythagorean triangle cannot be a square (of a rational number).*

We begin with the definition of a Pythagorean triangle and record a few basic facts.

A triangle is called *Pythagorean* if it is right angled with (the lengths) of all its sides integers.



Let a, b, c be the lengths with the side corresponding to c the hypotenuse. We recall that the Pythagorean triangle is called *primitive* if a and b are co-prime. Hence, in this case, we can assume without any loss in generality that a is even and b is odd. For if a and b were both odd, then the equation $c^2 = a^2 + b^2$ would imply that c^2 would be congruent to 2 modulo 4 which it cannot be, being a square. We also note that c must be odd. Examples of sides of primitive triangles are $a = 4,\ b = 3,\ c = 5$; $a = 12,\ b = 5,\ c = 13$; $a = 14,\ b = 9,\ c = 41$; etc. (Such examples were known to all the ancient civilisations. The rope stretchers of Egypt, the constructors of the sacrificial altars in India during the vedic period,... all must have known it.)

3. Some History

The problem on Pythagorean triangles considered by Fermat can be traced back to Diophantus of Alexandria (though a little indirectly). Of Diophantus we know very little. He probably lived around 250 A.D. An epigram written probably by some friend of his, not long after his death, which is in the form of a mathematical problem to determine Diophantus' age (denoted x) when he died, leads to the equation $\frac{x}{6} + \frac{x}{12} + \frac{x}{7} + 5 + \frac{x}{2} + 4 = x$ from which one concludes that the boyhood of Diophantus lasted for 14 years, his beard grew when he was 21, he married at 33, a son was born to him after 5 years who died at the age of 42 when his father (Diophantus) was 80 and Diophantus died 4 years later. Diophantus wrote the "Arithmetica" in thirteen books of which only six books survive now and he also wrote

a tract "On polygonal numbers" [5,6]. The first commentator of Diophantus of whom we hear is the very learned daughter Hypatia of Theon of Alexandria. Theon lived towards the end of the fourth century in Alexandria. According to Theon, Hypatia in fact collaborated with him in his commentary on Ptolemy. As Dreyer points out in his beautiful book "A History of Astronomy from Thales to Kepler" [4], this work of Theon was perhaps the very last scientific work which made use of the celebrated library at Alexandria. It was indeed destroyed soon, in Theon's own life time. As Heath in [5,6] and van der Waerden in [10] point out, Hypatia was renowned for her mastery of pagan science, philosophy and medicine. She was justly considered the personification of the highest Greek culture and thought. She had influence on Christianity, even though, she belonged to pagan hellenism and had connections in the highest circles not only in literary matters, but even in practical matters too. She was a professor of Philosophy at the University of Alexandria. She moved freely among men, commanding respect and decency. One of her friends was the Roman Prefect Orestes who was a mortal enemy of the Christian Bishop Cyrillus. She was accused by some Christian fanatics of having incited Orestes against Cyrillus, and was brutally murdered by a mob in 418 A.D. Hypatia's commentary on Diophantus is unfortunately not extant.

Among the more recent commentators of Diophantus' work, are Bombelli (1526-1572), an engineer in Rome, (who translated most of it and incorporated it in his book in Italian on Algebra) and Holzman(1532-1576) of Basel who was a humanist, hellenised his name to Xylander and took up Algebra as a hobby. But the two persons, whose versions of Diophantus influenced Fermat, are Viete(1540-1603),who was regarded a mathematician by his contemporaries and who published his *Zetetica* towards the end of the sixteenth century, and Bachet(1581-1638), a gentleman of independent means and classical tastes, who published his Latin version of Diophantus in 1621.

4. The Theorem

The theorem of Fermat on the non existence of a Pythagorean triangle with (rational) square area was motivated by problem on right angled triangles added by Bachet to Book VI of the "Arithmetica" of Diophantus. Bachet added this problem to the problems about right angled triangles found in Book VI of Diophantus' "Arithmetica"

The problem proposed by Bachet is the following:

"To find a (rational) right-angled triangle such that its area is equal to a given number."

The theorem of Fermat obviously settles the problem of Bachet in the negative. Before starting on the proof of Fermat's result, we begin with some generalities which we need. We begin with the following

Theorem 2. *Let a, b be the (lengths) of the sides of a primitive Pythagorean triangle with a even, and c the length of the hypotenuse. Then, there exist unique positive integers p and q, (called generators), $p > q$, with*

$$a = 2pq,\ b = p^2 - q^2,\ c = p^2 + q^2.$$

The integers p and q are co-prime, and with different parity.

Proof. We have $a^2 = c^2 - b^2 = (c+b)(c-b)$. Since b and c are co-prime, it follows that $c+b$ and $c-b$ have a common factor 2 and no other. We have

$$\frac{a^2}{4} = (\frac{c-b}{2})(\frac{c+b}{2}).$$

Since $a^2/4$ is a square of an integer, there exist integers p, q with $\frac{c+b}{2} = p^2$, $\frac{c-b}{2} = q^2$. Hence $b = p^2 - q^2$, $c = p^2 + q^2$ and $a = 2pq$. It is easily seen p, q are co-prime and with different parity and it is immediate that p, q are unique.

We note also that the lengths of the sides of a not necessarily primitive Pythagorean triangle are of the form $a = 2dpq, b = d(p^2 - q^2), c = d(p^2 + q^2)$ for some positive integer d, and that the area of a primitive Pythagorean triangle is

$$\frac{1}{2}ab = \frac{1}{2}2pq(p^2 - q^2) = pq(p+q)(p-q)$$

with the above notation.

We use the above theorem to prove Fermat's result.

Theorem 3. *(Fermat) There exists no Pythagorean triangle whose area is a (rational) square.*

Proof. Suppose that such a triangle exists. We may assume that it is primitive so that the lengths of its sides are $p^2 - q^2$, $2pq$ and the length of its diagonal is $p^2 + q^2$ where p, q are integers with $p > q$, p and q co-prime and p, q have different parity. The area of the triangle being $pq(p-q)(p+q)$ which is assumed to be a rational square, it follows, since p, q, $p-q$, $p+q$ are pairwise co-prime, that these are all squares. Let $p = x^2$, $q = y^2$, $p+q = u^2$ and $p - q = v^2$. We have $x^2 + y^2 = p + q = u^2$, $x^2 - y^2 = p - q = v^2$. (Note that this means that u^2, x^2, v^2 are three squares in an arithmetic progression whose common difference is a square, viz. y^2). We have $u^2 = v^2 + 2y^2$ so that $2y^2 = (u+v)(u-v)$. We note that since both u and v are odd, $u+v$ and $u-v$ are both even. We claim that the gcd of $u+v$ and

$u - v$ is 2. This is because any divisor of $u + v$ and $u - v$ must divide $2u$ and $2v$. Since $u^2 = x^2 + y^2$ and $v^2 = x^2 - y^2$ are co-prime, this divisor must be 2.

Thus, either $u + v = 2r^2$ and $u - v = 4s^2$ so that $u = r^2 + 2s^2$ and $v = r^2 - 2s^2$, or $u + v = 4s^2$ and $u - v = 2r^2$ in which case $u = r^2 + 2s^2$ and $-v = r^2 - 2s^2$. So, in any case, $u = r^2 + 2s^2$ and $\pm v = r^2 - 2s^2$ and $y^2 = 4r^2s^2$, $x^2 = \frac{1}{2}(u^2 + v^2) = r^4 + 4s^4$. We, therefore, obtain a rational right angled triangle with sides of lengths $\frac{u+v}{2}$ and $\frac{u-v}{2}$ (if $u > v$) and x and $x < x^4 + y^4 = p^2 + q^2$. However, $p^2 + q^2$ is the length of the hypotenuse of the original triangle. This completes the proof of the theorem, since we now have a Pythagorean triangle with its area also a square, and with its hypotenuse of strictly lesser length than that of the original triangle and of area a rational square namely r^2s^2 and we are through by an application of the principle of infinite descent. □

In fact, the proof given above establishes in particular among the statements below, the implications: 1)⇒ 2)⇒ 3).

1)There exists a Pythagorean triangle with its area a square.

2)[1]There exist two squares of integers whose sum and difference are both squares.

3)There exists an arithmetic progression consisting of three squares of integers such that their common difference is a square.

In what follows, we shall indicate a different method (using descent of course!) to disprove 3) which incidentally gives another proof of Fermat's theorem above. The next section is devoted to giving a parametrisation of three squares in arithmetic progression, a proof showing the impossibility of the existence of three squares of rationals in an arithmetic progression whose common difference is a square and finally a little bit of history.

5. Three Squares in an arithmetic progression and relation to Pythagorean Triangles

The problem of finding three rational squares in arithmetic progression must certainly date back to antiquity. In fact, as we shall see, finding such three squares is equivalent to finding Pythagorean triangles, using the algebraic identity $2(a^2 + b^2) = (a + b)^2 + (a - b)^2$. Let u^2, x^2, v^2 be rational squares in an arithmetic progression. Multiplying by a suitable square integer, we may assume u, x, v are integers. In this process, the common difference also gets multiplied by a square and is therefore a square integer if and only if the common

[1]With $x^2 + y^2 = u^2$ and $x^2 - y^2 = v^2$, we have $x^4 - y^4 = u^2v^2$, so that $x^4 - y^4 = z^2$ has a non-trivial integral solution, which is, of course, impossible. Fermat gave a proof of this impossibility which, in particular, implies that the equation $x^4 = y^4 + z^4$ has no non-trivial integral solution.

difference of the original progression is a rational square. Let us assume to start with that $u,\ x,\ v$ are integers with u^2, x^2, v^2 in an arithmetic progression.

We have $2x^2 = u^2+v^2$, so that $x^2 = (\frac{v-u}{2})^2+(\frac{v+u}{2})^2$. Since $u+v$ and $v-u$ are both divisible by 2, we obtain a Pythagorean triangle whose sides have length (if $u \leq v$), $(\frac{v-u}{2}, \frac{u+v}{2}, x)$. Thus there exist integers $p,\ q$ as in the parametrisation of Pythagorean triangles above and and a positive integer k such that one of $\frac{v-u}{2}$ and $\frac{u+v}{2}$ is $k(p^2-q^2)$, the other being $2kpq$ and $x = k(p^2+q^2)$. Hence any three squares in arithmetic progression can be written as

$$k^2(p^2-q^2-2pq)^2,\ k^2(p^2+q^2)^2,\ k^2(p^2-q^2+2pq)^2.$$

Note that the common difference of this arithmetic progression is $k^2(p^2+q^2)^2 - k^2(p^2-q^2-2pq)^2 = 4k^2pq(p+q)(p-q)$, so that, the arithmetic progression has its common difference a square if and only if $pq(p+q)(p-q)$ is a square. We thus have a parametrisation of three squares in an arithmetic progression in terms of Pythagorean triples, and under this parametrisation,the common difference of the progression is, upto squares of integers, equal to the area of the corresponding Pythagorean triangle.

Thus the question of the existence of a Pythagorean triangle whose area is a square is equivalent to the existence of three integer (rational) squares in arithmetic progression whose common difference is a square. Now we give a direct proof of the non-existence of a non-trivial arithmetic progression of three squares of integers whose common difference is also a square.

Theorem 4. *There are no three squares of integers in a non-trivial arithmetic progression whose common difference is a square.*

Proof. In view of what we have seen above, we need only to show that if we take $(p^2-q^2-2pq)^2,\ (p^2+q^2)^2,\ (p^2-q^2+2pq)^2$, where p, q correspond to a primitive Pythagorean triangle, then $pq(p+q)(p-q)$ cannot be the square of an integer. We prove this by infinite descent, by assuming that $pq(p+q)(p-q)$ is a square and by producing three other integer squares in an arithmetic progression whose common difference is strictly less than the common difference of the progression we started with. Suppose that $pq(p+q)(p-q)$ is a square. We note that by our choice of p and q, the integers $p,\ q,\ p-q,\ p+q$ are all pairwise co-prime. (In fact, since p and q are co-prime, it follows that all the pairs among the integers above, except possibly $p+q$ and $p-q$ are co-prime. However, any prime dividing $p+q$ and $p-q$ must divide $2p$ and $2q$. Therefore, the only possible common factor of $p+q$ and $p-q$ is 2, but this cannot be since p and q are of different parity, by assumption.) Therefore, $p-q = a^2,\ p = b^2,\ p+q = c^2$ and $q = d^2$, with $a,\ b,\ c,\ d$ integers. We thus have an

arithmetic progression of three squares whose common difference is $q = d^2$ with q strictly less than $4pq(p-q)(p+q)$. This contradiction proves the theorem. □

We close this section with a few remarks on the relation between Pythagorean triangles and three squares in an arithmetic progression, most of which is historical in nature.

Taking $p = 5$, $q = 4$ in the above notation, we get a primitive Pythagorean triangle whose sides are 40, 9, 41 and the corresponding three squares in arithmetic progression are 31^2, 41^2, 49^2. Curiously, these numbers which are 961, 1681, 2401 occur (cf. [5, p.158]) during the solution of Problem 7 in Book III of Diophantus. The above three numbers are also related to an interesting question asked of Leonardo of Pisa (also called Fibonacci) by one of the members of the entourage of Emperor Frederik II, when he visited Pisa in the thirteenth century along with some learned men. The question was to find three rational squares in an arithmetic progression whose common difference is 5 and Leonardo's answer was $(\frac{31}{12})^2, (\frac{41}{12})^2, (\frac{49}{12})^2$.

It is interesting to note that there is a problem in the Byzantian "Constantinople manuscript", (now in the Old Palace library of Isthanbul) and which probably belongs to the eleventh or twelfth century, asking for a rational right angled triangle whose area is divisible by 5. This manuscript has been published and translated by Heiberg, a German historian of Mathematics in 1907-08, commented by Zeuthen. We are told, as for the solution, to multiply 5 by some square containing 6 as a factor e.g.36. The Pythagorean triangle mentioned above with lengths of its sides 9, 41, 49 has area 180 and the rational right angled triangle with sides 9/6, 41/6, 49/6 is a solution to the problem. (An interesting point to note is that the author of this problem seems to be aware of the fact that the area of a Pythagorean triangle is always divisible by 6.) A.Weil [11, p.13] wonders whether Leonardo might have seen this manuscript. A.Weil also notes, in [11,p 14], that Leonardo analyses the question as to when the common difference of three square integers in an arithmetic progression can be a square by looking at many examples and in fact asserts that it can never be a square, but giving however a totally inadequate reason! As we have noted this statement had to wait for Fermat for a proof!

6. Non-Existence of Four Squares in Arithmetic Progression

We saw above as to how to parametrise three (rational) squares in an arithmetical progression and showed that there cannot exist three squares in a(non-trivial) arithmetic progression whose common difference is a square and in fact, that this question is equivalent to the theorem of Fermat on the non-existence of Pythagorean triangles with (rational) square

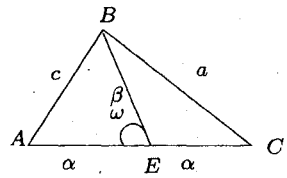
areas. One could ask the very natural question whether there can exist four rational squares in a non-trivial arithmetic progression. As we have remarked earlier, questions on arithmetic progressions date back to antiquity and probably Diophantus was well aware of such questions. Fermat in a communication to Frenicle in 1640, raises the question of the existence of four squares explicitly. Fermat must eventually have had a formal proof of their non-existence using his descent technique, as we learn from Jacques de Billy in his *Inventum Novum*, but Fermat's proof is not available. This question was in fact dealt with by Euler in 1780 in a paper published posthumously. As A.Weil points out [11,p.115], the paper is somewhat confusedly written, since probably at that time, Euler being totally blind, relied on his assistants. A.Weil himself gives a proof of this [11,p.147] by reducing it to a problem of the non-existence of rational points on a certain elliptic curve over rationals. There is also an elegant proof in the book by J.Itard [6], in the spirit of Fermat, using the technique of infinite descent. The aim of this last section is to point out a rather curious connection between this result and a question in elementary geometry which, in turn, has some connection with constructions by Kummer of quadrilaterals with rational sides and diagonals, motivated by the work of Brahmagupta. As is well known, Brahmagupta was the greatest Indian mathematician of the classical age. His work on the construction of rational cyclic quadrilaterals with rational diagonals (done in the 7th century in India) reached England through the English translation by H.T.Colebroke (1765-1837). The French geometer Chasles, who read it, wrote a very warm appreciation [2] of the work of Brahmagupta. This was read by the German mathematician Kummer who made a critical study of Chasles' note and showed in [8] more generally that the existence of quadrilaterals with rational sides and rational diagonals is equivalent to the existence of rational points of certain cubic curves. Kummer starts with a triangle ABC which is the juxtaposition of two rational triangles ABE and BEC, juxtaposed along BE, and completes it into a rational quadrilateral $ABCD$. In fact, he gives an iterative method of constructing infinite families of rational quadrilaterals, using the so called "ascent method" of Euler.This method constructs (in general) an infinity of solutions of polynomial equations in two variables in each of which the polynomial has degree 2, starting with one solution.

Kummer tacitly assumes that for the triangles that he starts with, $AE \neq EC$. If $AE = EC$, his construction does not work. We are, therefore, led to consider the question of existence of a rational triangle with a rational median. We show below (cf. [9]) that when the cosine of the angle which the median makes with AC has absolute value $1/3$, the existence of such a triangle is equivalent to the question of the existence of four rational squares in arithmetic progression, which, as we know, has a negative answer! Thus Kummer's

construction breaks down, since he cannot even start it in this case!

Proposition 1. *The existence of a rational triangle with a rational median such that the cosine of the base angles at the median is equal to $\pm\frac{1}{3}$ is equivalent to the existence of four rational squares in a non trivial arithmetic progression.*

Proof. .



If possible, let ABC be such a triangle with $AB = c$ and $BC = a$. Let E be the mid point of AC, so that BE, the median passing through the vertex B, making an angle ω with AC whose cosine has absolute value $1/3$. Let $AE = \alpha$ and $BE = \beta$. We have by the cosine formulae,

$$c^2 = \alpha^2 + \beta^2 - 2\alpha\beta/3,$$

$$a^2 = \alpha^2 + \beta^2 + 2\alpha\beta/3.$$

Adding the above equations and subtracting the first from the second , we get the following two equations.

$$a^2 + c^2 = (\alpha + \beta)^2 + (\alpha - \beta)^2,$$

$$3a^2 - 3c^2 = (\alpha + \beta)^2 - (\alpha - \beta)^2.$$

Adding the above equations and subtracting the second from the first and cancelling factors of 2 in both, we get the equations:

$$2a^2 - c^2 = (\alpha + \beta)^2,$$

$$2c^2 - a^2 = (\alpha - \beta)^2.$$

These equations imply that $(\alpha-\beta)^2$, c^2, a^2, $(\alpha+\beta)^2$ are in arithmetic progression. Conversely, if there are four rational squares in a non-trivial arithmetic progression, one can, by reversing the above steps, construct a triangle with the required property. □

7. Concluding remarks

Throughout his life, Fermat tried very hard to make his contemporary mathematicians get interested in the work he was engaged in, but unfortunately he did not succeed. A typical reaction was that of Huygens who wrote to Wallis "There is no lack of better things to do". One must remember that Fermat lived at a time when algebraic notation itself was not systematised and needed cleaning up. In any case, Fermat had innate difficulty in writing down mathematics. He would have been happy had he found someone suitable with whom he could have collaborated. He would have, for instance, liked to collaborate with Pascal, who was well known as a lucid expositor, but Pascal was plainly not interested, what with his preoccupations with religion and metaphysics.

During his later years, Fermat was indeed afraid that his mathematical tradition would be lost. The very last letter which Fermat wrote to Huygens (in 1659), whose English translation by A.Weil[11,p.118] I quote below, sums up his general melancholy :

'Such is in brief the tale of my musings on numbers. I have put it down only because I fear that I shall never find the leisure to write out and expand properly all the proofs and methods. Anyway, this will serve as a pointer to men of science for finding for themselves what I am not writing out... May be, posterity will be grateful to me for having shown that the ancients did not know everything, and this account may come to be regarded by my successors as the "handing on of the torch", in the words of the great chancellor of England [Francis Bacon], following whose intention and motto I shall add: "many will pass away but science will grow" '.

The great Euler picked up the long extinguished torch of Fermat in 1730 to keep it burning for another half a century.

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AUXOLOGICAL ATTAINMENTS OF ADOLESCENT GIRLS WITH PROTEIN ENERGY MALNUTRITION IN EARLY CHILDHOOD: A MIXED LONGITUDINAL STUDY

A. K.Bhalla

Child Growth & Anthropology Unit, Advanced Pediatrics Centre, PGIMER, Chandigrh-1600012

Abstract

Height and body weight amongst 67 girls known to be cases of severe protein-energy-malnutrition during early childhood and their 108 normal healthy counterparts living in sixteen villages of the block Sadhaura, district Ambala (Haryana, India) comprised the sample for this mixed-longitudinal study. Every girls was measured between 9 to 19 years of age at 6 monthly age intervals with time tolerance limit of ± 15 days in village schools using standardized anthropometric techniques and instruments. The malnourished girls remained significantly (p d" 0.01, 0.001) lighter and shorter than their normal counterparts throughout the period of adolescence. The yearly growth velocities recorded for both the parameters in malnourished girls in general, remained lesser than the normal girls. The magnitude of Peak-height-velocity (PHV) was found to be about two times lesser in malnourished girls (4.0 cm/yr) than the normal girls (8.6cm/yr). Peak-weight- velocities in malnourished and normal girls measured 3.1 kg/ yr and 5.4kg/yr respectively. As compared to their normal Delhi and American counterparts malnourished girls with early undernutrition demonstrated substantial degree of height and weight growth related deficits and failed to catch up with their normal counterparts during adolescence and finally ended up as stunted and lighter adult females.

Key words : Height, weight, protein-energy-malnutrition

INTRODUCTION

In developing countries, a substantial number of children reach adolescence with undernutrition. The failure to meet increased nutritional needs of children during adolescence often compromise their bodily growth attainments. Prolonged observations made on the survivors of malnutrition indicate that severe malnutrition in early life had adversely affected their subsequent growth which has resulted in stunting of their stature (Graham, 1968, Trowell, 1949, Suckling and Campbell 1956, Briers et at 1975, Branko, 1979). On the contrary evidence gathered from clinical and epidemiological studies (Hansen et al,1971,Cabak and Najdanovich, 1965 Garrow and Pike ,1967, Prader et al,1963, Graham & Andrianzen,1972) revealed that the catch-up growth subsequent to malnutrition compensates for previous malnutrition related growth retardation and has resulted in normal stature of previously malnourished children. Hence in view of the prevailing disagreement regarding the long-term effects of early malnutrition on the growth attainments of children it becomes imperative to understand the pattern of influence of undernutrition on the auxological attainments of children, growing under varied socio-cultural, nutritional, geographic and economic settings. This becomes even more important in the context of female adolescents who are going to be future mothers.

In India, efforts have been made by Indian Council of Medical Research (ICMR), 1996 to study effects of varying degree of protein-energy malnutrition (PEM) on growth of children during adolescence, but results presented suffered from some methodological problems. The longitudinal data collected by ICMR over the years have been treated as if these were cross-sectional in nature and no attempt was made to calculate rate of growth (velocity) for different growth parameters. Only distance growth related values were presented. The data for nutritional grades (PEM II & III) have been pooled. Also, the period of adolescence remained incompletely studied as the results were presented only for 10-16 years of age.

In this paper, an attempt has been made to study physical growth of rural girls who were diagnosed as cases of severe protein energy malnutrition (PEM grade III) in early childhood using a mixed longitudinal research design during the entire period of adolescence.

MATERIAL AND METHODS

A total of 67girls diagnosed as cases of severe protein energy (PEM) malnutrition at 5 to 7 years of age and their 108 normal healthy counterparts living in similar surrounding of 16 villages of Sadhaura block of District Ambala (Haryana) comprised the sample for this study. The girls were classified into respective nutritional grades using the classification given Indian Academy of

*Corresponding Author: anilbhalla@sify.com

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Pediatrics (IAP), 1972. Every subject was measured between 9 to 19 years at six monthly age intervals with a time tolerance limit of ± 15 days in village schools, but for this presentation available data obtained on girls with completed yearly ages have been utilized. The girls who could not be contacted at school on the scheduled dates were examined in their homes, and those who missed any two consecutive follow-ups were excluded from final data analysis of this presentation. Age-wise distribution of total girls (N) who could be measured at various completed yearly ages during different follow-ups, following mixed longitudinal growth research design is shown in Table 1. The biological age of each girl was determined on the basis of knowledge of birth date which was recorded from schools records. However, in doubtful cases use of local events calendar, crop pattern, festivals and season of the year etc. was made to verify the date of birth of children born to illiterate parents. Other details of the sample subjects and methods followed are given elsewhere (Bhalla & Walia, 2007). Each girl was measured for height and body weight using standardized anthropometric techniques (Weiner & Lourie, 1969) and instruments by trained anthropometrists. Weight was measured with the help of metallic Anthropometer (Make: UNA) up to the accuracy of 1mm, while body weight was measured with lever-actuated weighing scale with platform having least count of 100g.

Table 1: Mean (± SD) Height (cm) of normal and malnourished girls

Age (±Year)	Normal			Malnourished			Nutritional difference (t -value)
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	
9.0	12	127.8	4.5	2	117.2	1.1	3.07**
10.0	15	133.0	5.1	4	121.0	7.6	3.53***
11.0	16	139.4	4.8	4	123.9	5.0	5.43***
12.0	19	148.9	4.0	12	133.6	5.6	8.57***
13.0	14	151.6	4.7	7	141.3	6.3	3.92***
14.0	30	152.2	5.4	24	145.7	7.9	3.89***
15.0	19	153.2	5.0	11	148.4	7.6	2.01*
16.0	50	153.3	5.5	28	150.3	5.4	2.30*
17.0	93	155.0	5.2	33	150.7	4.6	4.17***
18.0	91	155.0	5.9	50	150.9	5.1	4.61***
19.0	74	155.0	6.5	40	152.1	5.5	2.37*

***P ≤ 0.05, ** P ≤ 0.01 *** p ≤ 0.001. df, N-2**

Tanner's 1951 method was used to compute distance (gross-size) and velocity (rate of growth) statistics (i.e. mean and SD values) for body weight and height of girls at each age level. Magnitude of nutritional difference between normal and malnourished girls for each parameter was calculated by applying students unpaired 't'-test.

RESULTS

The mean (X) and standard deviation (SD) computed for height of rural girls known to be cases of severe protein energy malnutrition (i.e. PEM grade III) during early childhood and their normal control counterparts are shown in Table 1. Malnourished girls measured 117.2 ± 1.1 cm at 9.0 years of age which grew to 152.1 ± 5.5 cm by 19.0 years. While the mean height values amongst normal girls at the corresponding ages were 127.8 ± 4.5 cm and 155.0 ± 6.5cm respectively. The malnourished girls remained significantly (p d" 0.05, 0.01) shorter than their normal girls throughout the period of study.

The malnourished girls weighed 16.3 ± 1.7kg at 9.0 years and 39.7 ± 5.2 kg at 19.0 years, while mean body weight values in normal rural girls grew form a mean of 24 .6 ± 2.3 kg at 9.0 years to 45.9 ±6.6 kg by 19.0 years of age. As compared to their normal

Table 2: Mean (± SD) Weight (kg) of normal and malnourished girls.

Age (±Year)	Normal			Malnourished			Nutritional difference (t -value)
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	
9.0	12	24.6	2.3	2	16.3	1.7	3.22**
10.0	15	27.3	3.6	4	17.5	3.0	4.73***
11.0	16	31.2	5.4	4	22.0	5.0	2.93**
12.0	19	34.6	4.2	12	25.6	4.3	5.57***
13.0	14	37.8	4.7	7	28.1	3.6	4.43***
14.0	30	40.3	5.7	24	31.2	3.9	6.55***
15.0	19	42.0	4.8	11	34.4	4.1	4.24***
16.0	51	42.9	5.1	28	37.7	3.7	4.68***
17.0	93	45.1	5.9	39	39.5	3.8	5.05***
18.0	91	46.2	6.3	50	39.7	4.1	6.52***
19.0	74	45.9	6.6	40	39.7	5.2	3.2**

***P ≤ 0.05, ** P ≤ 0.01 *** p ≤ 0.001. df=N-2**

counterparts malnourished girls weighed significantly (p d" 0.01, 0.001) lighter throughout the period of adolescence.

Yearly mean growth velocities for height and weight of study subjects along with their SD(s) are shown in Table 3 & 4, respectively. Malnourished girls possessed lower height growth velocity than their normal counterparts throughout the entire study span (9-19 years). However, the difference in yearly growth velocities was found to be statistically significant between 11 to 16 years of age. The attainment of peak height velocity (PHV) in malnourished girls (11.5yr) was earlier by 1 year than the controls (12.5 yr) and its magnitude in malnourished girls (4.0/cm yr) remained more than **two** times lesser than that observed for normal(8.6cm/cm) girls (Table 3).

Table 3: Height growth velocity (cm/yr) in normal and malnourished girls

Age Interval (Year)	Normal		Malnourished		Nutritional difference (t-value)
	$\bar{X}$	SD	$\bar{X}$	SD	
9-10	5.0	2.1	3.1	1.4	0.22
10-11	5.8	3.4	2.5	1.6	1.43
11-12	5.6	4.9	4.0	0.2	4.77***
12-13	8.6	3.2	3.1	0.3	3.69***
13-14	5.1	2.5	1.1	1.0	5.91***
14-15	1.2	4.1	0.2	2.5	4.50***
15-16	0.7	3.6	0.2	0.6	3.27**
16-17	0.6	1.9	0.2	0.5	0.63
17-18	0.5	0.8	0.3	1.1	0.28
18-19	0.6	1.1	0.1	1.8	0.29

***P ≤ 0.05, ** P ≤ 0.01 *** p ≤ 0.001. df = N-2**

The intensity of weight growth velocity recorded amongst malnourished girls remained significantly lower their normal counterparts at majority of yearly intervals. The peak weight velocity (PWV) in normal girls measured 5.4 kg/yr at 13.5 yrs , while it was 3.1kg/ yr in malnourished girls at 11.5 and 13.5 years (Table 4).

Table 4: Weight growth velocity (kg/yr) in normal and malnourished girls

Age Interval (Year)	Normal		Malnourished		Nutritional difference (t-value)
	$\bar{X}$	SD	$\bar{X}$	SD	
9-10	2.8	2.0	1.1	1.8	0.22
10-11	1.6	1.8	2.0	0.4	1.43
11-12	4.8	2.9	3.1	0.9	4.79***
12-13	0.9	1.5	2.6	1.4	3.69***
13-14	3.1	2.6	3.1	1.2	5.91***
14-15	5.4	3.5	2.7	1.4	4.50***
15-16	1.4	1.5	1.0	0.8	3.27**
16-17	2.1	1.9	0.9	1.6	0.63
17-18	1.4	1.4	1.3	1.5	0.51
18-19	0.8	2.7	1.7	2.4	0.93

*P $\leq$ 0.05, ** P $\leq$ 0.01 *** p $\leq$ 0.001. df = N-2

The comparison of mean height and weight growth attainments made with affluent Delhi (NFI, 1989) and age specific average data values obtained for the 50th and 3rd percentile of 2000 CDC growth charts established for American girls (Kuczmarski, 2000) presented by Ghai et al 2004 , demonstrated substantial degree of growth deficits amongst malnourished girls throughout the period of adolescence, as the curves plotted for these two growth parameters ran consistently below even the 3rd percentile of CDC growth charts.

DISCUSSION

The distance growth curves plotted for both height (Figure 1) and weight (Figure 2) of malnourished girls followed a curvilinear pattern as these ran significantly below those of the normal girls throughout the entire period of adolescence. In contrast to their normal counterparts, malnourished girls showed an initial slower gain in height between 9 to 11 years followed by a moderately sharp increase up to about sixteen years. Whereafter, these girls continued to grow slowly till 19.0 years in contrast to their normal counterparts who experienced a complete cessation of growth beyond 17 years of age, which is quite similar to the median age of 17.3 years recorded for cessation of height growth amongst normal American girls by Roche and Davila, (1972) . A net mean increase of 1.4 cm in height of malnourished girls was recoded between 17 to 19 years.

The malnourished girls representing present study remained shorter by 10.6 cm than the normal girls at 9.0years of age. This differential before commencing to decline grew to 15.3 cm by 12 years and finally became about 3.0 cm at 19.0 years of age (Table 1) Similar reduction in height difference between affluent Delhi and rural poor Maharshtrian girls (NNMB, 1980) from 9.0 to 18.0 years of age has also been documented by NFI (1989). Likewise, malnourished girls weighed lighter by 8.3 kg at 9.0 years and to a maximum of 9.7 kg at 13.0, years and finally by 6.2 kg at 19.0 years of age than their normal counterparts.

With advancement of age this considerable reduction in the magnitude of height and weight related deficit noticed amongst malnourished girls in comparison to controls confirms the existence of phenomenon of catch up growth, partially affecting the stature of attainments of these girls during adolescence. This shows that adolescence provides a second opportunity to malnourished girls to partially undo the deleterious effect of early malnutrition. This is in close agreement with the observations made by Satyanaryan at al (1981) who have noticed a partial catch up in height of rural girls in Andhra Pradesh.

Inter-population comparison of height (Figure 1) and weight (Figure 2) curves plotted for malnourished girls reveals that they remain shorter and lighter than their study controls, affluent Delhi (NFI, 1989) and Western American (Kuczmarski et al, 2000) counterparts throughout the age range considered and depict an extreme degree of malnutrition as curves for both the parameters run below 3rd percentile of the 2000 CDC growth standards (Kuczmarski et al, 2000). This shows that despite, showing some degree of partial catch-up during adolescence malnourished girls in comparison to their study control as well as affluent Delhi and American counterparts continued to be undernourished throughout the period of adolescence and finally ended up as shorter and lighter adult females.

From the foregoing account it becomes amply clear that girls with severe malnutrition during early childhood failed to completely make –up for the initial loss and entered womanhood as lighter and stunted individuals . These findings are in agreement with observations of earlier workers (Graham,1968, Chase and Martin,1970, Trowell, 1949, Suckling and Campbell , 1956 , Briers, 1975) . On the contrary our findings are at variance with those of the other researchers (Hansen et al 1971, Cabak and Najdanovich, 1965 ,Garrow and Pike, 1967 Prader et al, 1963 Graham, and Andrianzen 1972), who because of catch up had reported complete compensation for the previous undernutrition related growth deficit and attainment of normal stature in previously malnourished children .

Growth velocity

Growth velocity is considered as sensitive indicator of growth retardation. The malnourished girls representing the present study experienced a severe degree of height growth deficit throughout the period of adolescence since the velocity curve plotted for height in contract to their normal counterparts ran consistently below the 3rd percentile of growth velocity standards given for North-American girls (Tanner and Davies, 1985). Owing to their poor nutritional status malnourished girls experienced a smaller growth spurt in height in comparison to normal girls with a peak height velocity of 4.0 cm/yr which is about 2 times lesser than that recorded amongst normal girls (8.6cm/yr)

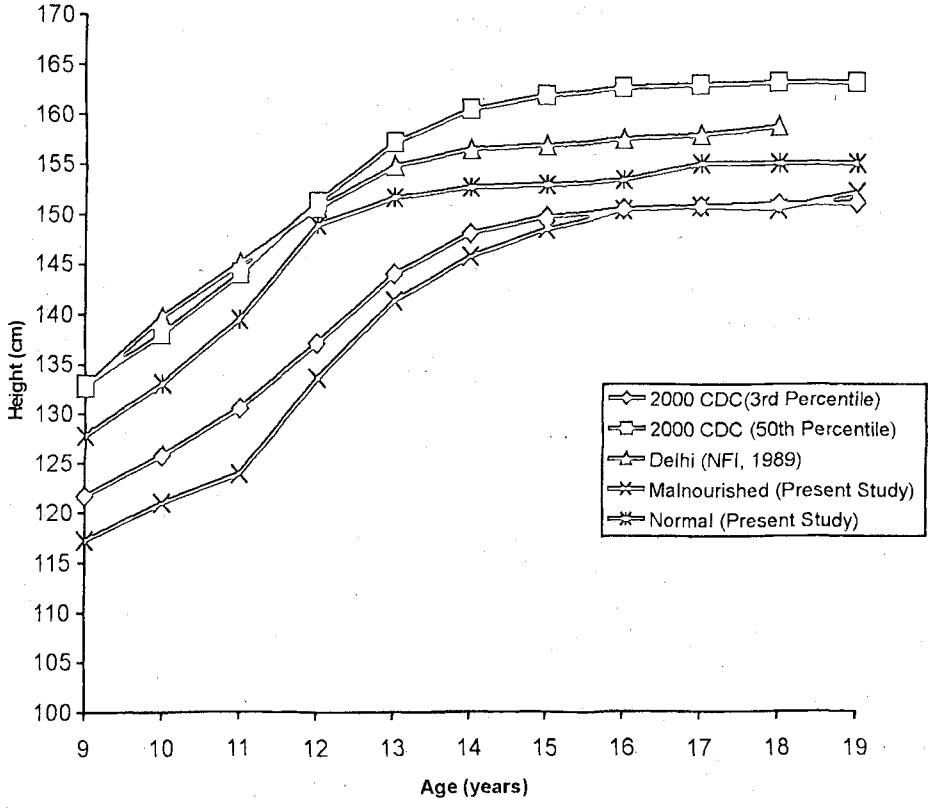

Fig. 1: Comparison of Height of Girls

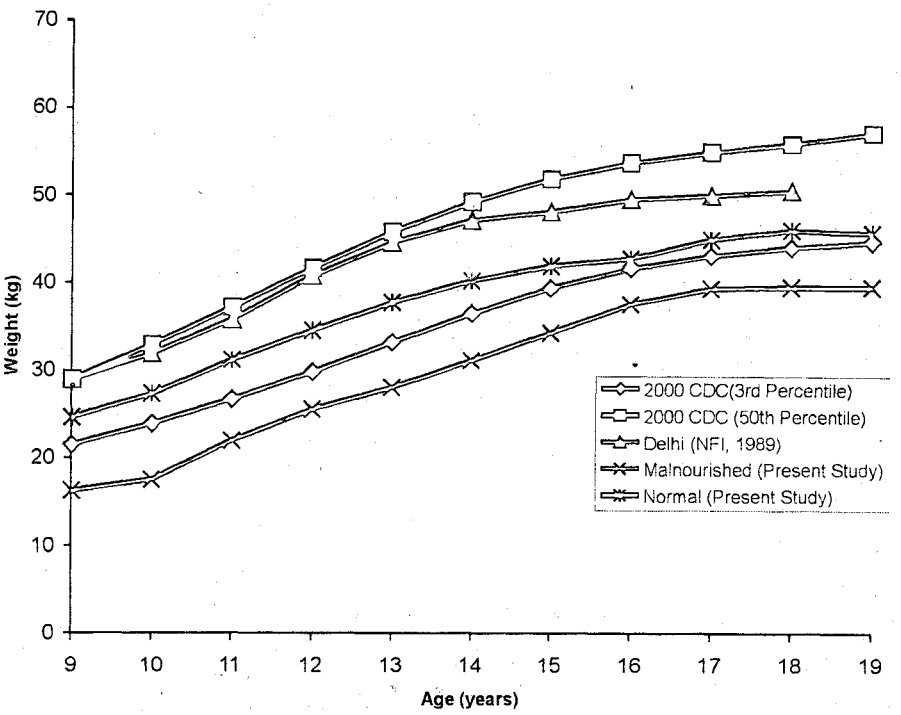

Fig. 2: Comparison of Weight of Girls

The smaller spurt recorded amongst our longitudinally followed malnourished adolescent girls not only corroborated but has re-confirmed the observations once made by Eveleth and Tanner, 1990 who opined, "lack of sufficient calories in principle might result in smaller spurt but we do not have any evidence from longitudinal studies, which we really need." Relatively, slower rate of height gain, delayed initiation and rapid cessation of growth spurt (i.e. between 10.5 to 14.5year) could be another possible reasons for the existence of smaller spurt in our malnourished girls, who took time (4 years) to complete adolescent spurt as compared to 6 years taken by normal girls (Figure 3). However, these findings differ from those of Billewicz and Mcgreger (1982) who noticed a similar gain in height during adolescence between chronically undernourished Gambian and normal British children.

It is interesting to note that severely malnourished girls attained PHV earlier by one year (i.e. at 11.5years) than the normal girls (12.5years) and thus have shown close resemblance to North-American girls, (Tanner & Davies, 1985) in respect of attainment of peak-height velocity. The lack of delay in attainment of PHV amongst malnourished girls is in marked contrast to the accepted view of occurrence of general pubertal delay during or following malnutrition in undernourished children. It clearly emerges that severely malnourished girls who entered adolescence as malnourished failed to gain height as much as their normal counterparts did during adolescence and consequently, remained shorter than their controls as adults. Weight velocity curve (Figure 4) plotted for both malnourished and normal girls depicted highly vascillatory pattern throughout the period of adolescence and appear to experience more than one peak weight velocity (PWV). The yearly weight growth velocity in malnourished girls measured substantially lesser than their normal girls during entire adolescence. The existence of more than one peak (i.e. PWV) speaks of the tendency of malnourished girls to adapt to prevailing adverse conditions by prolonging the span of adolescent growth spurt so as to undo effect of nutritional deprivations in which they continued to grow and failed to come out completely.

From the above discussion it becomes amply clear that girls who were severely malnourished (Grade III PEM) during early childhood did not show any improvement with regard to their auxological attainments throughout the period of adolescence and finally grew-up as stunted and lighter female adults. These girls exhibited a pattern of retarded growth which was consistent with their impoverished nutritional and socio-economic environments (Bhalla & Walia , 2007) which in fact was not much different from that experienced by the majority of word's children living in the developing countries.

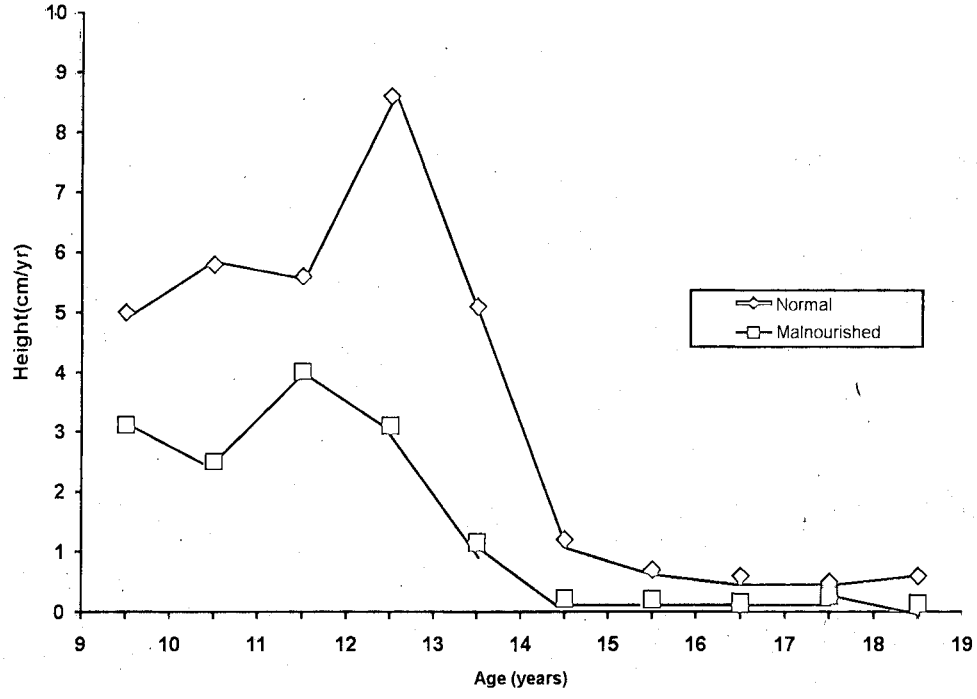

Fig. 3: Height Growth velocity of Malnourished & Normal Girls

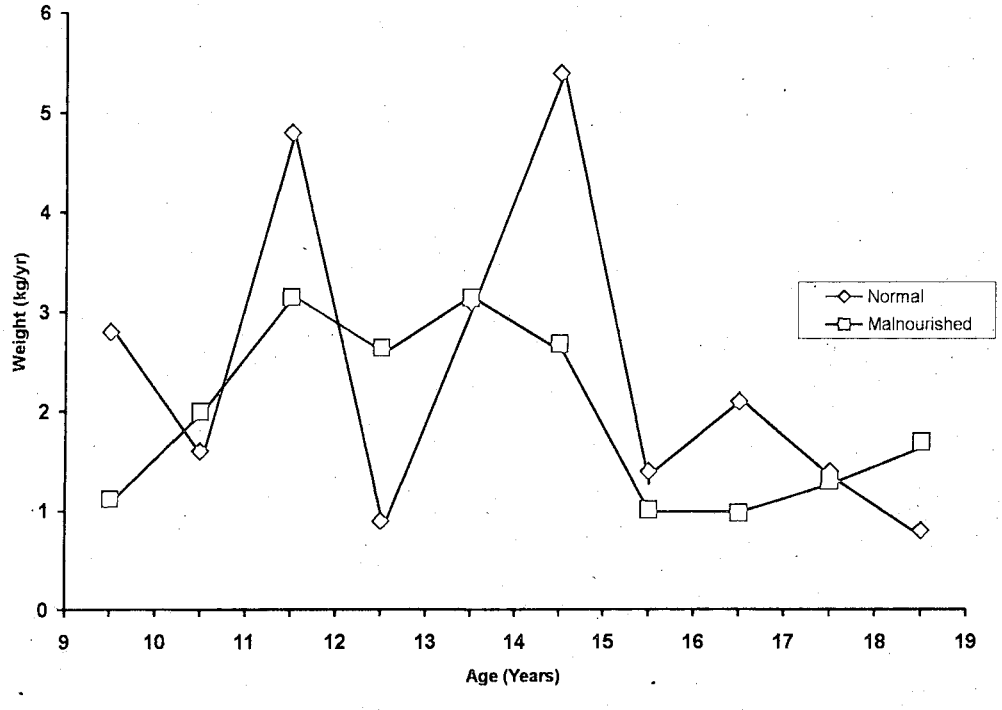

Fig. 4: Weight Growth velocity of Malnourished & Normal Girls

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CP VIOLATING PARAMETER $Sin2\beta$ AND ITS DEPENDENCE ON QUARK MASSES

Rohit Verma[1], Gulsheen Ahuja[2] , Manmohan Gupta[2]

[1] *Rayat Institute of Engineering and Information Technology, Ropar*
[2] *Department of Physics, Centre of Advanced Study, P.U., Chandigarh*

Abstract

The parameter $Sin2\beta$ measures the CP asymmetry in the decay $B_D \to \psi K_D$ and is very precisely known. An exact relationship has been derived for $Sin2\beta$ in terms of quark masses and the phases of Fritzsch-like texture 4 zero mass matrices.

Key words: CP violation, quark masses

In the last few years, several important developments have taken place in the context of phenomenology of Cabibbo-Kobayashi-Maskawa (CKM) matrix [1], both from theoretical as well as experimental point of view. We have entered the era of precision measurements of some of the CKM parameters like $|V_{us}|$, $|V_{cb}|$ and in particular of $Sin2\beta$ [2] which not only plays a crucial role in fixing the unitarity triangle, but also provides vital clues to the structural features of the mass matrices.

Realizing the importance of $Sin2\beta$, several authors [3-5] have explored its implications for the texture specific mass matrices. In particular, using assumption of strong hierarchy of the elements of the mass matrix and retaining terms up to the leading order, they arrive at several interesting relations of some of the CKM parameters in terms of the quark masses and the phases involved in the mass matrices, e.g.,

$$\left|\frac{V_{ub}}{V_{cb}}\right| = \sqrt{\frac{m_u}{m_c}}, \qquad \left|\frac{V_{td}}{V_{ts}}\right| = \sqrt{\frac{m_d}{m_s}}, \qquad |V_{us}| = \sqrt{\frac{m_d}{m_s}}e^{i\phi} - \sqrt{\frac{m_u}{m_c}}, \tag{1}$$

$$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right] = \arg\left[1 - \sqrt{\frac{m_u m_s}{m_c m_d}}e^{i\phi}\right]. \tag{2}$$

Unfortunately, the value of $Sin2\beta$ predicted by the above formula is less than 0.45, which is quite in disagreement with the recently measured PDG 2008 [2] value, e.g., 0.681±0.025. However, some of the recent analyses [6, 7], without getting into details, do not indicate any such conflict of CKM mixing data and texture 4 zero mass matrices. To this end, some attempts [4, 7] have been made to resolve the situation, however a detailed and comprehensive analysis in this regard is yet to be carried out.

In this context, it may be noted that the Fritzsch-like texture-4 zero mass matrices [8, 9] have given valuable insight in understanding several features of fermion masses and mixings. Therefore, it is of paramount importance to explore the compatibility of the Fritzsch-like texture-4 zero mass matrices with $Sin2\beta$. Such an analysis is expected to give information regarding the correct phase structure of the mass matrices and help in understanding the implications of hierarchy on the mass matrices.

The purpose of the present paper is to develop a formula for $Sin2\beta$ in terms of quark masses, phases and free parameters of the mass matrices so as to understand their implications on it. Also, we would like to compare this formula with the earlier relations to underline the importance of the present expression.

To begin with, we define the Fritzsch-like hermitian texture-2 zero mass matrix as

$$M_q = \begin{bmatrix} 0 & a_q & 0 \\ a_q^* & d_q & b_q \\ 0 & b_q^* & c_q \end{bmatrix}, \quad q = U, D \tag{3}$$

*Corresponding Author : mmgupta@pu.ac.in
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with, $a_q = |a_q| e^{i\alpha_i}$, $b_q = |b_q| e^{i\beta_i}$ and M_U, M_D, respectively corresponding to the mass matrices in the up and down sector. Clearly, M_q can be transformed into a real symmetric matrix $\tilde{M}_q$ by a phase transformation of the form

$$\tilde{M}_q = P_q M_q P_q^{+}, \tag{4}$$

where P_q is a diagonal phase matrix. The real symmetric matrix of the form $\tilde{M}_q$ can always be diagonalized by a real orthogonal transformation,

$$O^{+}\tilde{M}_q O = M_{Diag} = Diag\{m_1, m_2, m_3\}, \tag{5}$$

where 1, 2, 3 = *u, c, t* for the up sector and *d, s, b* for the down sector. This leads to the CKM matrix,

$$V_{CKM} = O_U^{+} P_U P_D^{+} O_D, \tag{6}$$

wherein

$$P_U P_D^{+} = Diag\left\{e^{-i\phi_1}, 1, e^{i\phi_2}\right\}, \tag{7}$$

with phase $\phi_1 = \alpha_U - \alpha_D$ and phase $\phi_2 = \beta_U - \beta_D$.

As a first step, it is instructive to reproduce the relations given in equations (1) and (2) using the Hall and Rasin [10] approach which clearly underlines the assumptions used in finding these. Using this approach, a real symmetric Fritzsch-like texture 2 zero matrix, mentioned in equation (3), can be diagonalized through three successive rotations about the first, second and the third axes given respectively by s_{23}, s_{13}, and s_{12}. These rotation angles can be expressed as

$$s_{23} = \frac{b}{c}, \quad s_{13} = \frac{ab}{c^2}, \quad s_{12} = \frac{ac}{(dc - b^2)}. \tag{8}$$

In case one assumes a strong hierarchy among the elements of the mass matrix as well as consider $d = m_2$, then

$$c \approx m_3, \quad b \approx \sqrt{m_1 m_3}, \quad a \approx \sqrt{m_1 m_2}. \tag{9}$$

This further implies,

$$s_{12} \approx \sqrt{\frac{m_1}{m_2}}, \quad s_{23} \approx \sqrt{\frac{m_1}{m_3}}, \quad s_{13} \approx \frac{m_1}{m_3}\sqrt{\frac{m_2}{m_3}}. \tag{10}$$

In view of the fact that the quark masses follow strong hierarchy, therefore $s_{13} << s_{23} << s_{12}$, hence terms containing s_{13} in the calculations can be ignored to a leading order. The resulting quark mixing matrix is then given as

$$V_{CKM} \approx \begin{bmatrix} e^{-i\phi_1} & (s_{12}^D e^{-i\phi_1} - s_{12}^U) & -s_{12}^U (s_{23}^D - s_{23}^U e^{i\phi_2}) \\ -(s_{12}^D - s_{12}^U e^{-i\phi_1}) & 1 & (s_{23}^D - s_{23}^U e^{i\phi_2}) \\ s_{12}^D (s_{23}^D e^{i\phi_2} - s_{23}^U) & -(s_{23}^D e^{i\phi_2} - s_{23}^U) & e^{i\phi_2} \end{bmatrix}, \tag{11}$$

with

$$s_{12}^U = \sqrt{\frac{m_u}{m_c}}, \quad s_{12}^D = \sqrt{\frac{m_d}{m_s}}, \quad s_{23}^U = \sqrt{\frac{m_u}{m_t}}, \quad s_{23}^D = \sqrt{\frac{m_d}{m_b}},$$

$$\phi_1 = \alpha_U - \alpha_D \quad \text{and} \quad \phi_2 = \beta_U - \beta_D. \tag{12}$$

Using the above mentioned mixing matrix and expressing the elements in terms of quark masses, we can then find the relationships of the CKM parameters mentioned in equations (1) and (2). Interestingly, the relations so obtained, using the Hall and Rasin approach, are the same as those mentioned earlier in equations (1) and (2). From the above discussion, one can conclude that the earlier derived relationships are valid only under the assumption of strong hierarchy among the diagonal elements of the mass matrices as well as retain terms up to leading order only.

In order to go beyond these relations, we have to incorporate the non leading terms as well as relax the condition of strong hierarchy among the diagonal elements of the mass matrices. To this end, we take note of the fact that the elements of mass matrices may not follow strong hierarchy, however the quark

masses are known to follow it. Also, we have to consider that texture 4 zero Hermitian mass matrices can be diagonalized exactly, therefore in principle, an exact formula of $Sin2\beta$ in terms of quark masses and phases can be derived.

The exact diagonalization of the mass matrix M_q given in equation (3) can be carried out using the invariants, $\mathrm{tr}\,\tilde{M}_q$, $\mathrm{tr}\,\tilde{M}_q^{\,2}$ and $\det \tilde{M}_q$. The elements of the mass matrix a, b and c can be expressed in terms of the free parameter d and the quark masses as

$$c = m_3 + m_2 - m_1 - d,$$
$$a = \sqrt{\frac{m_1 m_2 m_3}{c}},$$
$$b = \sqrt{\frac{(m_3 + m_2 - d)(d - m_2 + m_1)(m_3 - m_1 - d)}{c}}. \quad (13)$$

The exact diagonalizing transformation O_q is given by

$$O_q = \begin{bmatrix} \sqrt{\frac{m_2 m_3 (c_q + m_1)}{c_q (m_3 + m_1)(m_2 + m_1)}} & \sqrt{\frac{m_1 m_3 (c_q - m_2)}{c_q (m_3 - m_2)(m_2 + m_1)}} & \sqrt{\frac{m_1 m_2 (m_3 - c_q)}{c_q (m_3 - m_2)(m_3 + m_1)}} \\ -\sqrt{\frac{m_1 (c_q + m_1)}{(m_3 + m_1)(m_2 + m_1)}} & \sqrt{\frac{m_2 (c_q - m_2)}{(m_3 - m_2)(m_2 + m_1)}} & \sqrt{\frac{m_3 (m_3 - c_q)}{(m_3 - m_2)(m_3 + m_1)}} \\ \sqrt{\frac{m_1 (m_3 - c_q)(c_q - m_2)}{c_q (m_3 + m_1)(m_2 + m_1)}} & -\sqrt{\frac{m_2 (c_q + m_1)(m_3 - c_q)}{c_q (m_3 - m_2)(m_2 + m_1)}} & \sqrt{\frac{m_3 (c_q - m_1)(c_q - m_2)}{c_q (m_3 - m_2)(m_3 + m_1)}} \end{bmatrix} \quad (13)$$

The CKM matrix which measures the non-trivial mismatch between the diagonalizations of M_U and M_D and can be obtained through the relation (6). Explicitly, we have

$$V_{i\sigma} = O^U_{1i} O^D_{1\sigma} e^{-i\phi_1} + O^U_{2i} O^D_{2\sigma} + O^U_{3i} O^D_{3\sigma} e^{i\phi_2} \quad (15)$$

where the subscripts i and σ run respectively over u, c, t and d, s, b. As mentioned earlier, the two phases ϕ_1 and ϕ_2 are defined as $\phi_1 = \alpha_U - \alpha_D$ and $\phi_2 = \beta_U - \beta_D$.

The above mentioned equation (24) can be easily used to obtain the expressions of the CKM elements, however the elements so obtained are quite lengthy and complicated, which results in a correspondingly complicated expression for β from which one can hardly learn anything except through numerical evaluations. Such an expression neither sheds any light on the role of hierarchy, light quark masses or the phases of the mass matrices nor on the contributions of the non-leading order terms.

Therefore, in order to understand the detailed implications of input parameters, e.g. quark masses, free elements and phases of the quark mass matrices, on $Sin2\beta$, it is required to find a simple and compact relationship which reveals, in detail, its dependence on the parameters of the mass matrices. To this end, the diagonalizing transformation Oq can be rewritten keeping in mind $m_1 << m_2 << m_3$ and the element of the mass matrix $c >> m_1$, which is always valid without any dependence on the hierarchy of the elements of the mass matrices. It may be mentioned that this approximation induces less than a fraction of a percentage error in the numerical results. The structure of Oq can be simplified and expressed as

$$O_q \approx \begin{bmatrix} 1 & \sqrt{\frac{m_1}{m_2}}\sqrt{\frac{(c_q - m_2)}{c_q}} & \sqrt{\frac{m_1 m_2}{m_3^2}}\sqrt{\frac{(m_3 - c_q)}{c_q}} \\ -\sqrt{\frac{m_1}{m_2}}\sqrt{\frac{c_q}{m_3}} & \sqrt{\frac{(c_q - m_2)}{m_3}} & \sqrt{\frac{(m_3 - c_q)}{m_3}} \\ \sqrt{\frac{m_1}{m_2}}\sqrt{\frac{(m_3 - c_q)}{m_3}}\sqrt{\frac{(c_q - m_2)}{c_q}} & -\sqrt{\frac{(m_3 - c_q)}{m_3}} & \sqrt{\frac{(c_q - m_2)}{m_3}} \end{bmatrix} \quad (16)$$

Considering the definitions,

$$k_{1q}=\sqrt{\frac{c_q-m_2}{c_q}}, \qquad k_{2q}=\sqrt{\frac{m_3-c_q}{m_3}} \quad \text{and} \quad k_{3q}=\sqrt{\frac{c_q}{m_3}}, \tag{17}$$

we can rewrite the diagonalizing matrix as

$$O_q \approx \begin{bmatrix} 1 & k_{1q}\sqrt{\frac{m_1}{m_2}} & \frac{k_{2q}}{k_{3q}}\sqrt{\frac{m_1 m_2}{m_3^2}} \\ k_{3q}\sqrt{\frac{m_1}{m_2}} & -k_{1q}k_{3q} & k_{2q} \\ -k_{1q}k_{2q}\sqrt{\frac{m_1}{m_2}} & k_{2q} & k_{1q}k_{3q} \end{bmatrix}. \tag{18}$$

Making use of the above form of the diagonalizing transformation, the CKM matrix elements can now be easily expressed in terms of the quark masses and the phases ϕ_1 and ϕ_2. As an example, we mention below the expressions for those elements which are required to be known to evaluate β. Therefore, the elements $V_{cd}, V_{ch}, V_{td}, V_{th}$ are expressed as

$$V_{cd} = k_{1u}\sqrt{\frac{m_u}{m_c}}e^{-i\phi_1} - \sqrt{\frac{m_d}{m_s}}\left[k_{1u}k_{3u}k_{3d} + k_{2u}k_{1d}k_{2d}e^{i\phi_2}\right], \tag{19}$$

$$V_{cb} = \frac{k_{1u}k_{2d}}{k_{3d}}\sqrt{\frac{m_u m_d m_s}{m_c m_b^2}}e^{-i\phi_1} - \left[k_{1u}k_{3u}k_{2d} - k_{2u}k_{1d}k_{3d}e^{i\phi_2}\right], \tag{20}$$

$$V_{td} = \frac{k_{2u}}{k_{3u}}\sqrt{\frac{m_u m_c}{m_t^2}}e^{-i\phi_1} + \sqrt{\frac{m_d}{m_s}}\left[k_{2u}k_{3d} - k_{1u}k_{3u}k_{1d}k_{2d}e^{i\phi_2}\right], \tag{21}$$

$$V_{tb} = \frac{k_{2u}k_{2d}}{k_{3u}k_{3d}}\sqrt{\frac{m_u m_c m_d m_s}{m_t^2 m_b^2}}e^{-i\phi_1} + \left[k_{2u}k_{2d} + k_{1u}k_{3u}k_{1d}k_{3d}e^{i\phi_2}\right]. \tag{22}$$

Knowing the above elements enables one to evaluate the angle β, however it may be mentioned that to arrive at an expression, wherein the dependence of β on the quark masses and the elements of the quark mass matrices is visible in a simple and clear manner, is a non trivial task. To this end, we have defined the parameters r_1 and r_2 which can be expressed in terms of the quark masses and the elements of the quark mass matrices via the relations,

$$r_1 = \frac{k_{1u}k_{3u}k_{1d}k_{2d}}{k_{2u}k_{3d}} \quad \text{and} \quad r_2 = \frac{k_{1u}k_{3u}k_{2d}}{k_{2u}k_{1d}k_{3d}} \quad \text{such that} \quad r_1 = r_2 k_{1d}^2. \tag{23}$$

Making use of these, we reach at the expression of angle β given by

$$\beta = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right] = \left[k_{1d}^2 - \frac{k_{1u}k_{1d}}{V_{tb}^*}\sqrt{\frac{m_u m_s}{m_c m_d}}e^{-i(\phi_1+\phi_2)}\right]\left[\frac{(1-r_2 e^{i\phi_2})}{(1-r_1 e^{i\phi_2})}\right] \tag{24}$$

The above relation can be further simplified by considering $k_{1u} \approx k_{1d} \approx 1$ and $|V_{tb}| \approx 1$, leading to

$$\beta = \left[1 - \sqrt{\frac{m_u m_s}{m_c m_d}} e^{-i(\phi_1+\phi_2)}\right]\left[\frac{(1-r_2 e^{i\phi_2})}{(1-r_1 e^{i\phi_2})}\right] \tag{25}$$

It is important to note that these expressions hold for any values of d satisfying equation (13) both for the up and down sectors. We further observe that for strongly hierarchical mass matrices, satisfying $d \approx m_2 << c \approx m_3$, the parameters $k_{1u}, k_{1d}, k_{2u}, k_{2d}, k_{3u}, k_{3d}$ are approximated as

$$k_{1u} = k_{1d} = 1\ , k_{2u} = \sqrt{\frac{m_u}{m_t}},\ k_{2d} = \sqrt{\frac{m_d}{m_b}}, k_{3u} = k_{3d} = 1. \tag{26}$$

In such a case one obtains, up to a leading order, the following expressions

$$V_{us} = \sqrt{\frac{m_d}{m_s}} e^{-i\phi_1} - \sqrt{\frac{m_u}{m_c}}\left[1 - \sqrt{\frac{m_u}{m_t}}\sqrt{\frac{m_d}{m_b}} e^{i\phi_2}\right] = \sqrt{\frac{m_d}{m_s}} e^{-i\phi_1} - \sqrt{\frac{m_u}{m_c}}\ , \tag{27}$$

$$\left|\frac{V_{ub}}{V_{cb}}\right| = \sqrt{\frac{m_u}{m_c}}\left|1 + \sqrt{\frac{m_d m_s m_c}{m_u m_b^2}}\ \frac{e^{-i\phi_1}}{(1-e^{i\phi_2})}\right| \approx \sqrt{\frac{m_u}{m_c}}\ , \tag{28}$$

$$\left|\frac{V_{td}}{V_{ts}}\right| \approx \sqrt{\frac{m_d}{m_s}}\ , \tag{29}$$

and

$$\beta \approx \arg\left[\left(1 - \sqrt{\frac{m_u m_s}{m_c m_d}} e^{-i(\phi_1+\phi_2)}\right)\right]. \tag{30}$$

Thus we observe that the relations (1) and (2) are the special cases of the most general relations and hold only under the assumptions of strongly hierarchical mass matrices as well as by retaining terms up to the leading order.

One can easily show by using the expression (26) that Fritzsch like texture 4 zero mass matrices are fully compatible with the present value of parameter $Sin2\beta$. A detailed analysis in this regard would be presented elsewhere. To summarize, an almost exact expression for $Sin2\beta$, the CP violating parameter in the B decays, in terms of quark masses and the phases of mass matrices has been derived. The expression can be reduced to the usual form shedding important light on the role of hierarchy of the elements of the mass matrices as well as the phase structure of the mass matrices.

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EFFECT OF REPLACEMENT OF FISHMEAL WITH PROCESSED SOYBEAN ON DAILY EXCRETION OF AMMONICAL - NITROGEN (NH_4-N) AND ORTHO-PHOSPHATE (O-PO_4), IN *CHANNA PUNCTATUS* (BLOCH.)

***Meenakshi Jindal, S.K. Garg, and N.K. Yadava**

Department of Zoology and Aquaculture CCS HA.U., Hisar - 125 004

Abstract

To study the daily excretion patterns of wastes like ammonical nitrogen (NH_4-N) and ortho-phosphate (O-PO_4) fish were fed on 10 isonitrogenous diets (D_1 to D_{10}) formulated by replacing fishmeal (FM) with processed soybean at 4 inclusion levels (25, 50, 75 and 100g/kg) with and without supplementing the diets with a mineral premix and amino acids (MPA). Studies have reveled that oxygen levels (DO) fluctuated between 4 to 5 mg/l and pH remained alkaline (7.3 to 7.4). Significantly ($p<0.05$) highest conc. of NH_4-N and O-PO_4 were observed in the water medium in which fish were fed on reference diets D_1 and D_6 containing FM as the main protein source. The excretion decreased on increasing the inclusion levels of processed soybean. Further, in the groups of fish fed on diets D_6 to D_{10} the excretion of NH_4-N and O-PO_4 was lower than those observed in groups of fish where diets D_1 to D_5 were used indicating that incorporation of MPA reduces the excretion of NH_4-N and O-PO_4 in water medium. The peak time of excretion of NH_4-N was observed at the end of 6 hrs. of post-feeding and of O-PO_4 was observed at the end of 8 hrs. of post-feeding.

Key words: Ammonical nitrogen, *Channa punctatus*, excretion, fishmeal, ortho-phosphate, processed soybean.

INTRODUCTION

Nitrogen in waste wa er from aquaculture effluents is often considered a pollutant. In freshwater systems, nitrogen is sometimes a limiting nutrient, so adding it stimulates plant and algal growth. A majority of the excess nitrogen in either tank or pond culture systems originates as ammonia excreted by fish. (Fivelstad *et al.*, 1990; Beveridge *et al.*, 1991; Beveridge and Phillips, 1993; Kellay *et al.*, 1994; Bergheim and Asgard, 1996; Kibria *et al.*, 1996, 1998 and Jindal, 2001). The ammonia, as a waste product, is formed during the breakdown of proteins and excess amino acids not incorporated into tissues by the fish.

Fish excrete phosphorus in soluble and particulate forms (Lall, 1991 and Pillay, 1992; Vielman *et al.*, 2000.) The soluble fraction called ortho phosphate (O-PO_4), is most available for plant growth (Bostrom *et al.*, 1988). However the main loading of phosphorus to the environment was reported to be *via* faecal pellets (Pillay, 1992 and Kibria *et al.*, 1996).

Therefore, there is a need to research alternate protein sources that may also reduce the input of nitrogen and phosphorus into the environment. Feeds for cultivated species contain a significant amount of fishmeal (FM). But, The increasing costs and unpredictable availability of FM necessitates the search for its replacement with cheaply and abundantly available plant protein feed stuffs. Due to world wide dominance of soybean and its appreciation as quality protein, several workers have attempted to replace FM with soybean meal (SBM) in diets formulated for several fish species (Jindal 2001; Deepak and Garg, 2003; Jose *et al.*, 2006; Jindal *et al.*, 2007a,b and Robinson and Menghe, 2007).

Hence, the aim of present investigation was to search an alternate protein source of plant origin (*i.e.* soybean) that will not be only cost effective, but certainly would reduce excretion of nitrogenous wastes and total organic matter, possibly also of phosphrus, and alleviate pollution problems in intensive aqua-cultural systems.

MATERIAL AND METHODS

Specimens of *Channa punctatus* were obtained from fish dealers of Hisar. Specimens with mean body weight (8.0 to 15.0 g) were used in the studies. Fish were placed in the transparent glass aquaria (60X30X30 cm) kept in the laboratory where the temperature was maintained at 25±1°C and the lighting scheduled at 12h of light alternating with 12h of darkness. The fish were acclimatized for a minimum of 7 days prior to the initiation of experimental treatments. The water was renewed daily with chlorine free water.

Soybean was used as the main protein source. Soybean

**Corresponding Author* : mypshya@rediffmail.com
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seeds were cleaned, autoclaved for half an hour at 121.6°C at 15 lb pressure to remove antinutritional factors (ANFs) such as trypsin inhibitors, haemoglutinins, lectins and phytic acid. (Garg *et al.*, 2002). After oven drying at 60°C, it was ground into fine powder.

Groundnut oil cake, Rice bran, fishmeal and processed soybean were finely ground to pass through 0.5 mm sieve. All the ingredients were mixed according to Table-1 and dough was made using distilled water. Thereafter, the dough was passed to a mechanical palletizer to obtain pellets (0.5 mm thick) which were dried in an oven and used in the studies for 45 days.

The experimental diets were fed to duplicate groups of fish to satiation twice a day for a one week acclimatization period before starting the study. After this period, the fish were individually weighed and their initial weights recorded. The fish were then offered the test diets (1-10) twice a day (9:00h and 16:00h) to satiation, for 45 days. Fish were bulk weighed every tenth day and feeding rates adjusted accordingly to study the growth parameters using standard methods (Steffens, 1989). This period was considered enough to produce the effect of feeding on daily excretory pattern in the test species. Faeces were siphoned from culture aquaria every morning before fish feeding following the method of Spyridakis *et al.*(1989). In addition, about 20-50% of the culture water was replaced daily with new, fresh, dechlorinated water.

On the last day of experiment offer the same feed to the fish in sufficient quantity so that the same is consumed, wait for 2 hours. Maintain a fixed level of water in each aquarium (say 30-40 L). Remove the excess of feed. The various water quality parameters like dissolved oxygen, pH, temperature, conductivity, free carbondioxide, total alkalinity and total hardness of aquaria water were analyzed following APHA (1998) to see the influence of test diets on the pollution status of water.

Start collecting water samples from each aquarium in replicate of 2 for the determination of ammonical nitrogen (NH_4-N) and ortho-phosphate (O-PO_4) following APHA (1998) to see the influence of compounded feeds on

Table 1: Ingredient Composition (%) of compounded diets from D_1 to D_{10}

Ingredients	Diet number									
	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}
Groundnut oil cake[a1]	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Rice bran[a2]	24.0	24.0	24.0	24.0	24.0	23.0	23.0	23.0	23.0	23.0
Fish meal[b](FM)	10.0	7.5	5.0	2.5	-	10.0	7.5	5.0	2.5	-
Hydrothermically treated soybean[c] HPS	-	2.5	5.0	7.5	10.0	-	2.5	5.0	7.5	10.0
Chromic oxide[d] (Cr_2O_3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Binder[e] (Carboxyl methyl cellulose)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
MPA,Mineral mix[f]	-	-	-	-	-	1.0	1.0	1.0	1.0	1.0

D_1 and D_6 were used as reference diets

a1 and a2 → used as basal feed ingredients;

b and c → used as main protein source. FM was replaced by processed soybean (HPS)at each inclusion level.

d → used as an external indigestible marker for estimating apparent digestibility

e → used as binder to make the diets water stable

f → MPA added to supplement the diets with minerals and amino acids.

Each Kg contains Copper - 312mg; Cobalt - 45mg; Magnesium - 2.114g; Iron -979mg; Zinc - 2.13g; Iodine 156mg; DL-Methionine - 1.92g; L-lysine mono hydrochloride - 4.4g; Calcium 30% and Phosphorous - 8.25%

pollution status of receiving water in the aquaria.

Calculate the excretory levels of NH_4-N and O-PO_4 in treated water as follows:-

$$NH_4\text{-N excretion (mg/100g BW of fish)} = \frac{NH_4\text{-N (mg l}^{-1}\text{) in aquarium water}}{\text{Fish weight (mg) per L of water}}$$

$$O\text{-}PO_4 \text{ excretion (mg/100g BW of fish)} = \frac{O\text{-}PO_4 \text{ (mg l}^{-1}\text{) in aquarium water}}{\text{Fish weight (mg) per L of water}}$$

Statistical analysis

Data was analysed following ANOVA, Duncan Multiple Range Test (Duncan, 1955) and Multivariate Analysis (Prein *et al.*; 1993) at 5 percent probability level. Group means were compared by student 't' test (Snedecor and Cochran, 1982).

RESULTS AND DISCUSSION

Water quality parameters

The water quality parameters of different aquaria stocked with test species fed on compounded diets D_1 to D_{10} are shown in Table 2.

The table showed that oxygen levels (DO) fluctuated between 4-5 mg/l, conductivity between 0.44 to 0.51 micro mhos/cm, free CO_2 between 16.1 to 17.0 mg/l, total alkalinity between 236 to 245 mg/l and total hardness between 220 to 230 mg/l. The pH remained alkaline (7.2 to 7.4). The water temperature fluctuated between 25 to 26°C. Low DO values in aquaria stocked with fish fed on test diets D_6 to D_{10} clearly indicated its utilization by the growing fish. It showed that diets supplemented with MPA resulted in better growth of fish. These results are in agreement with those of Kalla and Garg (2004); Singh *et al.* (2004); Jindal (2001), Jindal *et al.* (2007a,b) ; Jindal (2007) and Jindal, 2008.

Post-prandial excretory levels of NH_4-N and O-PO_4

Significantly ($p< 0.05$) highest conc. of NH_4-N and O-PO_4 were observed in the water medium in which fish were fed on reference diets (D_1 and D_6) containing FM as the main protein sources (Table-3).

The excretion of NH_4-N and O-PO_4 decreased on increasing the inclusion levels of processed soybean in the diets. These results showed that fish fed on plant proteins (HPS based) excrete less ammonia and phosphorus in comparison to fish fed on animal protein diets (FM based). This also indicated that the fish can digest plant proteins much more easier than animal proteins (Jindal, 2001; Deepak and Garg, 2003; Kalla and Garg, 2004; Jindal and Garg, 2005; Jindal *et al.*, 2007a,b ; Robinson and Menghe, 2007 and Jindal, 2008). Further in the groups of fish fed on diets D_6 to D_{10}, the excretion of NH_4-N and O-PO_4 was lower than those observed in groups of fish where diets D_1 to D_5 were used indicating that incorporation of MPA reduces the excretion of NH_4-N and O-PO_4 in water medium (Table -2).Jindal (2007) reported the same results in *C. batrachus* and *H. fossilis* fingerlings. These results are also in agreement with those of Viola and Lahav (1993). According to them the calculated amounts of excreted (not retained) nitrogen per kg gain was reduced by 20% in the lysine supplemented feeds, as compared to the

Table 2: Water quality parameters of different aquariums stocked with *C. punctatus* fingerlings fed on compounded diet – D10

Parameters	Diet No.									
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D
Dissolved oxygen (DO) mg/l	4.6 ± 0.001	4.7 ± 0.003	4.8 ± 0.002	4.9 ± 0.008	5.0 ± 0.004	4.8 ± 0.004	4.2 ± 0.002	4.3 ± 0.006	4.2 ± 0.007	4 ± 0
Ph	7.20	7.30	7.30	7.20	7.40	7.40	7.30	7.30	7.30	7.
Water temperature (°C)	25.00	26.00	25.30	25.50	26.50	25.30	25.50	26.00	25.50	25
Conductivity micro (µ) mhos cm^{-1}	0.50 ± 0.005	0.49 ± 0.003	0.49 ± 0.000	0.51 ± 0.002	0.48 ± 0.007	0.47 ± 0.002	0.46 ± 0.007	0.45 ± 0.003	0.46 ± 0.005	0. ± 0
Free Carbon dioxide (Free CO_2) mg/l	16.90 ± 0.000	17.00 ± 0.002	16.80 ± 0.001	16.70 ± 0.004	16.80 ± 0.002	16.30 ± 0.000	16.40 ± 0.002	16.10 ± 0.001	16.20 ± 0.004	16 ± 0
Total alkalinity (mg/l)	215.0 ± 0.002	225.0 ± 0.000	215.0 ± 0.001	216.0 ± 0.003	214.0 ± 0.001	220.0 ± 0.005	225.0 ± 0.003	218.0 ± 0.006	221.0 ± 0.005	21 ± 0
Total hardness (mg/l)	213.0 ± 0.005	212.0 ± 0.004	219.0 ± 0.001	218.0 ± 0.003	228.0 ± 0.002	216.0 ± 0.002	218.0 ± 0.007	220.0 ± 0.005	214.0 ± 0.006	21 ± 0

* - All values are mean ± S.E. of mean of 3 observations

Table 3: Effect of feeding experimental diets from D_1 to D_{10} containing processed soybean and fishmeal (without and with mineral mix @ 10g/Kg of diet) on growth performance and excretory levels of NH_4-N and O-PO_4 in fish *Channa punctatus*

Diet No.	Survival %	Weight gain (g)	Growth % gain in Body Weight	Specific Growth Rate (SGR)	Feed Conversion Ratio (FCR)	Apparent Protein Digestibility (APD)	Protein Efficiency Ratio (PER)	NH_4-N (mg/100g BW of fish)	O-PO_4 (mg/100g BW of fish)
D_1	90	4.473^{A} ± 0.049	34.052^{A} ± 0.299	0.651^{A} ± 0.004	2.868^{A} ± 0.032	75.953^{A} ± 0.339	0.142^{A} ± 0.001	0.606 ±0.003	0.276 ±0.006
D_2	95	4.690^{AB} ± 0.043	35.443^{A} ± 0.362	0.674^{A} ± 0.005	2.771^{AB} ± 0.026	76.963^{B} ± 0.057	0.151^{AB} ± 0.001	0.553 ±0.003	0.263 ±0.008
D_3	96	5.023^{C} ± 0.006	38.694^{B} ± 0.270	0.726^{C} ± 0.004	2.597^{C} ± 0.003	78.457^{C} ± 0.264	0.164^{C} ± 0.000	0.523 ±0.008	0.253 ±0.008
D_4	93	5.223^{CD} ± 0.033	40.398^{BC} ± 0.322	0.754^{CD} ± 0.005	2.518^{CD} ± 0.016	82.143^{D} ± 0.380	0.173^{CD} ± 0.001	0.496 ±0.003	0.226 ±0.008
D_5	97	5.360^{DE} ± 0.105	41.197^{CD} ± 0.717	0.766^{DE} ± 0.011	2.476^{CE} ± 0.047	85.297^{E} ± 0.104	0.182^{DE} ± 0.005	0.473 ±0.003	0.190 ±0.005
D_6	92	4.583^{AF} ± 0.171	33.839^{A} ± 1.083	0.647^{A} ± 0.018	2.844^{AF} ± 0.103	76.827^{B} ± 0.088	0.144^{A} ± 0.004	0.506 ±0.003	0.240 ±0.000
D_7	96	4.850^{BCF} ± 0.043	35.847^{A} ± 0.327	0.680^{A} ± 0.005	2.703^{BCF} ± 0.024	79.137^{C} ± 0.426	0.155^{BC} ± 0.001	0.490 ±0.000	0.216 ±0.003
D_8	98	5.193^{CE} ± 0.013	39.980^{BD} ± 0.089	0.747^{CE} ± 0.001	2.551^{C} ± 0.006	80.823^{F} ± 0.160	0.169^{C} ± 0.000	0.480 ±0.005	0.203 ±0.003
D_9	95	5.676^{G} ± 0.017	43.797^{E} ± 1.314	0.807^{F} ± 0.020	2.381^{DEG} ± 0.075	83.517^{G} ± 0.280	0.187^{E} ± 0.007	0.453 ±0.003	0.190 ±0.000
D_{10}	98	5.983^{H} ± 0.113	45.883^{F} ± 0.815	0.839^{G} ± 0.012	2.282^{G} ± 0.042	87.990^{H} ± 0.324	0.199^{F} ± 0.005	0.426 ±0.008	0.173 ±0.003

All values are mean ± S.E. of mean; Diets D1 and D6 were used as control diets

Mean with same letter in the same column are not significantly ($p>0.05$) different.

Data were analysed by Duncan's Multiple Range Test

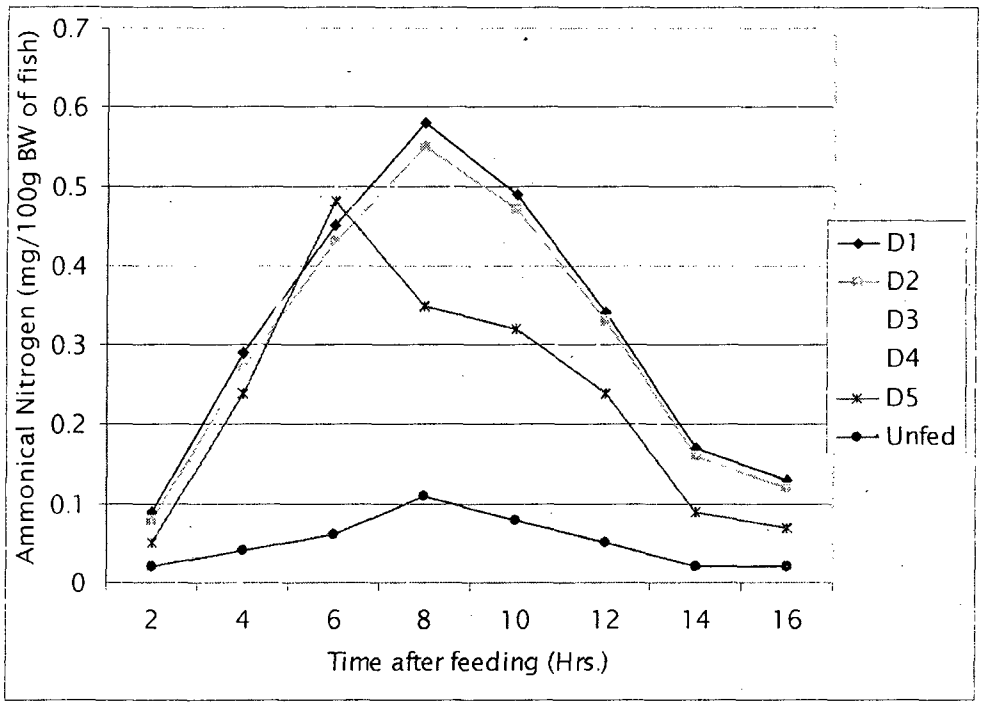

Fig. 1 (A)

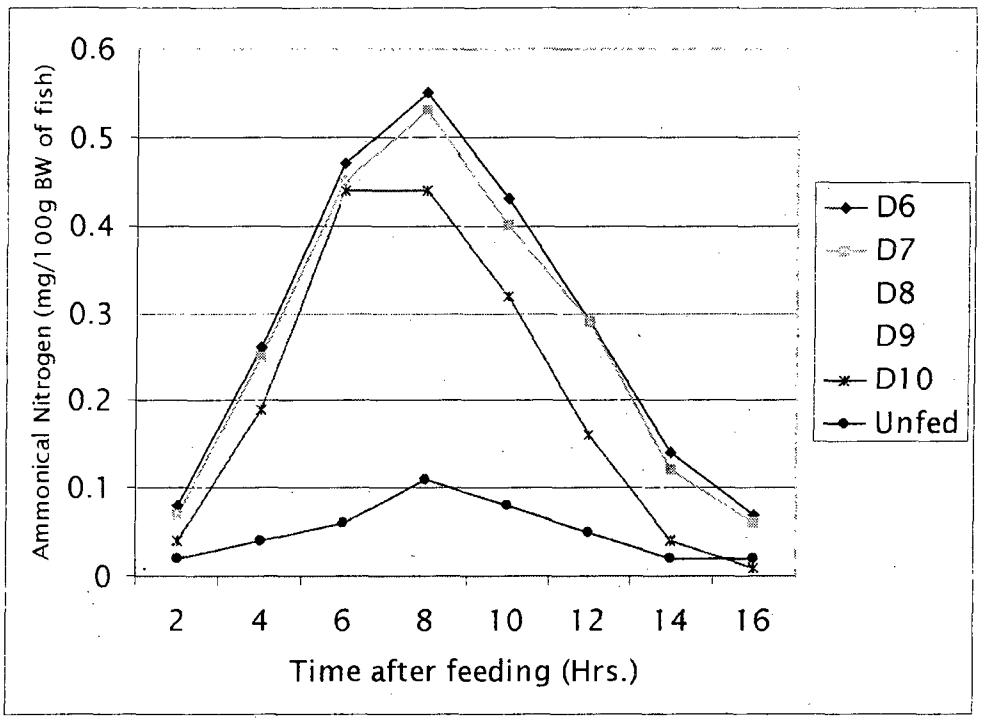

Fig. 1 (B)

Fig. 1: Diurnal excretory patterns of ammonical nitrogen, NH_4-N (mg/100g Body weight, BW) in treated waters in fish *Channa punctatus* fed on diets D_1 to D_{10} "A" without mineral mix and amino acids ($D_1$to D_5) "B" with mineral mix and amino acids (D_6 to D_{10}).

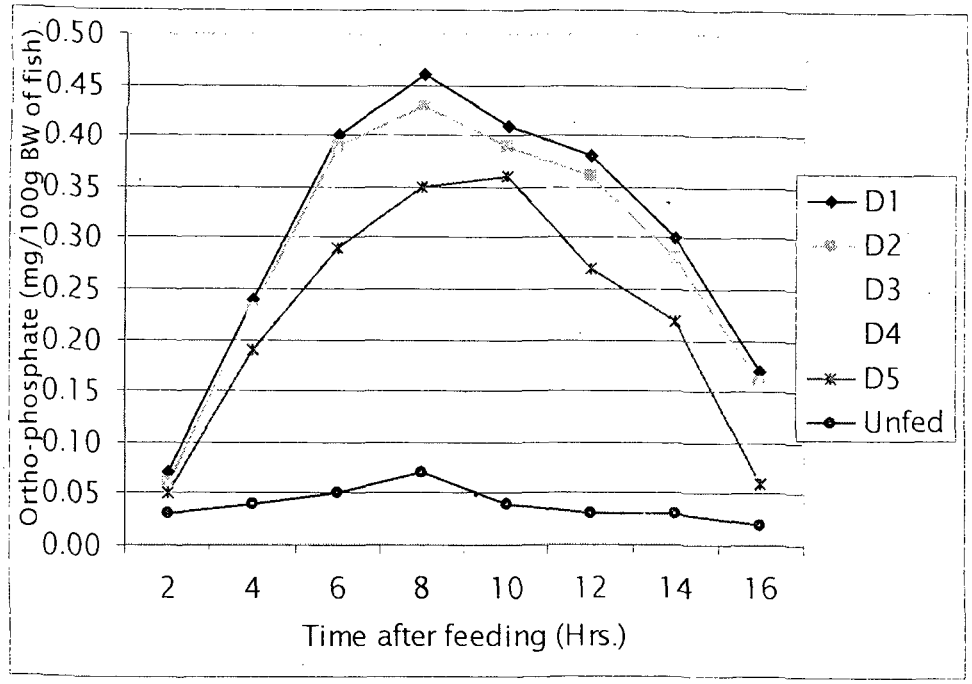

Fig. 2 (A)

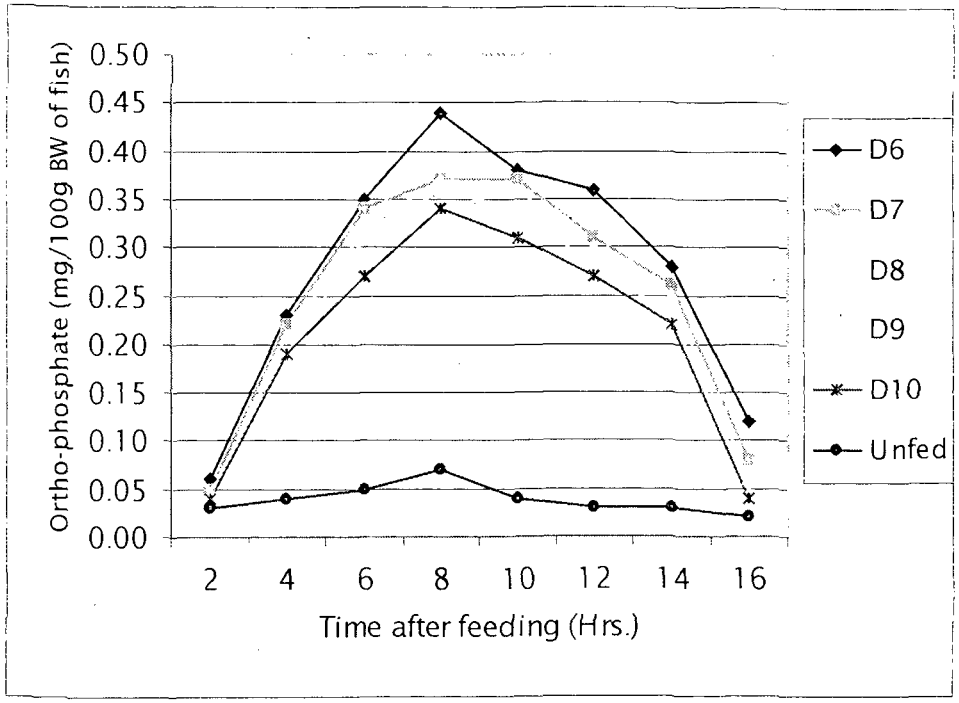

Fig. 2 (B)

Fig. 2: Diurnal excretory patterns of Ortho-phosphate O-PO_4 (mg/100g Body weight, BW) in treated waters in fish *Channa punctatus* fed on diets D_1 to D_{10} "A" without mineral mix and amino acids ($D_1$to D_5) "B" with mineral mix and amino acids (D_6 to D_{10}).

30% protein feed. Concomitantly, calculated phosphorus excretion per kg gain was also decreased approximately by 100%.

Diurnal pattern of NH_4-N and O-PO_4 excretion

Water samples were analysed for 16 hrs at 2 hr interval of post-feeding revealed peaks in NH_4-N and O-PO_4 excretion (Fig. 1 and Fig. 2).

The peak time of excretion of NH_4-N in groups of fish fed on diets D_1, D_2 and D_3 were observed at the end of 8 hrs. of post feeding but in groups of fish fed on diet D_4 and D_5, the peak time of excretion of NH_4-N was slightly earlier i.e. at the end of 6 hrs. of post-feeding (Fig. 1 A).

In the groups of fish fed on diets D_6 to D_{10} supplemented with MPA, the excretion of NH_4-N was lower than those observed in groups of fish fed on diets D_1 to D_5. But the pattern of excretion of NH_4-N was same as for groups of fish fed on diets D_1 to D_5 (Fig. 1B).

The peak time of excretion of O-PO_4 in the groups of fish fed on the diets D_1 to D_5 were observed at the end of 8 hrs. of post-feeding (Fig. 2A), whereas in the groups of fish fed on diets D_6 to D_{10} supplemented with MPA, the excretion of O-PO_4 was lower than those observed in the groups of fish fed on diet D_1 to D_5. But the pattern of excretion of O-PO_4 was same as for the groups of fish fed on the diets D_1 to D_5 (Fig. 2B).

These results are in agreement with those of Kaushik and Gomes, 1988; Kaushik and Cowey, 1991; Van Weerd *et al.*, 1993; Jindal, 2007 and Robinson and Menghe, 2007, who reported ammonia excretion peaks between 7-9 hr post feeding. A peak in NH_4-N and O-PO_4 excretion at the end of 6 hr of post feeding has also been reported by Jindal 2001; Deepak and Garg, 2003; Kalla *et al.*, 2003; Singh *et al.*, 2003; Kalla and Garg 2004; Singh *et al.*, 2004 ; Jindal and Garg, 2005; Jindal, 2007 ; Jindal *et al.*, 2007a,b and Jindal, 2008.

The differences between the present data and those of others on the peak in ammonia and phosphorus excretion may be attributed to the facilities used by different authors (e.g. the size of holding tanks etc.) and the prevailing environmental and rearing conditions etc. Perhaps it also depends on the species under investigation.

Growth parameters

Survival of fish in different dietary treatments was observed high and varied between 90 to 98% (Table 3).

A significantly ($p< 0.05$) high growth were observed as the inclusion level of HPS was increased in the diets. But, as the diets were supplemented with MPA (diets D_6 to D_{10}), a much better growth was observed. These results are in agreement with those of Jindal 2001; Deepak and Garg, 2003; Kalla and Garg 2004; Jindal and Garg, 2005; Jindal, 2007 ; Jindal *et al.*, 2007a,b and Jindal, 2008.

The studies further indicated that there is a negative correlation between growth parameters and FCR values. Further, the growth parameters also have negative correlation with NH_4-N and O-PO_4 excretion. This is the reason for the better growth and low excretory levels of NH_4-N and O-PO_4 excretion in the groups of fish fed on diets D_5 and D_{10} in comparison to the fish groups fed on diets D_1 and D_6. These results are in agreement with those of Jindal (2007) reported in *C. batrachus* and *H. fossilis* fingerlings.

CONCLUSIONS

The determination of nutrient budgets and daily patterns of waste excretion in aquaculture is important for evaluating the potential waste load of fish farming effluents (Cowey and Cho, 1991). This aspect of intensive fish farming is becoming increasingly important and is receiving much attention (Rosenthal *et al.*, 1993).

The decrease in ammonia and phosphorus excretion in receiving water with the use of protein of plant origin in feed has important implications on the management of highly intensive farming system. Such a replacement not only save total feed cost, but certainly would reduce excretion of nitrogenous wastes and total organic matter, possibly also of phosphorus, and alleviate pollution problems in intensive aqua-cultural systems.

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STATUS AND BIODIVERSITY OF ENDOMYCORRHIZAL FUNGI ASSOCIATED WITH SOME VEGETABLE CROPS

Anju Tanwar, Aditya Kumar, Sapana Sharma, and *Ashok Aggarwal

Department of Botany, Kurukshetra University, Kurukshetra – 136119

Abstract

Twenty two vegetable plant species belonging to ten famalies were screened for AM spore number and root colonization. The mycorrhizal root colonization ranged from 1.46% to 100%. *Solanum tuberosum* showed maximum (100±0) percent of mycorrhizal root colonization and *Brassica rapa* (1.5±0.1) least. *Brassica campestris, B. oleracea* var. *capitata* and *Spinacea oleracea* lack root colonization. The spore number ranged from 409±13.6 to 46±12.05 per 50 gm of soil sample. The highest mycorrhizal spore count was found in *Curcuma longa* (409±13.6) and the lowest in *B. oleracea* var. *capitata* (46±12.05). *Raphanus sativus, B. oleracea* var. *botrytis, B. rapa* are being found to have root colonization which is an exception to family Brassicaceae. Forty AM fungal species belonging to six genera i.e. *Glomus, Acaulospora, Gigaspora, Sclerocystis, Scutellospora* and *Entrophospora* were isolated. *Glomus* was the dominant genus and *Glomus mosseae* was found to be the dominating AM fungi among all *Glomus* spp. and was associated with seventeen vegetable plants. In this investigation maximum AM species were observed in *Curcuma longa* (19).

Key words: Biodiversity, AM fungi, vegetable, taxonomy.

INTRODUCTION

There is an increasing concern for food and environment quality. Microbial inoculations contribute to improved plant growth and health while they reduce chemical inputs. The goal of sustainable development in agriculture can be viewed broadly as maximum plant production with a minimum of soil loss. Among the different microbial groups, proposed for plant inoculation, much attention has been given to Glomalean fungi, i.e. Arbuscular mycorrhizal fungi.

Arbuscular mycorrhizal fungi form symbiotic association with the majority of plants and they are geographically ubiquitous (Bagyaraj, 1986). However, mycorrhizas are absent or rarely present in some species of distinct families. Powell (1975) listed those members of plants that do not always have a mycorrhizal status. The beneficial effect of mycorrhiza on plant growth can be related to higher efficiency in nutrient acquisition especially the phosphorus (Bolan, 1990).

The study of mycorrhizal association in vegetables is important from the angle of enhancement in fruit yield, nutritional status, so that vegetables inoculated with AM will have better vigour and would release pressure on farmers/ policy makers for increasing demand of these vegetables. There are eight AM fungal genera that are valid and known to be distributed through out the globe (Manoharachary, 2004). The genera are: *Acaulospora, Archaeospora, Entrophospora, Glomus, Paraglomus, Gigaspora, Scutellospora* and *Sclerocystis.*

The present investigation was aimed to isolate and identify the different AM fungi associated with different vegetable crops of Kurukshetra district and its adjoining areas. The main objective of this investigation was to understand the biodiversity of AM fungi in natural ecosystem.

MATERIAL AND METHODS

The study sites selected for the study of AM fungal association with vegetable crops are fields around Kurukshetra and its adjoining areas. Root and soil samples of vegetable crops were collected from the study site during Nov. 2006-Sep. 2007. It was done by digging out a small amount of soil close to the plant roots up to the depth of 15-30 cm. These samples were brought to the laboratory in polythene bags and stored at 5 - 10°C for further processing. Isolation of AM spore was done by using 'Wet sieving and Decanting technique' of Gerdemann and Nicolson (1963). Adholeya and Gaur (1994) modified Grid line intersect method was used for quantitative estimation of AM spores. These AM spores were identified using identification manual of Walker (1983), Sheneck and Perez (1990), Morton and Benny (1990) and Mukerji (1996).

Mycorrhizal root colonization was studied by 'Rapid clearing and Staining technique' of Phillips and Hayman (1970). The total percent of root colonization was determined by the Root Slide Technique, as described by Giovannetti and Mosse (1980). Percent root

*Corresponding Author : *aggarwal_vibha@rediffmail.com
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colonization was calculated by using the following formula:

$$\text{Percent root colonization} = \frac{\text{No. of root segments infected}}{\text{Total no. of root segments studied}} \times 100$$

RESULTS AND DISCUSSION

In the present investigation different vegetable crops were surveyed, identified and screened for AM colonization. A total of 22 plants belonging to ten families viz., Solanaceae, Liliaceae, Brassicaceae, Chenopodiaceae, Cucurbitaceae, Apiaceae, Leguminoseae, Zingiberaceae, Araceae and Malvaceae were screened. The mycorrhizal root colonization ranged from 1.56% to 100% (Table -1).

Solanum tuberosum showed 100±0 percent of mycorrhizal root colonization followed by *Solanum melongena* (98.77±2.1), *Allium cepa* (94.41±5.1), *Pisum sativum* (90.5±7.2), *Coriandrum sativum* (90.27±9.1) and *Lycopersicon esculentum* (70.3±1) respectively. The least mycorrhizal root colonization was observed in *Brassica rapa* (1.5±0.1). The three species, lacking mycorrhizal root colonization, were *B. campestris, B.*

Table 1: Mycorrhizal quantification and root colonization of vegetable crops

S. No	Botanical name	Local name	Family Presence of	M	V	A	%AM root colonization	AM spore no. / 50 gm soil
1.	*Ablmoschus esculentus* L.	Bhindi	Malvaceae	+	-	+	*52.66 ± 1	90.2 ±1
2.	*Allium cepa* L	Piaz	Liliaceae	+	+	-	94.4±5.13	302.6± 11.37
3.	*Allium sativa* L.	Lehsun	Liliaceae	-	-	-	62 ± 5.29	159.33 ± 7.02
4.	*Beta vulgaris* L.	Chakunder	Chenopodiaceae	-	-	-	27.7 ± 7.5	163.6 ± 12.50
5.	*Brassica campestris* L.	Sarson	Brassicaceae	-	-	-	0	203 ± 19.97
6.	*Brassica oleracea* var. *capitata* L.	Bandh Gobhi	Brassicaceae				0	46 ± 12.05
7.	*Brassica rapa* L.	Shalgum	Brassicaeae	+	-	-	1.56± 0.2	73.3±20.13
8.	*Brassica oleracea* var. *botrytis* L.	Phul gobhi	Brassicaeae	+	-	-	9.44 ±0.96	209±14.93
9.	*Capsicum frutescens* L.	Hari mirch	Solanaceae	+	+	-	42.2±6.33	133±14.73
10.	*Cicer arietinum* L.	Kala Chana	Fabaceae	+	+	+	60.76 ±7.73	250.6±10.06
11.	*Colocasia esculenta* (L)	Arbi	Araceae	+	+	+	55.57 ±9.05	113.3 ±11.04
12.	*Coriandrum sativum*L	Dhania	Apiaceae	+	+	+	*90.27 ±9.15	170.3 ±16.07
13.	*Curcuma longa* L.	Haldi	Zingiberaceae	+	+	+	65.19 ±8.56	409 ±13.65
14.	*Daucus carota* L.	Gazar	Apiacea	+	+	+	68.41 ±3.77	129 ±4.93
15.	*Luffa acutangula* (L.) Roxb.	Kali tori	Cucurbitaceae	+	+	-	54.5 ±7.27	320.6 ±4.72
16.	*Lycopersicon esculentum* Mill.	Tamatar	Solanaceae	+	+	-	70.33±1	186±6.0
17.	*Pisum sativum* L.	Matar	Fabaceae	+	+	-	90.50±7.27	240±12.49
18.	*Raphanus sativum* L.	Muli	Brassicaceae	+	+	+	52.08±3.60	235.3±18.44
19.	*Solanum melongena* L.	Baingan	Solanaceae	+	+	-	98.77±2.12	108±14.42
20.	*Solanum tuberosum* L.	Aloo	Solanaceae	+	+	+	100	180.3±15.30
21.	*Spinacea oleracea* L	Palak	Chenopodiaceae	-	-	-	0	246.6±13.65
22.	*Trigonella foenum-graceum* L.	Methi	Fabaceae	+	-	-	34.86±4.57	144±8.08

* = Mean of three readings
M = Mycelium, V = Vesicle, A = Arbuscule, + = Present, - = Absent
± = Standard deviation

oleracea var. *capitata* and *Spinacea oleracea*. The percent root colonization by AM fungi varied with the host. Gorsi (2002) found similar results. Variation in the percent AM colonization might be due to the influence of host plant on AM colonization (Santhaguru *et al.*, 1995; Rahman *et al.*, 2003) or may be due to the presence of chemicals in the roots that inhibit mycorrhiza formation (Brundrett, 1991). Plants of non-mycorrhizal families are known to accumulate several secondary metabolites, which resist mycorrhizal formation (Kumar and Mahadevan, 1984). It can also be due to sulphur compounds and betalins. These both have fungistatic properties. In the present investigation four members of Brassicaceae have been studied for AM colonoization and *R. sativus, B. oleracea* var. *botrytis*, *B. rapa* are being found to have root colonization which is an exception to this family (Table- 1). *R. sativus* contains 52.08 ± 3.60 percent root colonization, vesicles and arbuscules. Kamalakannan and Manivannan, (2002); Orlowska *et al.* (2002) and Regvar *et al.* (2003) found similar results.

Regarding the quantification of mycorrhizal spore number it varied with different hosts (Table–1). The highest mycorrhizal spore count was found in *Curcuma longa* (409±13.6), followed by *Luffa acutangula* (320±4.7), *Allium cepa* (302.6±11.3), *Cicer arietinum* (250.6±10.6) and *Pisum sativum* (240±12.4). The lowest mycorrhizal spore number was found in *B. oleracea* var. *capitata* (46±12.05). It was also observed that the number of spores in the rhizosphere was frequently unrelated with the intensity of AM root colonization for example, *S. tuberosum* showed less AM spore number but had highest degree of root colonization, same observation were observed in *S. melongena* and *C. sativum*. Muthukumar and Udaiyan (2001) observed that AM fungal sporulation depends upon wide range of host fungal and environmental factors and that spore number in natural soil were not always correlated with colonization level.

A total of forty AM fungi species belonging to six genera i.e. *Glomus, Acaulospora, Gigaspora, Sclerocystis, Scutellospora* and *Entrophospora* were found to be associated with soil samples of vegetable plants studied (Table–2 and Figure-1, 2, 3, 4, 5). *Glomus* was the dominant genus followed by *Acaulospora, Gigaspora, Sclerocystis, Scutellospora* and *Entrophospora.* Similarly Reddy *et al.* (2006) studied distribution, density and quantitative composition of AM fungi colonizing three solanaceous vegetable crops and found *Glomus* to be the dominating AM fungi. Twenty three species belonging to *Glomus*, eleven belonging to *Acaulospora,* two each of *Gigaspora* and *Sclerocystis* and one each of *Scutellospora* and *Entrophospora* were isolated. *Glomus mosseae* was found to be the dominating AM fungi among all *Glomus* spp. and was associated with seventeen vegetable plants, followed by *G. diaphanum, G. geosporum, G. aggregatum, G. velum, G. constrictum* and *G. fasciculatum*. Parkash *et al.* (2003), Parkash (2004), and Sharma *et al.* (2005), and also found *G. mosseae* to be the most dominating AM fungi while working in different parts of India. All the soil samples were nutrient deficient and neutral to slightly alkaline in nature. The species of *Entrophospora* and *Scutellospora* were very limited in distribution and found to be associated with only six and two plants. Dalal and Hippalgaonker (1995) suggested that *Glomus* favours neutral and alkaline soil whereas *Acaulospora* prefers plain and acidic soil (Abbot and Robson, 1991), *Scutellospora* and *Gigaspora* prefers sandy soils (Muthukumar and Udaiyan, 2001). The rhizospheric soil of the studied area was calcareous, alkaline and hence *Glomus* species predominate in this site.

In this investigation, maximum AM species were observed in *Curcuma longa* (19), followed by *B. campestris* (14), *Lycopersicon esculentum* (13), *Raphanus sativus* (13) and *Luffa acutangula* (12). In *Curcuma longa,* 10 species of *Glomus*, 6 species of *Acaulospora*, 1 species each of *Gigaspora, Sclerocystis, Scutellospora* and *Entrophospora* were isolated. Vegetables shows highly diversified distribution of AM fungi in the rhizospheric soil. *Curcuma longa* showed maximum AM species diversity (Table–1 & 2) and this diversity might be responsible for maximum root colonization.

The vesicles were hyaline, either singly or in groups associated with the cortical tissue of roots. Different shaped vesicles were found in different crops. Elongated vesicles were found in the sample of *C. longa.* Elongated vesicles were also reported in all samples of *C. longa* studied by Reddy *et al.* (2003). Rounded vesicles were found in *S. melongena, Colocasia esculenta* and *L. acutangula* where as oval vesicles were common in mainly *C. frutescence, C. sativum, R. sativum, C. arietinum* and *A. cepa. P. sativum* and *R. sativus* shows beaked vesicles. More than two shaped vesicles were found in *R. sativus, C. longa, D. carota* and *C. arietinum*. In the studied roots H shaped, Y shaped and parallel shaped hyphae were found.

Thus, in the present study it was found that most vegetables growing under natural conditions possess AM fungi and mycorrhizal spore as a regular component of soil microflora. Vegetable seedlings must have adequate amount of mycorrhizal root colonization in the

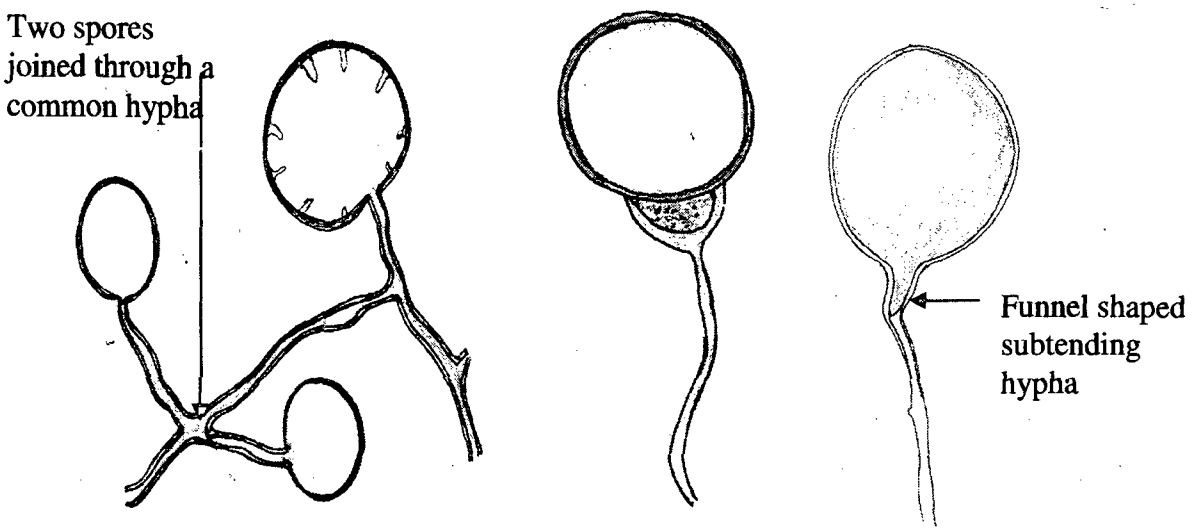
Table – 2 AM spores diversity associated with the rizospheric soil of vegetable crops of Kurukshetra

S. No	Botanical name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1.	*Abelmoschus esculentus* L.				+							+												+	3										+					
2.	*Allium cepa*				+			+					+											+	6															
3.	*Allium sativum*				+		+						+				+			+					10		+		+	+			+					+		
4.	*Beta vulgaris*							+												+					1,9										1			+	+	
5.	*Brassica campestris*			+				+		+			+	+			+	+	+	+	+	+						+					+						+	
6.	*Brassica oleracea* var *capitata*				+			+		+			+							+					14		+													
7.	*Brassica rapa*	+										+								+		+																		
8.	*Brassica oleracea* var *botrytis*	+			+	+		+					+							+	+			+	15,16		+			+	+								
9.	*Capsicum frutescens*		+			+		+												+							+		+							2	+		+	
10.	*Coriandrum sativum*	+							+											+				+	2,4	+	+			+							+			
11.	*Colocasia esculenta*					+		+												+			+				+	+	+		+					2		+		

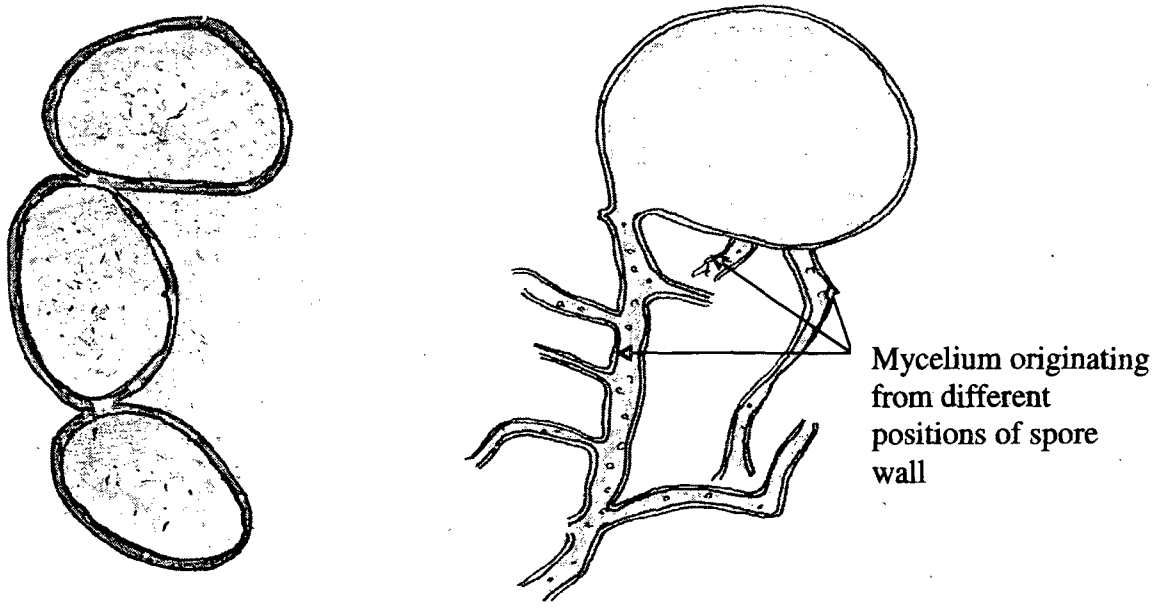
S. No	Botanical name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
12.	*Cicer arietinum*		+		+			+				+	+				+								9, 12	+					+		+						+		
13.	*Curcuma longa*	+					+					+	+							+	+	+	+	+	11		+	+		+	+		+			2	2	+		+	+
14.	*Daucus carota*								+								+			+			+	+	13				+	+							2				
15.	*Lycopersi-con esculentum*	+				+		+		+			+					+						+	17 ,5		+		+								2	+		+	
16.	*Luffa acutangula*	+						+	+	+		+	+							+			+					+	+				+			2				
17.	*Pisum sativum*							+		+							+				+						+			+				+	+			+			
18.	*Raphanus sativus*		+			+					+		+	+				+		+			+		7				+		+								+		
19.	*Spinacia oleracea*	+			+			+					+			+				+							+													
20.	*Solanum tuberosum*	+			+		+			+				+						+					8,		+			+	+				3	2				
21.	*Solanum melongena*	+						+	+	+										+							+												+	+	
22.	*Trigonella foenum graecim*	+													+					+				+			+		+		+						1 , 2	+	+		

1. *Glomus aggregatum* Sch. & Smith
2. *Glomus caledonicum* (Nicol. & Gerd.) Gerd. & Trappe
3. *Glomus carum* Nicol. & Sch.
4. *Glomus constrictum* Trappe
5. *Glomus convolutum* Gerd. & Trappe
6. *Glomus deserticola* Trappe , Bloss & Menge
7. *Glomus diaphanum* Mor. & Walk.
8. *Glomus etunicatum* Bec. & Gerd.
9. *Glomus fasciculatum* Gerd.& Trappe
10. *Glomus fragile* (Berk. & Broome) Trappe & Gerd.
11. *Glomus fuegianum* Trappe & Gerd.
12. *Glomus geosporum* Walk.
13. *Glomus indicum*
14. *Glomus intraradices* Sch. & Smith
15. *Glomus microaggregatum* Koske, Gemma & Olexia
16. *Glomus macrocarpum* Tul & Tul
17. *Glomus morredum* Porter & Hall
18. *Glomus monosporum* Gerd. & Trappe
19. *Glomus mosseae* (Nicol. & Gerd.) Gerd. & Trappe
20. *Glomus multicaule* Gerd. & Bakshi
21. *Glomus pallidum* Hall
22. *Glomus reticulatum* Bhat & Muk.
23. *Glomus velum* Porter & Hall
24. *Glomus* spp. (1 – 17)
25. *Acaulospora bireticulata* Roth. & Trappe
26. *Acaulospora foveata* Trappe & Janos
27. Acaulospora gerdemanii Sch. & Nicol.
28. *Acaulospora laevis* Gerd & Trappe
29. *Acaulospora lacunose* Mor.
30. *Acaulospora scrobiculata* Trappe
31. *Acaulospora mellea* Spain & Sch.
32. *Acaulospora nicolsonii* Walk. Reed & Sand
33. *Acaulospora rehmii* Sieverding & Toro
34. *Acaulospora trappe* Ames & Linderman
35. *Acaulospora* spp. (1 – 3)
36. *Sclerocystis* spp. (1 & 2)
37. *Gigaspora margarita* Becker & Hall
38. *Gigaspora* sp.
39. *Entrophospora* sp.
40. *Scutellospora* sp.

Fig. 1



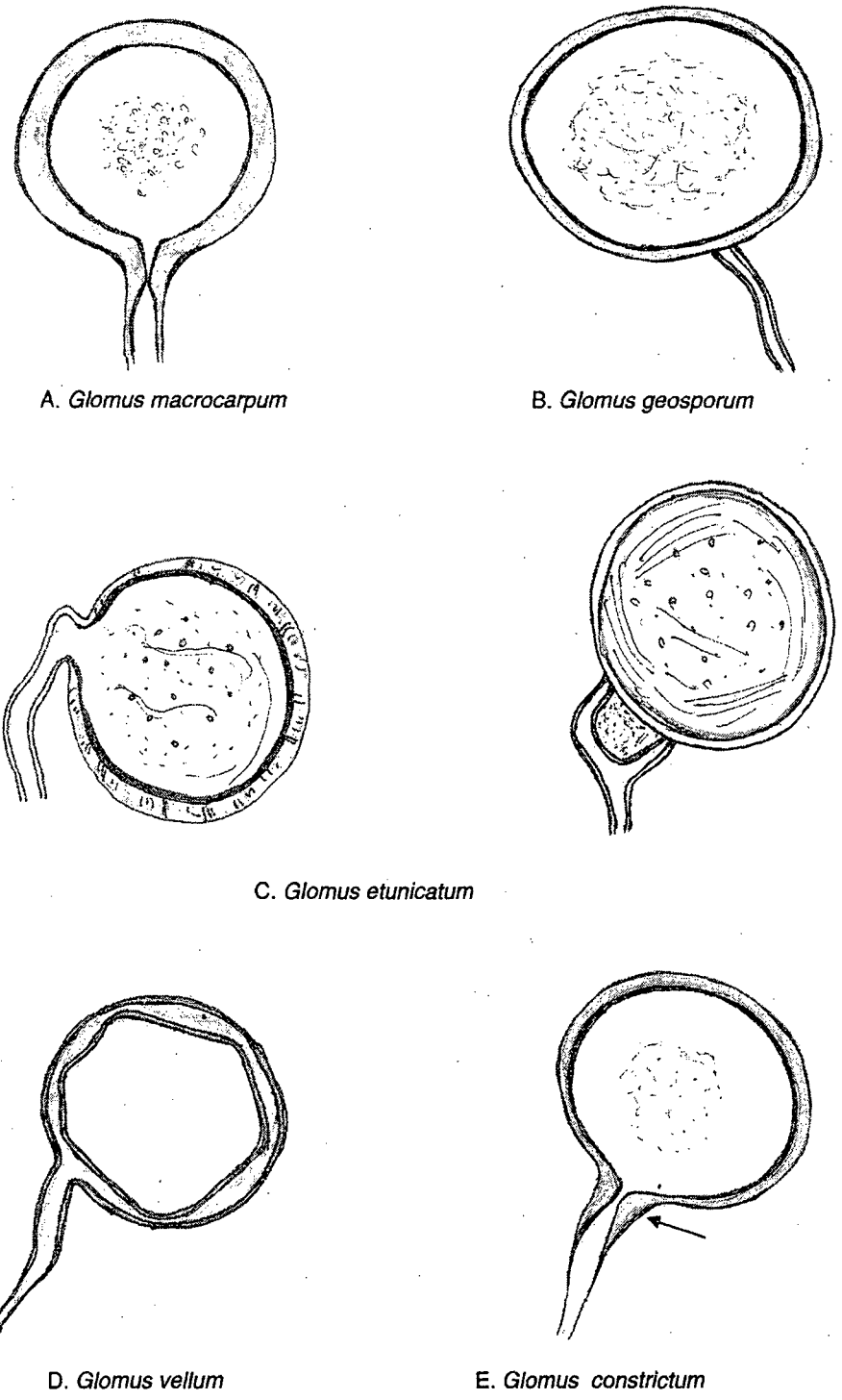
A. *Glomus fasciculatum* B. *Glomus mosseae*



C. *Glomus fuegianum* D. *Glomus multicaulis*

Fig. 2

Fig.1: Different AM spores isolated from rhizosphere of vegetables: (A) *Glomus diaphanum* (B) *Glomus mosseae* (C) *Glomus fuegianum* (D) *Glomus multicaulis*



A. *Glomus macrocarpum*

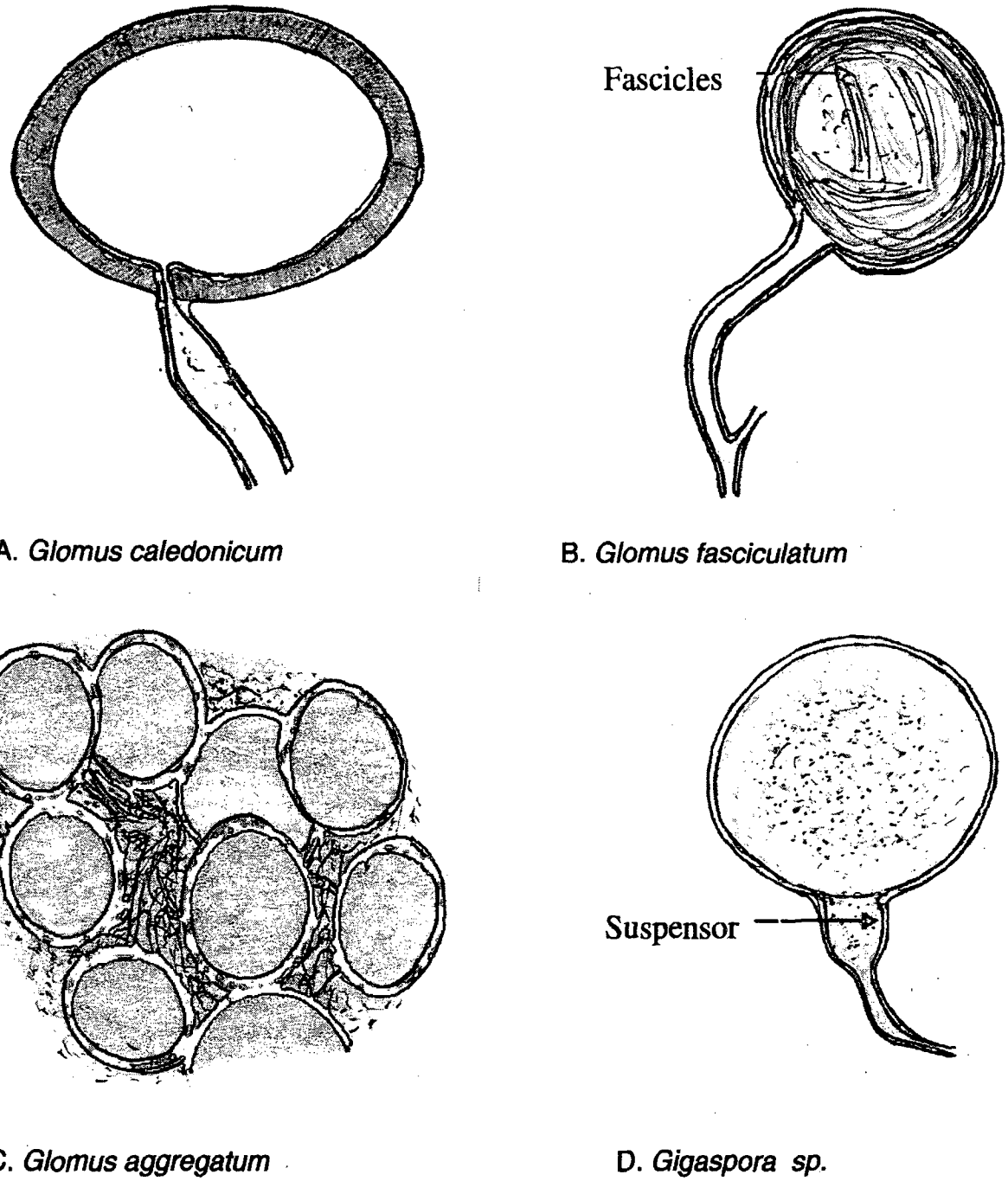
B. *Glomus geosporum*

C. *Glomus etunicatum*

D. *Glomus vellum*

E. *Glomus constrictum*

Fig. 2: Different AM spores isolated from rhizosphere of vegetables. (A) *Glomus macrocarpum* (B) *Glomus geosporum* (C) *Glomus etunicatum* (D) *Glomus vellum* (E) *Glomus constrictum*



A. *Glomus caledonicum*

B. *Glomus fasciculatum*

C. *Glomus aggregatum*

D. *Gigaspora sp.*

Fig. 3

Fig. 3 : Different AM spores isolated from rhizosphere of vegetables: (A) *Glomus caledonicum* (B) *Glomus fasciculatum* (C) *Glomus aggregatum* (D) *Gigaspora sp.*

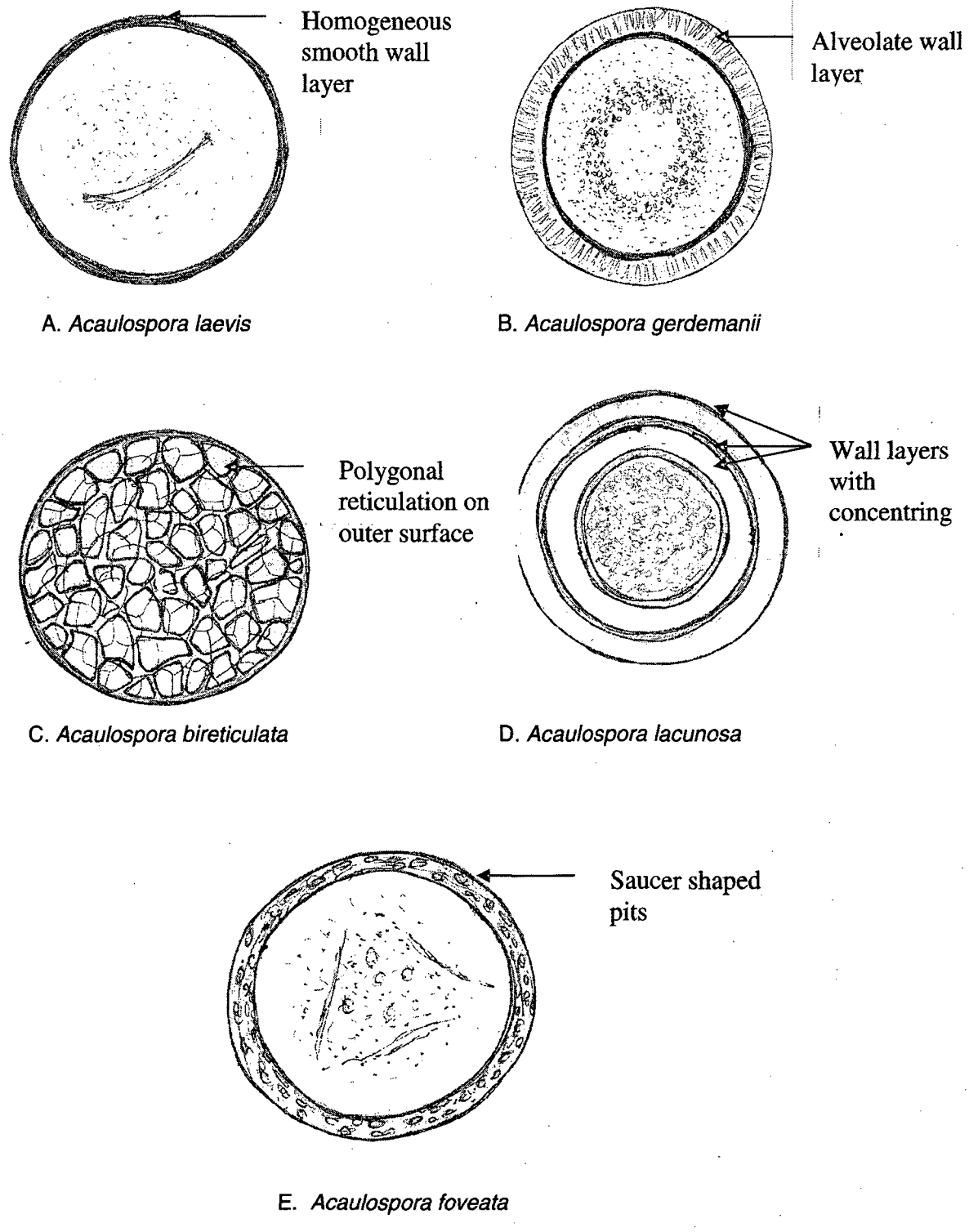


Fig. 4

Fig.4: Different AM spores isolated from rhizosphere of vegetables : (A) *Acaulospora laevis* (B) *Acaulospora gerdemanii* (C) *Acaulospora bireticulata* (D) *Acaulospora lacunose* (E) *Acaulospora foveata*

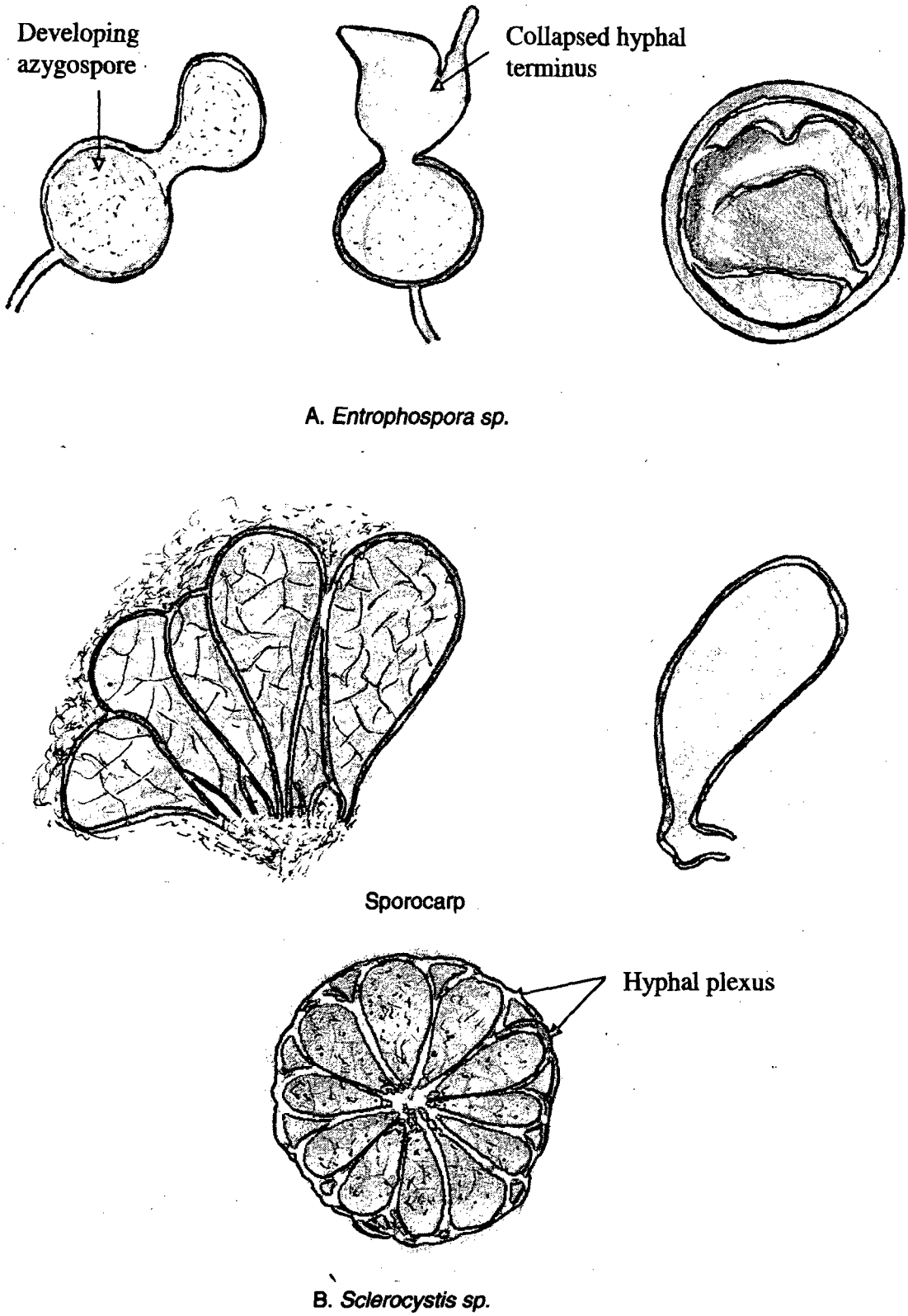


Fig.5: Different AM spores isolated from rhizosphere of vegetables : (A) *Entrophospora sp.* (B) *Sclerocystis sp.*

planting stage in order to establish into the field.

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IN VITRO CULTURE OF *PLASMODIUM BERGHEI* USING GLUCOSE AND RETICULOCYTES ENRICHED BLOOD CELLS

***U. Bagai, R. Gupta, and S. Chandel**

Department of Zoology, Panjab University, Chandigarh-160 014

Abstract

In the present study, an attempt has been made to assess *in vitro* conditions for maintenance of continuous growth of rodent malaria parasite *Plasmodium berghei.* Eight experiment culture conditions (A-H) were analysed. G type containing medium (RPMI-1640 supplemented with HEPES, sodium bicarbonate and glucose), normal mouse serum and phenylhydrazine hydrochloride (PHC)-induced reticulocyte rich blood proved to be most effective in maintaining long-term *in vitro* culture of *P. berghei.* The viability of the parasite in long term culture was assessed by i.p. injection of 1×10^6 *P. berghei*- infected erythrocytes from terminated culture plates after every 24 h till 7 days in normal mice. *In vitro* cultivation of erythrocytic stages of malarial parasite will be of great help in understanding the biology of the parasite to locate new targets for drug designing and vaccine development.

Key words: culture, malarial parasite, *Plasmodium berghei*, reticulocytes.

INTRODUCTION

Malaria is a widespread parasitic disease in the world with an estimated 300-500 million clinical cases causing 1.2–2.8 million deaths each year (Sherman, 1998; Guerin *et al.,* 2002; Tripathi *et al.,* 2005, Guadalupe *et al.*, 2007). Most of the victims are young children below the age of five years (Schwartlander, 1997). The rising resistance to classical medication stresses the need for the intensive research on biology of the parasite and its mode of action.

The establishment of *in vitro* culture (Haynes *et al.,* 1976; Trager and Jensen, 1976) paved the way for the rapid screening of antimalarial components, and to check cross resistance pattern of *Plasmodium* for different antimalarial components. Of the four species of *Plasmodium, P. falciparum* and *P. vivax* infection carries the substantial risk of death (Olliaro *et al.,* 1996). *P. falciparum* invades mature erythrocytes (Pasvol *et al.,* 1980), while *P. vivax* preferentially invades human reticulocytes and immature reticulocytes if they are positive for Duffy blood group antigens. In long term *in vitro* culture of *P. berghei* ranging from 17-90 days, peak parasitaemia over 20% was observed. Using long term culture, *P. berghei* was established for 45 weeks RPMI-1640 modified by additional glucose and bactopeptone (Janse *et al.*, 1984). 10% normal mouse serum was used to prepare complete medium. Preferential invasion of reticulocyte by *P. vivax* was demonstrated both *in vitro* and *in vivo* (Mons *et al.*, 1988). Using static candle jar and shaker method, long term culture of *P. vivax* was maintained successfully for 10-14 days (Golenda *et al.*, 1997). Since *P. berghei* acts as a simulated model of *P. vivax*. It is therefore, the present study was conducted to assess the viability in continuous cultures of *P. berghei* maintained by static candle jar method under varied conditions.

MATERIAL AND METHODS

NK-65 strain of *Plasmodium berghei* was maintained in white swiss mice, *Mus musculus* (Balb/C). 1×10^6 *P. berghei* infected erythrocytes were injected i.p. into naïve mice and parasitaemia was monitored daily by preparing thin Giemsa stained blood smears. Reticulocytosis was induced by i.p. injection of 0.4% (w/v) phenylhydrazine hydrochloride (PHC) in PBS, pH 7.2 to each mouse on alternate days.

Two types of culture media were prepared for present study; (1) Normal medium: standard incomplete medium having RPMI-1640 (HIMEDIA, India) supplemented with 5% (w/v) sodium bicarbonate, 0.6% (w/v) HEPES, 50 µg/ml gentamycin, 100µl/ml penicillin and 100µg/ml streptomycin. (2) Modified medium : incomplete medium in (1) was modified by adding glucose (1mg/1ml). Both these incomplete media were made complete either by adding 5% (v/v) fetal calf serum (FCS) or 5% (v/v) normal mouse serum (NMS).

Short term *in vitro* culture was maintained in 24-well culture trays (Laxbro, India). 4% haematocrit was prepared and 1 ml culture was incubated in candle

**Corresponding Author* : upmabagai@yahoo.co.in
MS Received July 09, 2007; Accepted May 20, 2008

jar at 37°C in 8 types of wells (A-H, each type in duplicate). The types and conditions used for different cultures are explained in Table 1. Culture was terminated after 21h and thin blood smears were prepared. Observations were made for both 0 h and 21h smear by differential count of parasite stage i.e. rings, trophozoites and schizonts.

Percent invasion was calculated as:

$$\% \text{ of inhibition} = 100 - \frac{\text{No. of infected erythrocytes}}{\text{Total number of erythrocytes}} \times 100$$

For maintaining the parasite for longer duration *in vitro*, the culture was carried in 5ml petridishes and incubated at 37°C in candle jar. After every 24 h, culture of one Petri dish was terminated and Giemsa stained thin blood smears were prepared. Differential count of parasite stages was done after every 24h till 168 h. In the remaining petridish medium was changed daily.

RESULTS AND DISCUSSION

Induction of reticulocytosis

Normal mice showed reticulocyte count of 0.7%-1.0%. However, when i.p. injection of PHC was given on alternate days, 20%-22% reticulocytes were observed on day 4. Blood from PHC treated mice having high percentage of reticulocytes was used for maintaining long term *in vitro* culture of *P. berghei.*

In vitro invasion under different culture conditions

Culture smear of both 0h and 21 h from all types of wells were compared as shown in Fig 1. In G type well, 2.05% parasitaemia was observed after 21h which was 1.7 times higher than at 0 h. In C and A type wells, there was 1.6 and 1.0 fold increase in parasitaemia at 21h as compared to 0h. In all other wells, there was a decrease in parasitaemia after 21h incubation of culture under different conditions. However, increased numbers of newly invaded rings were observed in all wells.

Continuous culture of *P. berghei*

Since maximum parasitaemia was observed in G type wells, an attempt was made to maintain continuous culture of *P. berghei* using these conditions (Fig 2). The culture was maintained successfully for one week. Percent infection was maximum at 24 h (almost 2 fold) and it gradually decreased thereafter to almost one fourth at 168h.

Four fold increase in the number of newly invaded rings were observed in 24h culture smear. Significant numbers of newly invaded rings were observed in smears prepared up to 168h culture while the number of mature parasite reduced in 6th and 7th day cultures.

Inoculation of mice from culture wells

1×10^6 *P. berghei*-infected erythrocytes taken from culture after 48h incubation and onward were injected i.p. into each of three normal mice of three groups. Course of parasitaemia was monitored in Geimsa stained thin blood smears prepared every alternate day till day 6 post infection. In all cases, parasite appeared by day 2 and parasitaemia gradually increased (Fig. 3) confirming the viability of cultures.

Erythrocyte invasion is a process essential for the survival of malaria parasite. Moreover, it is because of the availability of *in vitro* invasion assays that this

Table1: Culture conditions used for maintaining short-term *in vitro* culture of *Plasmodium berghei*

Type of well	Medium	Serum	Haematocrit
A	NM	NMS	RBC
B	NM	FCS	RBC
C	MM	NMS	RBC
D	MM	FCS	RBC
E	NM	NMS	RBCr
F	NM	FCS	RBCr
G	MM	NMS	RBCr
H	MM	FCS	RBCr

NM Normal medium i.e. RPMI – 1640 supplemented with 5% (w/v) $NaHCO_3$, 0.6% (w/v) HEPES, 50 µg/ml gentamycin, 100 IU/ml penicillin and 100 µg/ml streptomycin; **MM** Modified medium i.e. all ingredients of normal medium plus 1 mg/1 ml glucose; **NMS** 5% (w/v) normal mouse serum; **FCS** 5% (w/v) foetal calf serum; **RBC** red blood cells, 4% haematocrit; **RBCr** Blood cells containing 20% - 22% PHC induced reticulocytes.

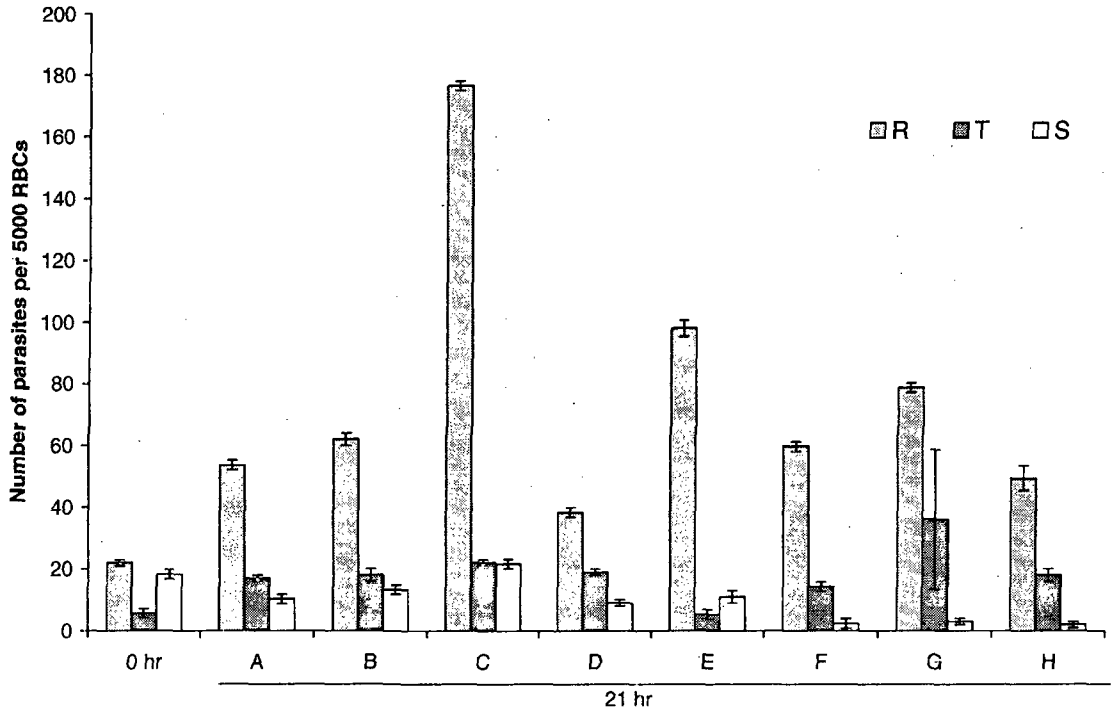

Fig. 1: Histogram showing *in vitro* invasion of mouse erythrocytes by *P. berghei* under different culture conditions.
R = rings, S = schizonts, T = trophozoites.

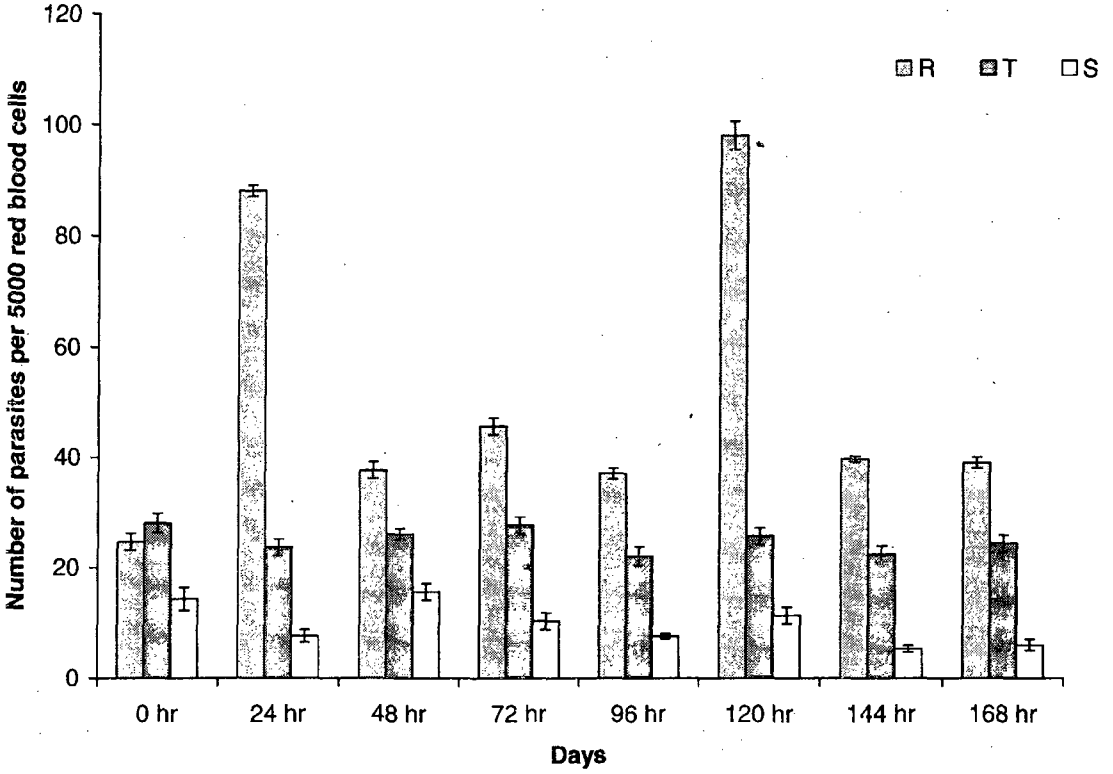

Fig. 2: Histogram showing *in vitro* invasion of mouse erythrocytes by *P. berghei* in continuous culture.
R = rings, S = schizonts, T = trophozoites

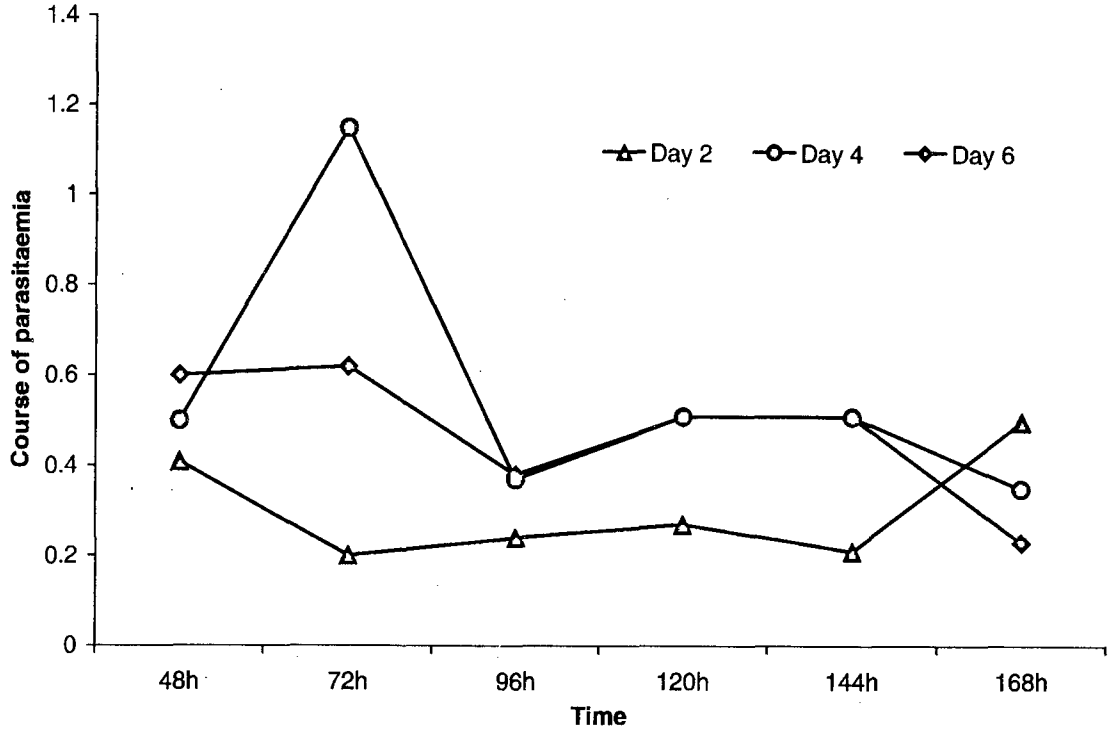

Fig. 3: Parasitaemia in mice infected with 1 x 10^6 *P. berghei* infected red blood cells taken from *in vitro* culture at 48h, 72h, 96h, 120h, 144h and 168h.

process can be examined relatively easily. This study has shown that *P. berghei* can be maintained *in vitro* using RPMI-1640 supplemented with glucose and normal mouse serum in reticulocyte enriched red blood cells in candle jar. *Plasmodium* exhibits high degree of host as well as host cell specificity for invasion. This specificity changes drastically especially under *in vitro* conditions. It has already been reported that *P. berghei* can be grown in erythrocytes of different animals *in vitro* i.e. hamster, rat, guinea pig etc. However, parasitaemia remains very low in such cases (Ramaiya and Renapurkar, 1988). *P. berghei* merozoites have been shown to prefer reticulocytes during invasion.

Reticulocyte enriched blood has been used as haematocrit for maintenance of continuous *in vitro* culture of *P. berghei* in present study. 20%-22% reticulocytosis was induced in normal mice by i.p. injection of PHC on alternate days. It was observed that both C and G type wells proved to be most suitable condition after 21h *in vitro* culture. While 5.8% increase in newly invaded rings were observed in C type wells, an approximate 4.4% increase was observed in G type wells. However, conditions of G type wells were used to maintain long term *in vitro* culture of *P. berghei* because reticulocytes are preferred for invasion by merozoite and 50% heat inactive FCS has been reported to provide the best growth rate for *P. berghei*. (*Ramaiya et al., 1987*) In present study, 5% of FCS was used and parasite did grow in this medium but the invasion was less as compared to normal mouse serum. In earlier studies 10% NMS has been used while in the present investigation long term *in vitro* culture was maintained using 5% NMS and satisfactory growth was observed.

The present study shows that modified RPMI-1640 medium (with mg/ ml glucose) and addition of 20%-22% reticulocyte containing blood along with 5% NMS can aid in long term cultivation of *P. berghei* as compared to 50% FCS used in earlier studies. The present continuous culture shows maximum invasion at 24h (4 fold) and thereafter the invasion follows the order; 48h (1.8) < 72h (2 fold) <96h (approx. 2.3 fold). The viability of cultures has been established with the inoculation of 1 x 10^6 *P. berghei* – infected erythrocytes from culture up to 7^{th} day into normal mice. These parasitized cells have been able to infect normal mice. Slight modification of temperature, medium, and higher concentrations of reticulocytes can further refine this petridish candle jar method for continuously growing *P. berghei in vitro.*

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STUDIES ON PROTEIN REQUIREMENTS OF THE FISH *CHANNA PUNCTATUS* (BLOCH.) USING DEFATTED CANOLA AS THE PROTEIN SOURCE

***Meenakshi Jindal, N. K. Yadava, and S.K. Garg**

Department of Zoology and Aquaculture, CCS H.A.U., Hisar - 125 004

Abstract

The purpose of this study was to determine optimum protein levels required for growth of fingerlings of *Channa punctatus*. Four diets with varying protein levels (from 31.5 to 41.71 %) were formulated by using defatted canola as the major protein source. The fingerlings were maintained in glass aquaria under laboratory conditions and fed twice daily at 2 % body weight per day for 45 days. Studies have revealed an increase in live weight gain (g), growth per cent gain in body weight, specific growth rate, apparent protein digestibility, protein efficiency ratio and energy retention in the fingerlings fed on a diet containing 38.79% crude protein in comparison with the fish fed on other diets containing low or high protein levels. Carcass composition also revealed high accumulation of protein, fat & energy in fish fed on a diet containing 38.79% protein, while those of moisture and ash contents remained low. Excretory levels of ammonical nitrogen and ortho-phosphate were significantly ($P<0.05$) low in the groups of fish fed on diet containing 38.79% protein. These findings suggest that about 38.79 % crude protein in diets appears to be sufficient for maximizing the optimum growth of *C. punctatus* fingerlings when defatted canola is used as the major protein source.

Key words: Ammonical nitrogen, carcass, defatted canola, excretion, growth, protein digestibility, ortho-phosphate.

INTRODUCTION

Protein is the major item of formulated feeds. It is required in large quantity by many cultivable fishes. Protein requirement of fishes is uniformly high irrespective of their food habits and ranging from 35 to 70% dry weight of the feed.

Fishmeal (FM) has traditionally been used as a major protein source because of its high protein content and palatability. However, the high cost and short supply of quality FM has made it necessary to substitute it with other cheaper protein sources. Since the quality of FM available in the interior parts of India is generally very poor, adulteration and microbial infestation are very common. Further, FM contains very high percentage of phosphorous. Therefore, alternative dietary protein sources need to be researched (Kikuchi, 1999). Even though proteins of plant origin such as soybean, canola, moong etc. offer great potentials, presence of many endogenous antinutritional factors (ANFs) and toxic substances interfere with appetite, absorption efficiency and metabolism (Tacon, 1993). Therefore, to remove ANFs, plant proteins have to be suitably processed before incorporation in the diets (Garg *et al.,* 2002; Singh *et al.,* 2003).

The earlier studies have revealed that diets consisting of only rice bran and oil cake commonly used by farmers neither contain essential nutrients in sufficient quantity nor optimum protein levels (Singh, 2001). These studies have also revealed that growth and survival appeared to be a function of dietary protein level.

Soybean meal is a leading candidate to replace a portion of FM. However, Canola meal is a leading competitor, and price dictates use patterns. Acceptable inclusion levels of rapeseed/canola (low erusic acid and glucosinolates) meal range from 10-25% depending on the species and age of the fish, and glucosinolate content of the meal.

Rapeseed is primarily used for edible purposes, while the defatted meal is utilized as animal feed. Canola meal, has about 40% protein (on a dry matter, oil free basis) and a relatively well balanced amino acid composition. Canola meal is a high protein feed ingredient of plant origin, however, it possesses some ANFs such as glucosides and tannins. Furthermore, protein in canola is surrounded by relatively indigestible carbohydrate, which can not be broken down without the use of added enzymes (Akylidiz, 1979 and Buchman *et al.,* 1997).

This plant based diet affects neither the growth nor the flesh quality of fish. It is, however, necessary to

**Corresponding Author :* meenakshi@hau.ernet.in

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supplement it with certain amino acids, which are present at lower levels than in the proteins of FM. Therefore, in the present studies, efforts were made to determine the optimum dietary protein levels by using canola (*Brassica napus*) as the main protein source in *Channa punctatus* fingerlings. Effect of defatted canola diets on post prandial excretion of ammonical nitrogen (NH_4-N) and ortho- phosphate (o-PO4) in the treated water was also examined.

C. punctatus is regarded as an excellent table fish. It is perhaps the commonest and economically, the most important food fish. It is also very hardy fish, so can survive in extended periods of hot and cold temperature and in marginal water conditions. The growth of this fish is good. Moreover, this fish is easily available in Haryana and surroundings. These are the reasons fore the selection of this fish for experimental studies.

MATERIAL AND METHODS

Experimental diets

Groundnut oil cake, rice bran and canola were procured locally from Hisar market. Canola was de-fattened to remove anti-nutritional factors after expelling oil (Garg *et al.*, 2002). All these ingredients were grounded and powdered and subjected to proximate analysis following AOAC (1995) prior to the preparation of diets (Table 1).

Four diets (D_1 - D_4) with varying protein levels (31.5-41.7%) were formulated by supplementing the diets with a mineral premix and amino acids (MPA) (Table 2). The proximate composition of the diet revealed that per cent content of crude protein ranged between 31.5 – 41.7 %, crude fat 6.3 - 9.4 %, crude fiber 10.5 - 11.3%, Ash 5.9 - 9.2%, nitrogen free extract 33.2 - 47.0% and energy 17.2-18.7 KJg^{-1} (Table 3).

Experimental design

Fingerlings of *C. punctatus* (Mean body weight 12.93g ± 0.70) were obtained from fish dealers of Hisar during April-May and acclimated in the laboratory of Department of Zoology and Aquaculture, Chaudhary Charan Singh Haryana Agricultural University, Hisar, for a minimum period of 15 days and were fed *ad libitum* on a feed containing FM as the protein source between $08^{00} – 09^{00}$h.

All treatments were conducted in transparent glass aquaria (60 × 30 × 30 cm), containing 30L of chlorine free water, in replicate of three, kept in the laboratory where the temperature was maintained at 25 ± 1^0 C and a lighting schedule at 12:12h of light. All groups of fish were fed daily only once between $08^{00} – 09^{00}$ h, at the fixed feeding rate of 2% BWd^{-1} for the whole experimental duration of 45 days on different diets depending upon the treatment.

Table 1 : Proximate composition of feed ingredients (% dry Matter)

S. No.	Name of the ingredient	Crude Protein	Crude Fat	Crude Fiber	Total Ash	Nitrogen Free Extract	Gross Energy (KJ/g)
1	**Defatted canola cake (Rapeseed)**	33.443 ± 0.371	11.013 ± 0.292	10.950 ± 0.727	10.313 ± 0.230	35.280 ± 1.106	18.077 ± 0.118
2	**Rice bran**	12.873 ± 0.485	1.760 ± 0.155	19.957 ± 0.266	20.676 ± 0.333	44.733 ± 0.732	11.410 ± 0.025
3	**Groundnut oil cake**	43.490 ± 0.736	8.933 ± 0.067	7.833 ± 0.033	7.000 ± 0.057	32.740 ± 0.623	19.430 ± 0.046

All Values are mean ± S.E. of mean

Table 2: Ingredient Composition (%) of compounded diets from D_1 to D_4

Ingredients	Diet number			
	D_1	D_2	D_3	D_4
Groundnut oil cake[a1]	60.0	60.0	60.0	53.0
Rice bran[a2]	23.0	13.0	3.0	-
Defatted canola (rapeseed)[b]	10.0	20.0	30.0	40.0
Chromic oxide[c] (Cr_2O_3)	1.0	1.0	1.0	1.0
Binder[d] (Carboxyl methyl cellulose)	5.0	5.0	5.0	5.0
Mineral mix[e] (MPA)	1.0	1.0	1.0	1.0

a1 and a2 → used as basal feed ingredients;

b → used as main protein source.

c → used as an external indigestible marker for estimating apparent digestibility

d → used as binder to make the diets water stable

e → MPA added to supplement the diets with minerals and amino acids.

Each Kg contains Copper - 312mg; Cobalt - 45mg; Magnesium - 2.114g; Iron -979mg; Zinc - 2.13g; Iodine 156mg; DL-Methionine - 1.92g; L-lysine mono hydrochloride - 4.4g; Calcium 30% and Phosphorous - 8.25%

Fish were bulk weighed every 10th day and feeding rates adjusted accordingly. In order to maintain water quality, water in the aquaria was replenished daily with the water which had been previously equilibrated to the desired temperature (20°C).

Fish fingerlings were fed with respective diets and thereafter, the uneaten feed was siphoned out and stored separately for calculating the feed conversion ratio (FCR). Faecal matter was collected by pippeting following the method of Spyridakis *et al.* (1989) every morning. The pooled faecal samples were dried in an oven maintained at 60°C for subsequent analysis. Individual weight of the fish fingerlings was recorded at the beginning and at the end of the experiment.

Analytical Technique

The feed ingredients, experimental diets, faecal samples and fish carcass (initial and final) were analysed following the procedure of AOAC (1995). Chromide oxide levels in the diets as well as in the faecal samples were estimated spectrophotometrically following the method of Furukawa and Tsukhara (1966).

Live weight gain (g), growth per cent gain, specific growth rate (SGR, $\%d^{-1}$), protein efficiency ratio (PER) and gross conversion efficiency (GCE) were calculated using standard methods (Steffens, 1989). Apparent nutrient digestibility (APD) of the diets were calculated according to Cho *et al.* (1982) as follows:

$$APD = 100 - \frac{100 \times \%\ Cr_2O_3 \text{ in diet} \times \%\ \text{nutrient in faeces}}{\%\ Cr_2O_3 \text{ in faeces} \times \%\ \text{nutrient in diet}}$$

Water Quality Parameters

Water quality parameters like dissolved oxygen, pH,

Table 3: Proximate composition (% dry weight) of four experimental diets from D_1 to D_4

Diet No.	Crude Protein	Crude Fat	Crude Fiber	Total Ash	Nitrogen Free Extract	Gross Energy (KJg^{-1})
D_1	31.500^{A} ± 0.505	6.367^{A} ± 0.033	10.570^{A} ± 0.033	9.167^{A} ± 0.033	42.400^{AB} ± 0.447	17.240^{A} ± 0.032
D_2	33.540^{B} ± 0.292	6.900^{B} ± 0.058	10.730^{AB} ± 0.033	8.467^{B} ± 0.067	47.030^{BD} ± 0.325	18.720^{B} ± 1.174
D_3	38.790^{C} ± 0.292	9.367^{C} ± 0.033	11.230^{AC} ± 0.067	7.233^{C} ± 0.088	33.379^{C} ± 0.429	18.600^{B} ± 0.003
D_4	41.710^{D} ± 0.583	7.833^{D} ± 0.033	11.300^{BC} ± 0.058	5.933^{D} ± 0.088	33.230^{CD} ± 0.501	18.660^{B} ± 0.046

All values are mean ± S.E. of mean
Mean with same letter in the same column are not significantly ($p>0.05$) different.
Data were analysed by Duncan's Multiple Range Test

free carbondioxide, conductivity, total alkalinity, hardness were determined following APHA (1998) after every 15 days interval. At the end of feeding trials, water samples from each aquarium were collected at 2h interval for the estimation of excretory levels of ammonical nitrogen (NH_4-N) and ortho-phosphate (o-PO_4) following APHA (1998) and calculated as follows:

$$\text{Ammonical nitrogen excretion} = \frac{NH_4\text{-N (mg l}^{-1}\text{) in water}}{(\text{mg } 100g^{-1}BWd^{-1}) \quad \text{fish biomass (mg) per L of water}}$$

$$\text{Ortho-phosphate production} = \frac{o\text{-}PO_4 \text{ (mg l}^{-1}\text{) in water}}{(\text{mg } 100g^{-1}BWd^{-1}) \quad \text{fish biomass (mg) per L of water}}$$

Statistical analysis

Data was analysed following ANOVA, Duncan Multiple Range Test (Duncan, 1955) and Multivariate Analysis (Prein *et al.*, 1993) at 5 per cent probability level. Group means were compared by student 't' test (Snedecor and Cochran, 1982).

RESULTS AND DISCUSSION

I. Growth and digestibility

Feeding results have revealed low mortality in all dietary treatments. Significantly ($P<0.05$) highest values in weight gain (g) growth per cent gain in body weight and specific growth rate (SGR % per day) were observed in group of fish fed on D_3 containing 38.79% protein (Fig 1). However a significant ($P<0.05$) decrease in weight gain took place in the groups of fish fed on D_4 containing 41.7% protein (Table 4).

Results on optimum protein levels for *C. punctatus* are in broad agreement with those of Winfree and Stickney (1984), on channel catfish; *Ictalurus punctatus*; of Patra and Ray (1998) on *Clarias batrachus*, of Deepak and Garg (2002) on *H. fossilis*, of Hassan and Jafri (1996) on *Cirrhinus mrigala*, Samantaray and Mohanty (1997) on *Channa striata* and Kalla *et al.* (2004) on Indian major carps; of Jindal (2007 and 2008) on *Clarias batrachus*. These authors have also obtained high growth & feed efficiency in fish when fed on a diet containing 35-40% crude protein.

Table 4: Growth performance of fish *Channa punctatus* fed on four experimental diets containing D_1 - 31%, D_2 - 33%, D_3 - 39% and D_4 - 42% protein, respectively.

Diet No.	Weight gain (g)	Growth % gain in Body Weight	Growth/ day (%) Body Weight	Specific Growth Rate (SGR) (%per	Relative Growth Rate (RGR)	Food Consumption /day (%) Body Weight	Feed Conversion Ratio (FCR)	Apparent Protein Digestibility (APD)	Gross Conversion Efficiency (GCE)	Protein Efficiency Ratio (PER)
D_1	4.090^{A} ±0.020	44.900^{A} ±0.450	0.814^{A} ±0.007	0.824^{A} ±0.007	0.022^{A} ±0.000	1.770^{A} ±0.007	2.173^{A} ±0.011	86.670^{A} ±0.164	0.460^{AB} ±0.002	0.129^{A} ±0.001
D_2	4.300^{B} ±0.025	47.760^{B} ±0.123	0.856^{B} ±0.002	0.867^{B} ±0.002	0.022^{A} ±0.000	1.829^{B} ±0.013	2.139^{A} ±0.013	87.403^{A} ±0.225	0.468^{AB} ±0.003	0.128^{A} ±0.000
D_3	5.010^{C} ±0.012	57.477^{C} ±0.181	0.992^{C} ±0.002	1.009^{C} ±0.002	0.022^{A} ±0.000	1.972^{C} ±0.005	1.988^{B} ±0.005	91.303^{B} ±0.425	0.503^{B} ±0.001	0.129^{A} ±0.001
D_4	4.551^{C} ±0.026	52.078^{D} ±0.850	0.918^{D} ±0.012	0.931^{C} ±0.012	0.022^{A} ±0.000	1.967^{C} ±0.016	2.143^{A} ±0.013	90.300^{B} ±0.383	0.461^{B} ±0.003	0.109^{B} ±0.002

All values are mean ± S.E. of mean
Mean with same letter in the same column are not significantly ($p>0.05$) different.
Data were analysed by Duncan's Multiple Range Test
Duration of experimental period – 45 days

Further, growth depressing effect of high dietary protein levels has been reported for several fish species like, snakehead (Samantaray and Mohanty, 1997), walking catfish, *Clarias batrachus* fry (Chuapochuk, 1987), Indian catfish *H. fossilis* (Deepak and Garg, 2002) and *Clarias batrachus* (Jindal, 2007 and 2008) and on other carnivorous fish species (Hepher, 1988).

Feed conversion ratio (FCR) remained significantly ($P<0.05$) low in fish fed on diet D_3 containing 38.79% crude protein in comparison with the fish fed on low (31.5 and 33.5%) or high protein (41.7 %) diets. Apparent protein digestibility (APD) was significantly ($p<0.05$) high in fish fed on D_3. Protein efficiency ratio (PER) was significantly high in fish fed on D_1, D_2 and D_3 diets (31-39% protein level) in comparison to the fish fed on high protein diets (Table 4).

The studies further indicated that there is a negative correlation between growth parameters and FCR values. Further, the growth parameters also have negative correlation with NH_4-N and o-PO_4 excretion. This is the reason for the better growth and low excretory levels of NH_4-N and o-PO_4 excretion in the groups of fish fed on diets D_3 in comparison to the fish groups fed on diets D_1, D_2 and D_4 These results are in agreement with those of Jindal (2007) reported in *C. batrachus* and *H. fossilis* fingerlings.

Decrease in growth performance of fish at high protein levels may be attributed either to insufficient non-protein energy (NRC-NAS, 1983) or to the inhibitory effects of high dietary protein on the production/release of digestive enzyme (such as protease etc.). Inhibitory effects of high dietary protein levels on intestinal enzyme activity have already been shown by Kalla and Garg (2004) and Jindal (2007 and 2008).

II. Post prandial excretory levels of Ammonical nitrogen (NH_4-N) and ortho-phosphate (o-PO_4)

The pH of the aquaria water fluctuated between 7.1 to 7.5 and dissolved oxygen contents ranged between 5-7

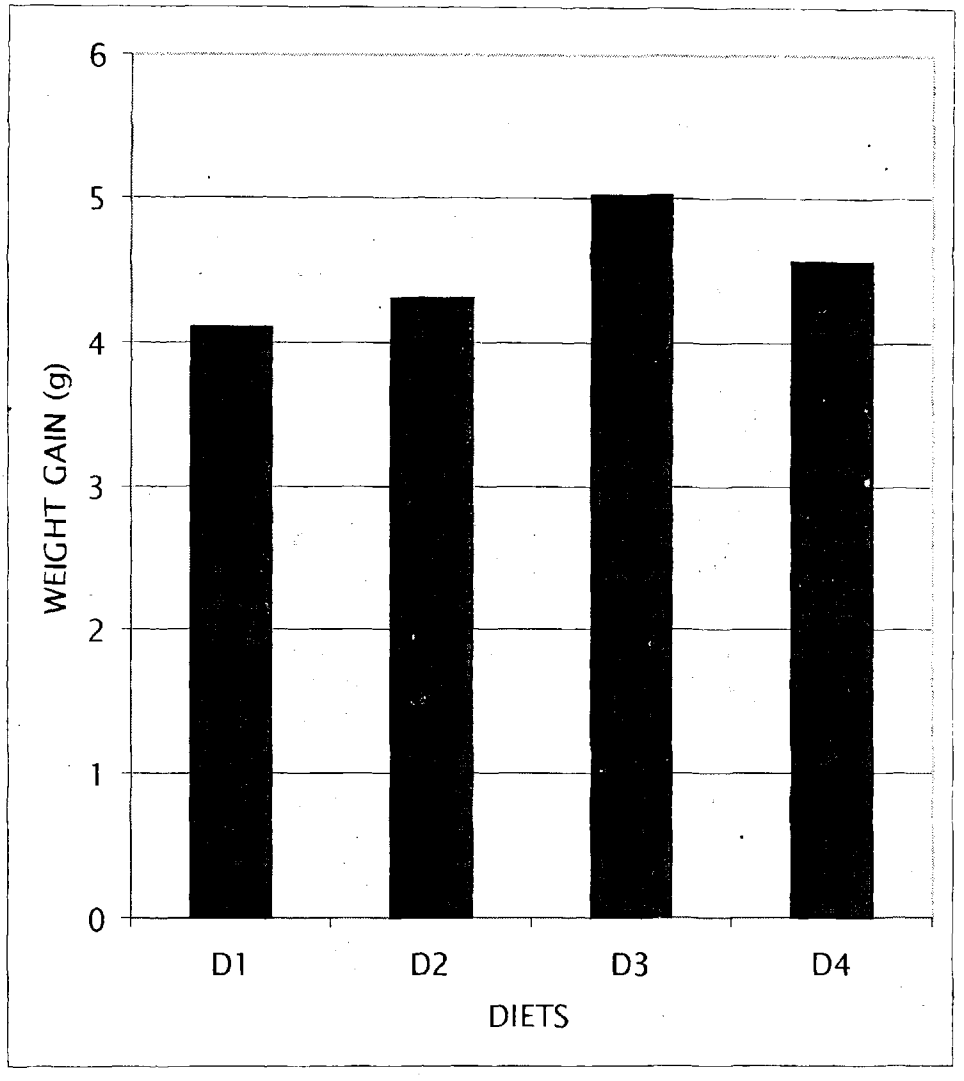

Fig. 1: Weight gain (g) in *Channa punctatus* fed on D_1 to D_4 containing different protein levels (31.0 to 42.0%)

mg l^{-1} (Table 5). Low DO content in diet D_3 (38.79% protein level) showed better utilization of diet by the fish, hence better growth. These results are in agreement with those of Kalla and Garg (2004) and Jindal (2007 and 2008).

A significant ($P<0.05$) decrease in NH_4-N and o-PO_4 was observed in the receiving waters with increase in the protein levels of the diets (Table 5) but in groups of fish fed on diets above 38.79% protein, again increase in NH_4-N and o-PO_4 excretion was observed. These results showed that when protein levels in the diets exceeds the limits of digestibility (above 38.79%) are de-aminized and are excreted as ammonia in the aquaria water. The growth and digestibility parameters were found to be negatively correlated with NH_4-N and o-PO4 excretion. This is one of the reason for the better growth of fish fed on diet D_3 (at 38.79% protein level).These results are in agreement with those of Vielman *et al.* (2000), Jindal (2001, 2007, 2008), Deepak and Garg (2002), Kalla *et al.*(2004), Robinson and Menghe (2007) , Jindal *et al.* (2007 a ,b).

The peaks in the excretion of NH_4-N were observed at 8h of post-feeding (Fig 2) But the excretion of o-PO_4 was observed at 6h of post-feeding (Fig 3). These peaks indicated the time at which the fish excrete NH_4-N and o-PO_4 at its maximum. These peaks also showed that when fish were fed with diets, then at start the excretion rate was low, but as the time passed out excretion started increasing up to a limit *i.e.* the peak time and after that excretion again started decreasing. These peaks also

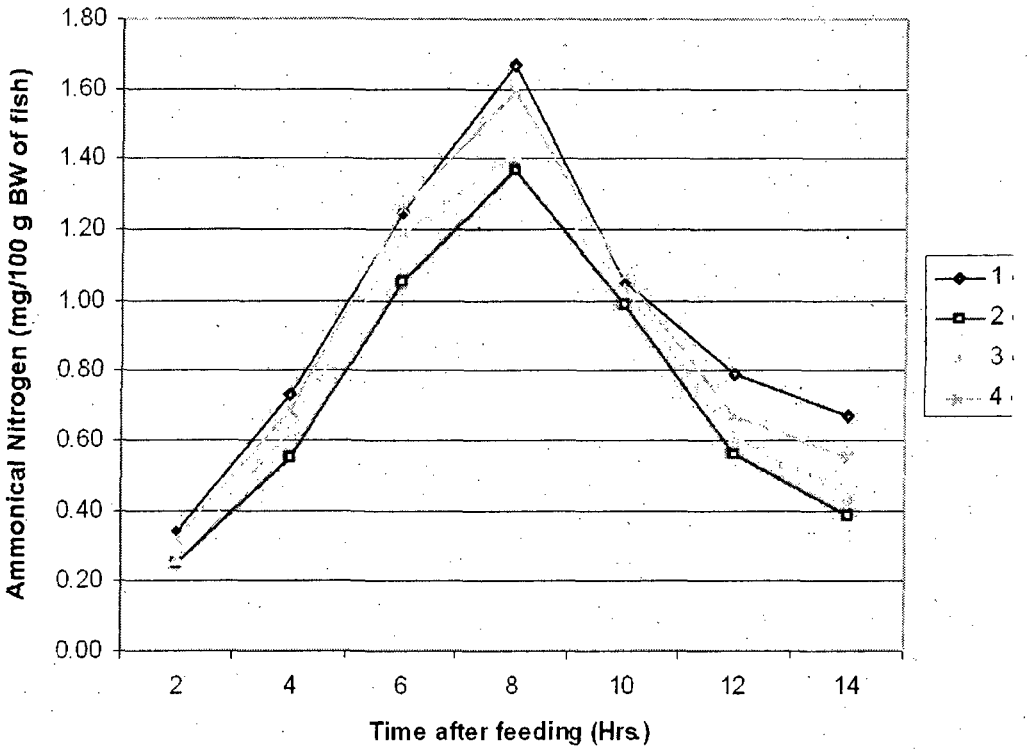

Fig. 2: Diurnal excretory pattern of ammonical nitrogen (NH_4-N) in treated waters in fish *C. punctatus* fed on diets D_1 - D_4

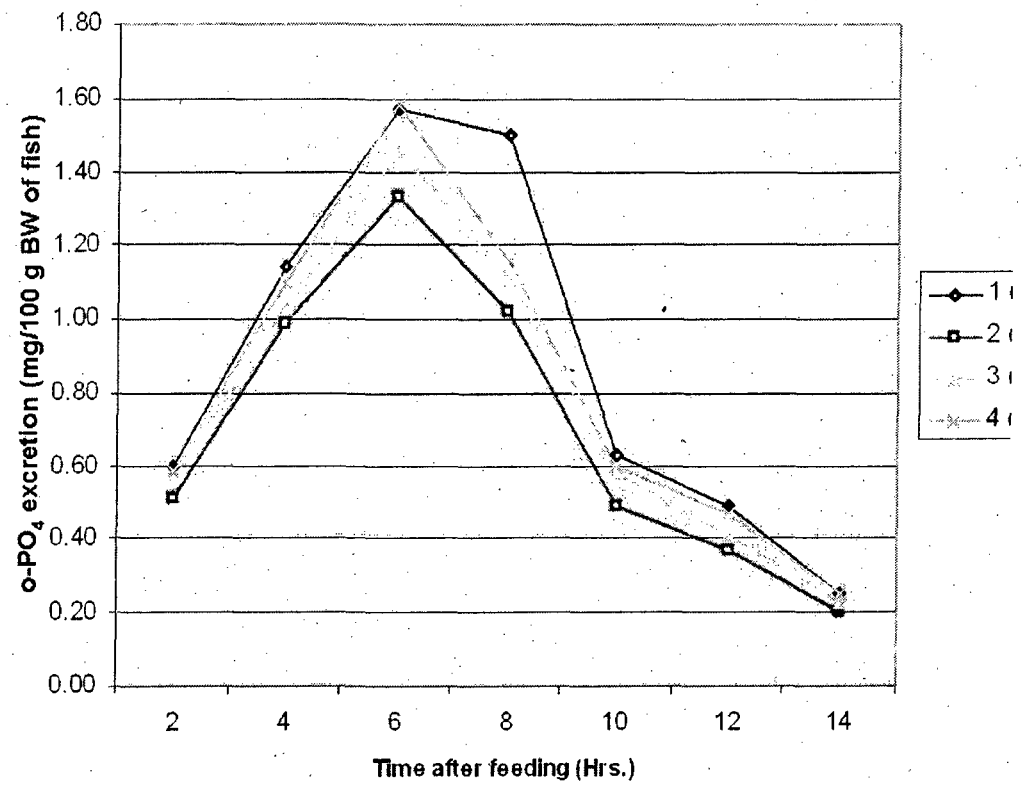

Fig. 3: Diurnal excretory pattern of ortho-phosphate (o-PO_4) in treated waters in fish *C. punctatus* fed on diets D_1 - D_4

Table 5: Water quality parameters of different aquariums stocked with *C. punctatus* fingerlings fed on defatted canola experimental diets (diets D_1-D_4) at different dietary protein levels (31.0 - 42.0%)

Parameters	Diet No.			
	D_1	D2	D_3	D_4
Dissolved oxygen (DO) mg l^{-1}	5.85 ± 0.001	5.70 ± 0.003	5.45 ± 0.002	5.70 ± 0.008
pH	7.50	7.40	7.10	7.30
Water temperature (^{0}C)	26.00	25.50	25.00	25.50
Conductivity micro (μ) mhos cm^{-1}	0.63 ± 0.005	0.65 ± 0.003	0.60 ± 0.000	0.75 ± 0.002
Free carbon dioxide (Free CO_2) mg l^{-1}	16.70 ± 0.000	16.90 ± 0.002	16.20 ± 0.001	16.50 ± 0.004
Total alkalinity (mg l^{-1})	270.0 ± 0.002	272.0 ± 0.000	262.0 ± 0.001	269.0 ± 0.003
Total hardness (mg l^{-1})	220.0 ± 0.005	225.0 ± 0.004	219.0 ± 0.001	222.0 ± 0.003
Ammonical nitrogen (NH_4-N) excretion (mg 100g^{-1} BW of fish)	1.485 ± 0.015	1.565 ± 0.045	1.245 ±0.015	1.745 ± 0.035
Ortho-phosphate (o-PO_4) excretion (mg 100g^{-1} BW of fish)	1.578 ± 0.020	1.448 ± 0.030	1.389 ± 0.020	1.451 ± 0.010

All values are mean ± S.E. of mean of 3 observations.

showed the time at which maximum absorption of nutrients from feed took place. These results were in agreement with those of Van Weerd *et al.* (1993), Jindal (2001, 2007, 2008), Kalla and Garg (2004), Jindal and Garg (2005), Robinson and Menghe (2007) and Jindal *et al.* (2007 a, b).

III. Effect of Diets on carcass composition

The changes in the carcass composition indicated that the protein accumulation in the carcass increase up to the protein level 38.79% (Diet D_3), but as the protein levels in the diets increased it started decreasing. These results indicated that optimum protein level in the diet results in higher growth, better digestibility with greater efficiency of protein deposition in the carcass (Table 6). These results are in agreement with the results observed by Majid *et al.* (1994), Shearer (1994), Kalla *et al.* (2003), Jindal (2001, 2007, 2008) and Jindal and Garg (2005).

CONCLUSIONS

Fish have the ability to handle protein in excess of that needed for growth and maintenance by deaminizing amino acid bronchially and excreting ammonia. Protein levels above optimum requirements may results in

Table 6 : Proximate composition (% fresh weight) of the fish *Channa punctatus* fed on four experimental diets from D_1 to D_4

Diet No.	Moisture	Crude Protein	Crude Fat	Total Ash	Nitrogen Free Extract	Gross Energy (KJg^{-1})
D_1	75.817^{A} ± 0.003	15.441^{A} ± 0.012	4.565^{A} ± 0.009	3.158^{A} ± 0.005	1.019^{A} ± 0.007	5.630^{A} ± 0.001
D_2	74.647^{B} ± 0.057	15.803^{B} ± 0.108	5.215^{B} ± 0.019	3.245^{B} ± 0.007	0.990^{A} ± 0.064	5.991^{B} ± 0.022
D_3	74.707^{B} ± 0.008	15.949^{C} ± 0.128	4.658^{C} ± 0.000	3.654^{C} ± 0.016	1.032^{A} ± 0.105	5.789^{C} ± 0.012
D_4	75.540^{C} ± 0.036	14.630^{D} ± 0.047	4.438^{D} ± 0.001	3.409^{D} ± 0.011	1.982^{B} ± 0.073	5.553^{D} ± 0.001

All values are mean ± S.E. of mean
Mean with same letter in the same column are not significantly ($p>0.05$) different.
Data were analysed by Duncan's Multiple Range Test

decreased growth rates because of a reduction in dietary energy available for growth due to energy required to de-aminate and excrete excess absorbed amino acids .Present studies on *Channa punctatus*, thus, have established that when protein levels in the diet exceeds the limits of digestibility (above 38.79%) are de-aminized and are excreted as ammonia in the aquaria water, which sometimes may be stressful for the fish especially in small impoundments and impedes growth.

The results of this study clearly demonstrated that defatted canola supplemented with MPA can be recommended as a replacement of FM based diet for *C. punctatus*, up to the protein levels of 38.79%. This not only save total feed cost, but certainly would also reduce excretion of nitrogenous and total organic matter, possibly also of phosphorous and alleviate pollution problems in the intensive aqua-cultural systems.

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A CHECKLIST OF GELECHIOID MOTH-FAUNA OF SIROHI AND UDAIPUR DISTRICTS IN RAJASTHAN (LEPIDOPTERA: GELECHIOIDEA)

***V.K. Walia and D. Wadhawan**

**Department of Zoology, Panjab University, Chandigarh – 160 014*

Abstract

The thorough surveying of different localities during the year 2002-2003 from March to October, having variable physiographic conditions, in Sirohi and Udaipur districts of Rajasthan, has yielded 296 specimens belonging to 23 species of superfamily Gelechioidea(Lepidoptera). It has been observed that so far recording of merely 11 species of this superfamily from the entire State of Rajasthan is not because of exiguous fauna but due to negligible sampling.

Key words: Checklist, Gelechioidea, Sirohi, Udaipur (Rajasthan).

INTRODUCTION

Superfamily Gelechioidea of order Lepidoptera is represented by as many as 16,616 species from all over the world (Heppner, 1991, 98), including over 317 species from India (Roonwal, 1991). Out of these, just 11 species have been recorded from Rajasthan. Scant sampling in this State is evident from previous report of only 10 species by Bengtsson (1995) from four localities viz. Jodhpur (6), Ajmer (2), Bharatpur (1) and Khewara (1), in addition to earlier record of *Gelechia biclavata* Meyrick from The Great Indian Desert (Meyrick, 1930-1936).

Keeping in view the division of Rajasthan State into three zones on the basis of annual rainfall (Roonwal, 1963), repeated surveys were carried out in specific places in districts Sirohi and Udaipur, covering all the three zones to bring to light the undiscovered gelechioid-fauna, between March to October during 2000 to 2003.

After critically examining the material and comparing these with all the relevant descriptions documented in the available literature (Bengtsson, 1995; Clarke, 1955, 1963, 1965; 1969; Fletcher, 1929; Gaede, 1937; Meyrick, 1894, 1904, 1906, 1908, 1909, 1910a, , 1912–16, 1913, 1916–23, 1922, 1923–30, 1925, 1930–36; Pajni and Deepak Mehta, 1986; Park, 1995, 1999, 2000; Rose and Pathania, 2003a, 2003b; Pathania and Rose, 2004; Robinson, Tuck and Schäffer, 1994; Stainton,1858; Walker, 1864), out of 23 species, 10 species were new, in addition to proposing a new combination for an already described species. Five new species pertaining to families Gelechiidae and Cosmopterigidae, have already been published by the present authors, whereas publication of the remaining species is under process (Walia and Wadhawan, 2004a, 2004b, 2005; Wadhawan and Walia 2005, 2006a, 2006b, 2006c, 2006d, 2007).

MATERIAL AND METHODS

To collect the gelechioid-fauna from Sirohi and Udaipur districts of Rajasthan, collection trips were executed between March to October ± 5 days of Amavasya (moonless night) during pre-monsoon, monsoon and post-monsoon periods. A "light lure," comprising of a white sheet measuring 9' × 7', illuminated by two mercury bulbs of 160W each was employed (Holloway *et al.*, 1984; Robinson *et al.*, 1994; Walia and Wadhawan, 2002). As the microlepidopterans kept arriving at the installed light lure throughout the night, therefore, collection work too was continued.

The stretching techniques given by Landry and Landry (1994), and Walia and Wadhawan (2003) were used with some innovations. In case of species whose specimens were abundantly available on a particular day, the technique of carrying back half stretched moths by "tower spreading method" devised by Mikkola (1986) was employed to ensure collection of enough specimens of both the sexes to enable evaluation of actual abundance and biodiversity of gelechioid-fauna of the surveyed sites. Every stretched specimen was finally mounted on a E.V.A. strip as per the method given by Lindquist (1956), labelled with date, place and name of collector and then stored in fumigated insect storage box.

SYSTEMATIC ACCOUNT

Taxonomic status of the studied 23 gelechioid

**Corresponding Author* : virinder_k_walia@rediffmail.com

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species, along with number of specimens and months of collection, is given below. The abbreviations used for status of abundance are as: VC-Very Common; C-Common; R-Rare; VR-Very Rare.

ORDER: LEPIDOPTERA

SUPERFAMILY: GELECHIOIDEA

A) FAMILY: GELECHIIDAE

i) **SUBFAMILY:** GELECHIINAE

1. *Polyhymno alcimacha* Meyrick **VR**

   Polyhymno alcimacha Meyrick, 1918, *Exotic Microlepidoptera*, **2:** 129.

   Material examined: 1♂; Jharoal (Forest Rest House); August, 2000.

2. *Syrmadaula signumforcipatus* Walia & Wadhawan **C**

   Syrmadaula signumforcipatus Walia & Wadhawan, 2004, *Biol. Memoirs,* **30(2):** 100-103, 3 phs., 6 figs.

   Material examined: 5♂♂, 2♀♀; Jharoal (Forest Rest House),Nahargarh (Forest Rest House), Mt. Abu (Forest Rest House); August and October, 2000.

3. *Pityocona bifurcatus* Wadhawan & Walia **R**

   Pityocona bifurcatus Wadhawan & Walia, 2006, *Pol. Jour. of Ent.*,**75** : 465-469.

   Material examined: 3♂♂, 2♀♀; Jharol (Forest Rest House), Hanumangarh (Forest Rest House); August and October, 2000-01.

4. *Stegasta valvulata* Walia & Wadhawan **VC**

   Stegasta valvulata Walia & Wadhawan, 2004, *Pb. Univ. Res. Journ. (Sci.),* **54:** 117-126.

   Material examined: 11♂♂, 18♀♀; Kotra (Forest Rest House), Ranakpur (Kumbhalgarh Wildlife Sanctuary), Jharoal (Forest Rest House), Udaipur, Mount Abu; March and August to October, 2000 and 2002-03.

5. *Stegasta comissata* Meyrick **VC**

   Stegasta comissata Meyrick, 1923, *Exotic Microlepidoptera,* **3** : 18.

   Material examined: 62♂♂, 25♀♀; Ranakpur (Kumbhalgarh Wildlife Sanctuary), Mt. Abu (Forest Rest House), Udaipur, Kotra (Forest Rest House), Jharoal (Forest Rest House), August to October, 2001-03.

6. *Gelechia ranakpurensis* Walia & Wadhawan **C**

   Gelechia ranakpurensis Walia & Wadhawan, 2005, *Proc. zool. Soc., Calcutta*, 58 **(2):** 75-78.

   Material examined: 3♂♂, 4♀♀; Ranakpur (Kumbhalgarh Wildlife Sanctuary); April and October, 2001-02.

7. *Anarsia reciproca* Meyrick **R**

   Anarsia reciproca Meyrick., 1916, *Exotic Microlepidoptera*, **2:** 300.

   Material examined: 4♂♂, 1♀; Jharoal (Forest Rest House), Ranakpur (Kumbhalgarh Wildlife Sanctuary); August and October, 2001-02.

ii) **SUBFAMILY** : SYMMOCINAE

8. *Apiuncusa indigata* (Meyrick) comb. nov. **VC**

   Symmoca indigata Meyrick, 1918, *Exotic Microlepidoptera,* **2:** 155.

   Material examined: 13♂♂, 30♀♀; Mamer (Phulwari Ki Nal Sanctuary); March and October, 2002-03.

B) FAMILY: LECITHOCERIDAE

i) **SUBFAMILY:** LECITHOCERINAE

9. *Frisilia dimorphicata* Wadhawan & Walia **VC**

   Frisilia dimorphicata Wadhawan & Walia. 2006. *Pol. Jour. of Ent.* (Communicated)

   Material examined: 12♂♂, 22♀♀; Mamer (Phulwari Ki Nal Sanctuary), Kotra (Forest Rest House), Ranakpur (Kumbhalgarh Wildlife Sanctuary); April and October, 2001-02.

10. *Heteralcis spatulata* Wadhawan & Walia **R**

    Heteralcis spatulata Wadhawan & Walia. 2006. *Proc. zool. Soc., Calcutta.* (Communicated)

    Material examined: 6♂♂; Ranakpur (Kumbhalgarh Wildlife Sanctuary); August to September, 2003.

11. *Lecithocera oxycona* Meyrick **VC**

    Lecithocera oxycona Meyrick, 1910, *Journ. Bombay nat. Hist. Soc.,* **20:** 444.

    Material examined: 11♂♂, 12♀♀; Ranakpur (Kumbhalgarh Wildlife Sanctuary), Jharoal

(Forest Rest House), Mamer (Phulwari Ki Nal Sanctuary); October, 2002.

12. *Lecithocera xanthocostalis* Wadhawan & Walia **R**

Lecithocera xanthocostalis Wadhawan & Walia. 2006. *Pb. Univ. Res. Journ. (Sci.)*, **56**: 167-178.

Material examined: 1♂; Mamer (Phulwari Ki Nal Sanctuary); October, 2002.

ii) **SUBFAMILY:** TORODORINAE

13. *Torodora biovalata* Wadhawan & Walia **VR**

Torodora biovalata Wadhawan & Walia. 2007. *Pol. Jour. of Ent.*, (Communicated)

Material examined: 1♂; Jharoal (Forest Rest House); September, 2000.

C) **FAMILY:** OECOPHORIDAE

i) **SUBFAMILY:** STATHMOPODINAE

14. *Stathmopoda theoris* (Meyrick) **VR**

Aeoloscis theoris Meyrick, 1906, *J. Bombay. nat. Hist. Soc.*, **17**: 410.

Material examined: 1♂; Jharoal (Forest Rest House); August, 2000.

15. *Stathmopoda anconias* Meyrick **R**

Stathmopoda anconias Meyrick, 1910, *Rec. Indian Mus.*, **15**: 223.

Material examined: 3♂♂; Ranakpur (Kumbhalgarh Wildlife Sanctuary); August and September, 2000 and 2003.

16. *Stathmopoda mathewi* sp. nov. **VR**

Material examined: 1♂; Kotra (Forest Rest House), Ranakpur (Kumbhalgarh Wildlife Santuary); September, 2002.

ii) **SUBFAMILY:** AUTOSTICHINAE

17. *Apethistis insulsa* (Meyrick) **VR**

Brachmia insulsa Meyrick, 1913, *Journ. Bombay nat. Hist. Soc.*, **22**: 774.

Material examined: 2♂♂; Sita Mata Sanctuary, Ranakpur (Kumbhalgarh Wildlife Sanctuary); May and August, 2000-01.

iii) **SUBFAMILY:** ETHMIINAE

18. *Ethmia acontias* Meyrick **VR**

Ethmia acontias Meyrick, 1906, *J. Bombay nat. Hist. Soc.*, **17**: 410.

Material examined: 1♂; Ranakpur (Kumbhalgarh Wildlife Sanctuary); August, 2003.

D) **FAMILY:** COSMOPTERIGIDAE

19. *Macrobathra gentilis* Meyrick **VR**

Macrobathra gentilis Meyrick, 1918, *Exotic Microlepidoptera*, **2**: 212.

Material examined: 1♂; Sitamata Sanctuary; August, 2000.

20. *Labdia symbolias* (Meyrick) **VR**

Macrobathra gentilis Meyrick, 1918, *Exotic Microlepidoptera*, **2**: 212.

Material examined: 2♂♂; Kotra (Forest Rest House); August, 2003.

21. *Cosmopterix albilinearis* Wadhawan & Walia **VR**

Cosmopterix albilinearis Wadhawan & Walia, 2005, *Pol. Jour. of Ent.*, **74**(4): 471-477, 9 figs.

Material examined: 1♀; Sitamata Sanctuary; August, 2000.

22. *Cosmopterix mimetis* Meyrick **C**

Cosmopterix mimetis, Meyrick, 1909. *J. Bombay nat. Hist. Soc.*, **19**: 417.

Material examined: 7♂♂; Mt. Abu (Forest Rest House); Kotra (Forest Rest House); March and September to October, 2000 and 2002-03.

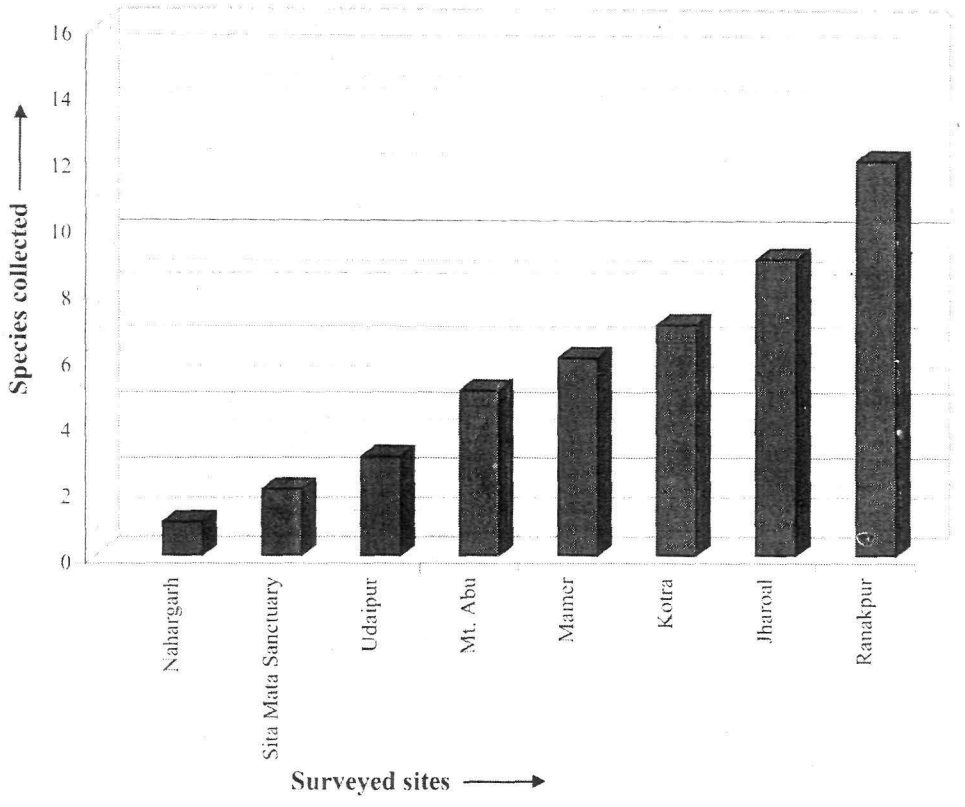
E) **FAMILY:** SCYTHRIDIDAE

23. *Eretmocera impactella* (Walker) **VC**

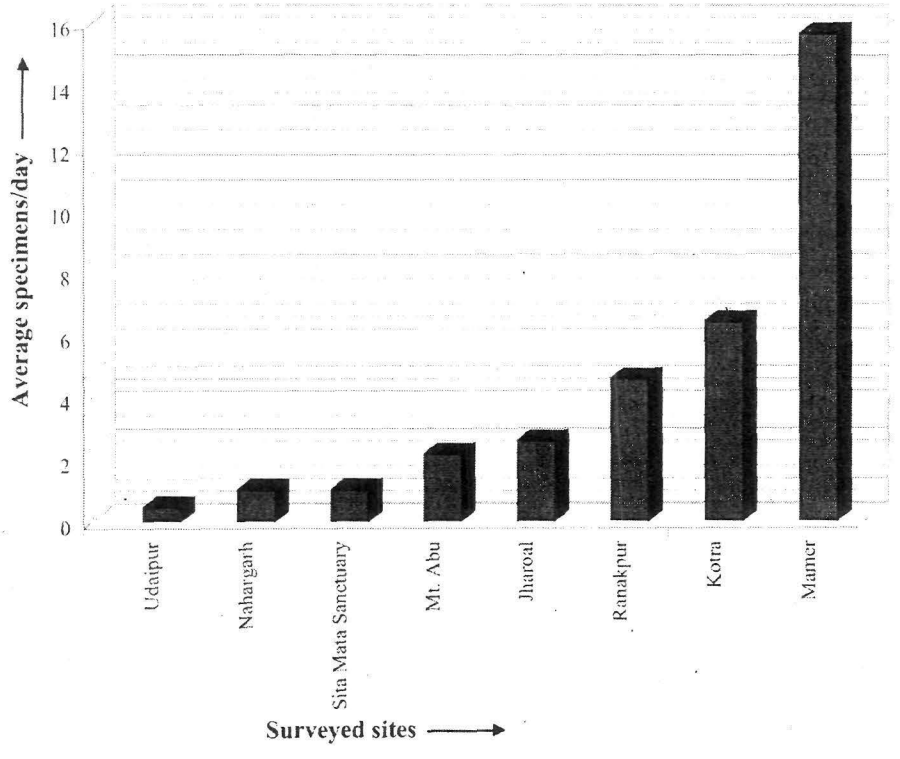
Gelechia impactella, Walker, 1864, *Cat. Lep. Het. Brit. Mus.*, **29**: 637.

Material examined: 28♂♂; Ranakpur (Kumbhalgarh Sanctuary); Mt. Abu (Forest Rest House); Udaipur; Mamer (Phulwari Ki Nal Sanctuary); Jharoal (Phulwari ki Nal Sanctuary); March and September to October, 2000-03.

Graph 1: Biodiversity of Superfamily Gelechioidea in Rajasthan during 2000-2003



Graph 2: site wise abundance of Gelechioid fauna in Rajasthan during 2000-2003



CONCLUSIONS

Repeated sampling of the surveyed localities, namely Hanumangarh, Jharoal, Kotra, Mamer, Mt. Abu, Ranakpur, Sitamata Sanctuary and Udaipur in Sirohi and Udaipur districts of Rajasthan, have brought to light significant field observations regarding relative abundance and diversity of gelechioid-fauna. These are as follows:

Mamer and Ranakpur revealed maximum richness in abundance and biodiversity of gelechioidea-fauna out of the explored 8 localities.

- Ranakpur and Jharoal, both of Udaipur district have been concluded as richest spots amongst various localities investigated for the gelechioid-fauna. These two sites alone contributed 73.9 % of total species collected from this Indian State.
- The family-wise ratio of the number of identified 23 species is as 8: 5: 5: 4: 1 for Gelechiidae, Lecithoceridae,Oecophoridae, Cosmopterygidae and Scythrididae respectively and showed the dominance of Gelechiidae fauna.
- Peak season of prevalence of the concerned fauna both in terms of number of species and specimens is couple of months succeeding termination of winters (i.e.March and April)and around monsoon period (i.e. August and September).
- Out of total 296 collected specimens covering 23 species, males constituted 59.45%. Furthermore, arrival of comparatively more male specimens at the light lure system was also indicated by 91.30% of these species represented by male examples – including 39.13% by both sexes and 52.17% by only male specimens.
- Against experienced dominance of male specimens arriving at the light lure system, collected female specimens of 5 species have been encountered, viz. *Stegasta valvulata* Walia & Wadhawan, *Gelechia ranakpurensis* Walia & Wadhawan, *Apiuncusa indigata* (Meyrick) comb. nov., *Frisilia dimorphicata* Wadhawan & Walia and *Lecithocera oxycona* Meyrick exceeded those of males. Futhermore, no males of *Cosmopterix albilinearis* Wadhawan & Walia and *Stathmopoda anconias* Meyrick could be collected during field endeavours lasting for four years.

ACKNOWLEDGEMENTS

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EFFECT OF LOW MAGENETIC FIELD AND VOLTAGE ON THE GROWTH OF *LACTOBACILLUS CASEI*- A PRELIMINARY STUDY

***Geeta Shukla, Pushpa Devi[1], and Durg V. Rai[2]**

[1]*Department of Microbiology, Panjab University, Chandigarh, 160 014*

[2]*Department of Biophysics, Panjab University, Chandigarh, 160 014*

Abstract

The present study was designed with an aim to observe the effect of magnetic field / voltage on the growth pattern of *Lactobacillus casei*- a probiotic. Phenotypically, *L. casei* was found to be a gram positive, non motile, forming non pigmented pin head size colonies with smooth, glistening and convex surface. Biochemically, it was bile tolerant, catalase negative and capable of fermenting various sugars. It was further observed that the lag period of *L. casei* was prolonged (6 hours) under the influence of magnetic field as compared to control, thereafter, the growth increased exponentially, resulting into the alteration of pH of the medium. However, the growth pattern remained unaltered under the influence of low voltage and was identical to control group. Taken together, it seems that magnetic field prolongs the lag phase of *L. casei* and warrants further study.

Keywords: Growth, *Lactobacillus casei*, Magnetic field, Voltage

INTRODUCTION

Evidence has continued to accumulate over the last several years that a wide variety of organisms are sensitive to electromagnetic field. These include bacteria, insects, marine invertebrates, fishes, birds, amphibians and mammals. The influence of external magnetic field on chemical and biological systems may be classified as either 'Static' or "dynamic" effects (Tenforde, 1978). The unexpected finding that certain bacterial cells were geomagnetically responsive, were permanently magnetized and contained iron-rich structural particles "magnetosomes" precipitated search to study the effect of magnetic field on the growth and behavior of microorganisms and to further use in the treatment of various kinds of diseases (Watson, 1991). Exposure to non ionizing electromagnetic field (EMF) is an unavoidable product of our technological civilization. Therefore, it has also been reported that weak EMF exposure do have biological effects but are difficult to be evaluated, as the change is apparently small and is difficult to measure (Aldrich *et al.*, 1992).

It is therefore, relevant to observe whether there is any adverse effect of interaction between magnetic field or electric field and living organisms (Michael *et al.*, 1999). Lactobacillus, a normal microflora of our intestine does not have any adverse effect under normal circumstances, instead has a beneficial effects on both humans and animals when consumed in adequate quantity (Shulka *et al.*, 2008, Benyacoub *et al.*, 2005 , Oyetaya *et al.*, 2003 Rolfe, 2000). Due to increase in antibiotic resistance, the scenario is diverting from antibiotics to natural therapeutic agents such as **probiotics**.

Probiotics, a greek word means 'for life' and can be defined as "live microorganisms which when administered in adequate amount confers health benefits on the host. It improves digestion of lactose and reduces intestinal blotting and discomfort. It enhances the immune system and reduces the chance of falling prey to diseases. Further, it also helps in alleviating some of the symptoms of food allergies such as those associated with milk proteins (Leila, 2006, Ewaschuk and Dieleman 2006, Saavedra, 2001). In the present study, attempts have been made to study the effect of magnetic field and voltage on the growth pattern of *Lactobacillus casei*- a probiotic.

MATERIAL AND METHODS

Bacterial Strain

L. casei MTCC 1423 was procured from the Institute of Microbial Technology (IMTECH), Chandigarh and was maintained on MRS (de Man Rogosa Sharpe) medium purchased from Hi-media laboratories, Mumbai, by incubating at 37°C for 48 hrs. The phenotypic and biochemical characteristics were identified as per Kandler and Weiss (1986).

Composition of MRS media

MRS media basically comprises of peptone 10g, beef

**Corresponding Author* : geeta_shukla@pu.ac.in

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extract 10g, glucose 20g, sodium acetate 5g, tri ammonium citrate 2g, di-sodium hydrogen orthophosphate 2g, magnesium sulphate 0.2g, manganese sulphate 0.2g and tween-80 1ml. All ingredients were dissolved in 1000 ml distilled water, pH was adjusted to 6.5 ± 0.02 and was autoclaved at 15 lbs/in^2 for 20 minutes.

Magnetic field study

Flask containing 20 ml of MRS broth was inoculated with a single colony and incubated overnight at 37°C under the influence of 25 Gauss magnetic field. From over night grown culture, 10^8 bacterial cells were used to inoculate the flask containing 20 ml of MRS broth and was incubated at 37°C for different time interval 0, 2, 4, 6, 8, 10 and 24 hrs under the influence of magnetic field. After different incubation time, 3 ml of the incubated culture was taken and optical density was read at 600nm. For control counterparts, experiment was performed in the same manner but was devoid of magnetic field.

Voltage exposure

A flask containing 20 ml MRS broth was inoculated with a single colony and was incubated overnight at 37°C under the influence of voltage. Voltage having a magnitude of 2V was applied across the electrode inserted into the flask. After over night incubation a fresh flask containing 20 ml of MRS broth was again inoculated with 10^8 cells taken from over night grown culture and was incubated at 37°C under influence of voltage for different time intervals i.e. 0, 2, 4, 6, 8, 10, 24 hours. Aliquots were aseptically drawn at different time intervals and optical density was read at 600 nm. The growth curve was plotted in terms of optical density v/s time. In control, voltage was not applied and rest of the procedure was followed in the same manner.

RESULTS

Identification of *L.Casei*

Microscopically, *L.casei* was found to be gram positive, non motile rods occurring either singly or in short chains (Fig 1) . Phenotypically, it was found that *L.casei* had pin head , non pigmented colonies with entire margin, convex, smooth, glistening and opaque surface. Biochemically, it was catalase negative , bile tolerant and fermented various sugars like Cellubiose , Fructose , Galactose , Glucose , Lactose , Maltose , Mannitol , Sorbitol (Fig. 2).

Effect of magnetic field on growth of *L. casei*

Under normal condition *Lactobacillus casei* had a lag phase of 4 hrs followed by rapid logarithmic or exponential growth whereas, under the influence of magnetic field, the lag phase was further extended to 6 hrs after, that it grew exponentially. The initial inoculum was same in both the conditions but no significant difference in the growth patterns was observed till lag phase. However, under the influence of magnetic field the growth rate was decreased in the exponential phase of growth (Fig. 3).

Effect of voltage

The growth pattern of *L. casei* under the influence of voltage was identical to the growth in control but had only a slight increase in the exponential phase of the growth (Fig. 4).

Effect of growth on medium pH

Initially, pH of the medium changed very slowly in both the groups (till 4 hours) thereafter pH of the medium changed rapidly in control as compared to pH of the medium exposed to magnetic field (Fig. 5).

DISCUSSION

The biological effects of the weak low frequency magnetic field have attracted attention of many researchers, not only to establish the basic mechanism of this interaction but also its potential practical applications. However, the mechanisms through which these fields might interact with the biological system are debated. The biological effects of electromagnetic fields have been studied, particularly on mammalian cells, T-lymphocytes, tissues, tumors, biomolecules, chemical reactions and microorganisms, as well as on other animals and human cells (Baureus *et al.*, 2003 and Tenforde, 1996).

Most of the work has been carried out mainly with the pathogenic microorganisms *e.g. E. coli, Listeria, Salmonella, Bacillus, S. aureus, Candida* (Fojt *et al.*, 2004). The fermentation capability of *Lactococcus lactis* under the influence of magnetic field (5mT) have been reported and it has been documented that upto 4 hr of incubation, nisin production was enhanced but further incubation decreased the production of nisin by 62% showing a negative effect of magnetic field in term of metabolite production (David *et al.*, 2006). These findings indirectly support our data as we too have observed decreased growth under the influence of magnetic field. This could be due to adaptation of *L. casei* to magnetic stimuli which in turn may have decreased the physiological functioning resulting in the reduced level of metabolite production as was evidenced by slow

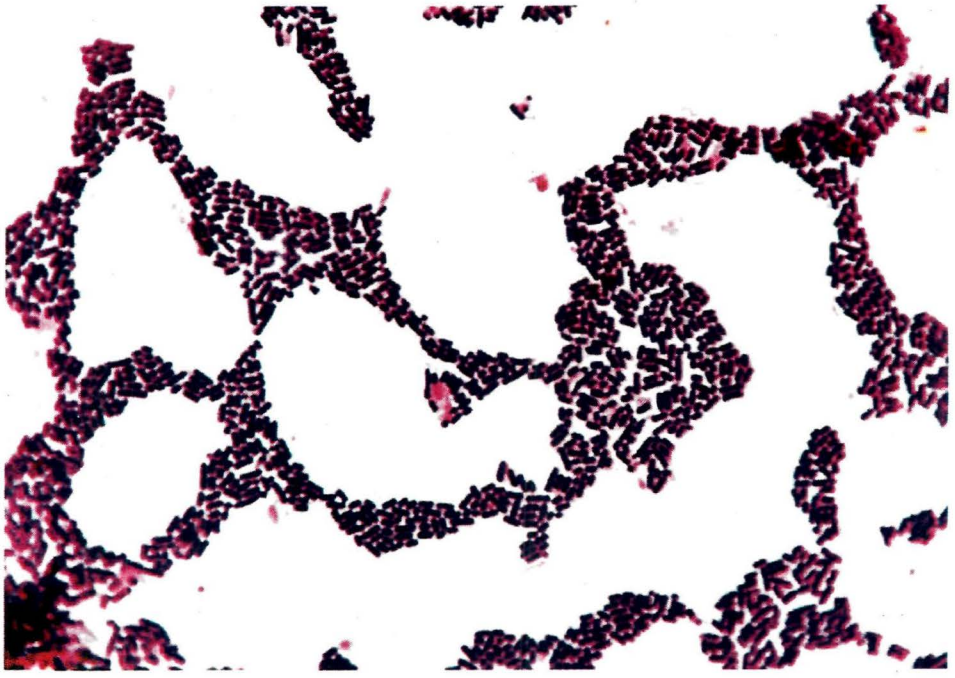

Fig. 1: Gram positive rods of *L .casei* (Gram staining, 100X).

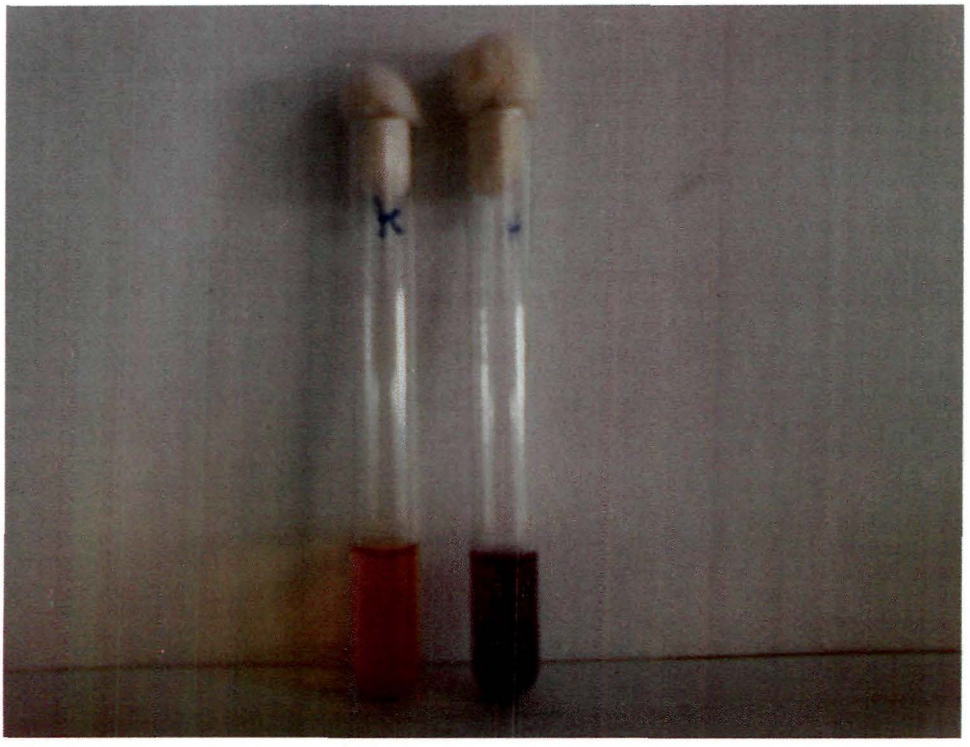

Fig. 2 : Fermentation of sugars by *L .casei* showing positive (Yellow colour) and negative (Purple colour) result.

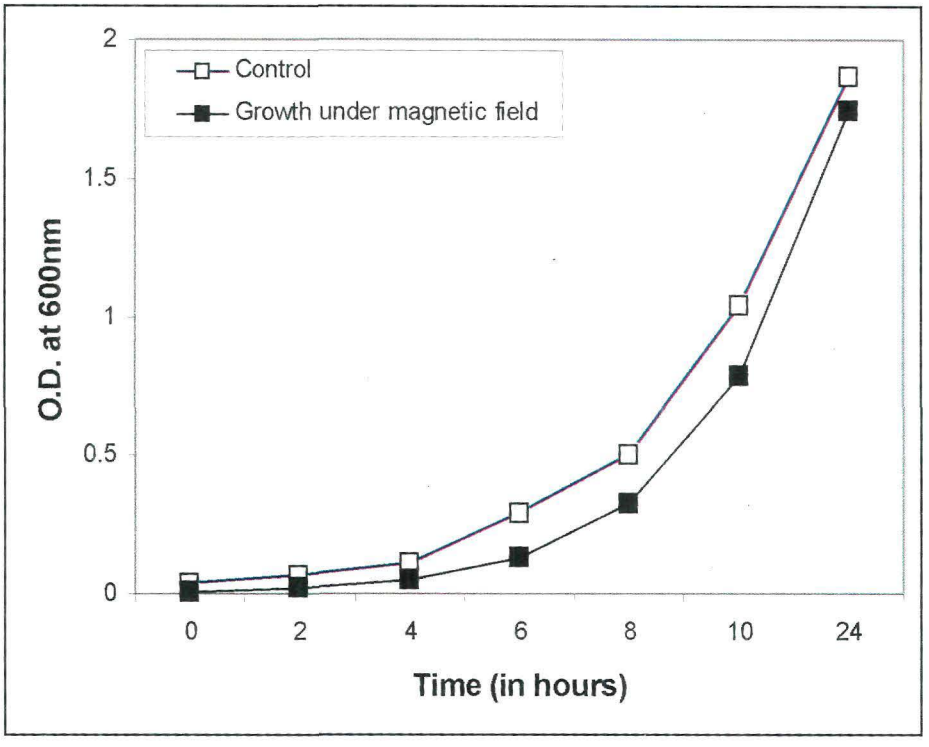

Fig. 3: Comparison of growth pattern of *L. casei* under influence of magnetic field.

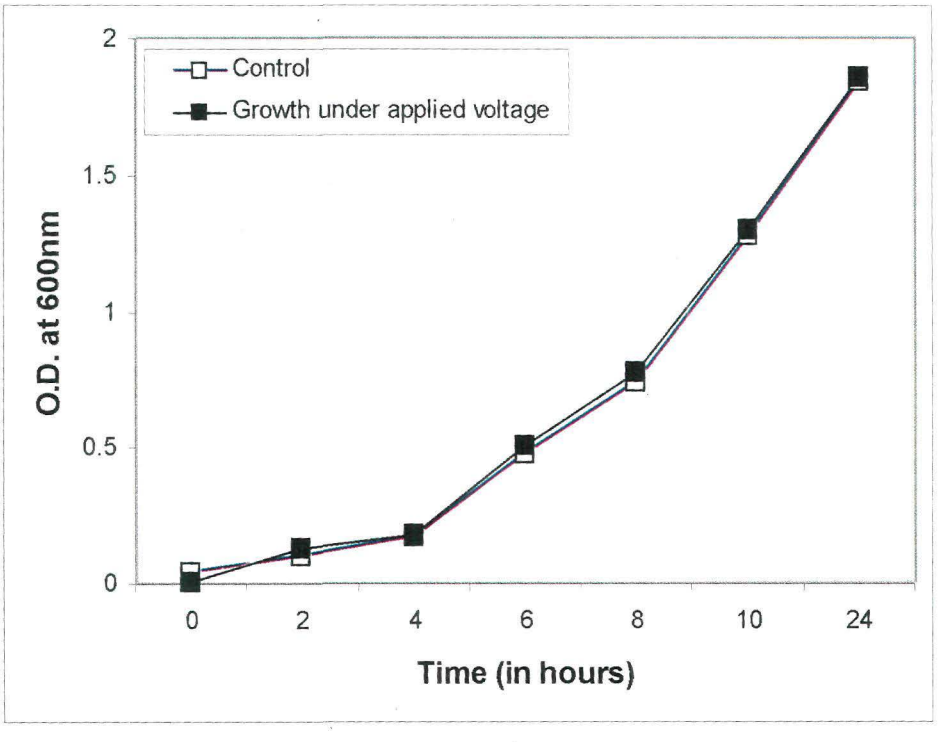

Fig. 4: Comparison of growth pattern of *L. casei* under influence of voltage

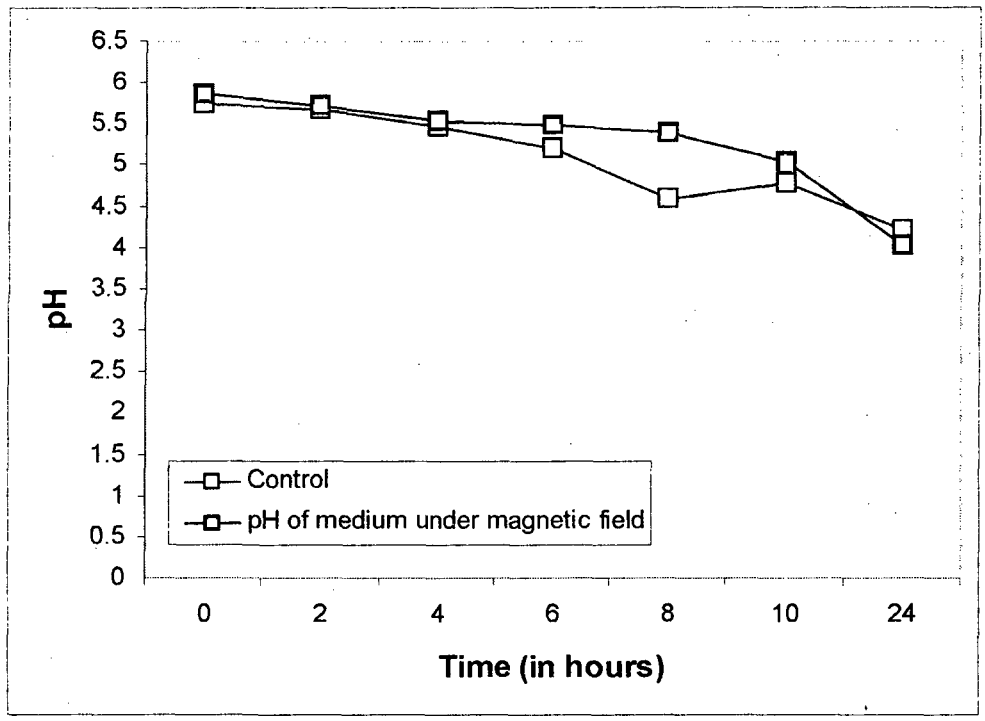

Fig. 5: Comparison of pH of the medium under influence of magnetic field and control.

decrease in pH of the medium. Also, it has been observed that constant magnetic field (CMF) caused an increase in acid formation by lactic acid bacteria and maximum effect was achieved by treating the cells with CMF for 1 or 2 hr (Alaverdyan *et al.*, 1994). This observation also suggest that magnetic field affects the various physiological/biological functioning of living organism, e.g. DNA synthesis, transcription and ion transportation through cell membranes (Liburdy, 1992 and Philips *et al.*, 1992).

We also observed that the growth pattern was not altered much under the influence of voltage that could be due to inadequate applied voltage . This observation is in accordance with Moore, 1979, who also observed that stimulation and inhibition of the growth of five bacterial species and yeast was dependent on the field strength , frequency and bacterium kind. Therefore, from this preliminary study it can be concluded that magnetic field and voltage do have impact on the growth of the beneficial microorganisms and may have effect on their physiological/biological activity.

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ABO AND RH(D) BLOOD GROUPS AMONG YADAV OF DISTRICT JAUNPUR

***Pradeep Kumar[1], Manoj Yadav[2] and Vandana Rai[1]**

[1] *Department of Biotechnology,*

[2] *Department of Applied Biochemistry,*

V B S Purvanchal University, Jaunpur-222 001

Abstract

The distribution of ABO blood groups and Rh (D) factor has been studied among the Yadav caste group population o Jaunpur (U.P.). The O, A, B, and AB blood group percentage were recorded as 40%, 17%, 35.5% and 6.5% respectively The allele frequencies of O, A and B groups were found to be 0.6300, 0.1252, and 0.2447 respectively. The allelic frequency of Rh (D) was found to be 0.8.

Key Words: Antigens, ABO, Allele Frequency, Phenotype, Rh (D), Yadav

INTRODUCTION

Red blood cell antigens are inherited characters and are important in transfusion medicine (Knight and deSilva, 1996). Nearly 300 different blood group antigens have been discovered so far (Contreras and Lubenko1999). With the advancement in antigen recognition techniques further blood groups are regularly added in this list. Inspite of discovery of a long list of red blood cell antigens no blood group could gain more importance than ABO and Rh system because of its unique position in blood transfusion. Even after 100 years of its discovery by Landsteiner in 1900, the single most important test performed in blood banking services is determination of ABO blood group to avoid morbidity and mortality (Honig and Bore, 1980). Rh system emerged as second most important blood group system due to hemolytic disease of new born and its importance in Rh negative individuals in subsequent transfusions once they develop Rh antibodies(Dennis *et al.*,1998).

Although several reports are published on RBC antigens of various ethnic groups /castes from U.P. as well as from all over the India like- Voddes caste, Andhra pradesh (Reddy and Reddy, 2005), Brahmins and Rajputs of Himanchal Pradesh (Mukhopadhyay and Kshatriya, 2004) and Scheduled caste population of Punjab (Sidhu, 2003). But data on the genetic markers among Yadav caste population of U.P. is not available. So we planned this study to find out the frequency of ABO and Rh(D) phenotypes in Yadav caste of U.P.

MATERIAL AND METHODS

Blood samples from a total of 200 unrelated individuals of both sexes were drawn at random from the Yadav settlements of Jaunpur district of U.P. Blood samples were taken from finger pricks, and usual open slide method of testing for ABO blood groups and Rh(D) factor was followed(Bhasin and Chahal,1996). ABO Grouping and Rhesus Typing antisera of Tulip were used for ABO and Rh Typing. Proper controls were set to ensure the validity of results. The gene frequencies for these two systems were calculated according to the method of Mourant et al. (1976). The details of each subject such as name, age, sex etc. were collected using a brief questionnaire.

RESULTS AND DISCUSSION

The frequency distributions of ABO phenotypes with gene frequencies are presented in table 1. It is clear from the table that O phenotype has the highest frequency (40%) followed by B (35.5%), A (17%) and AB (6.0%). The overall picture of phenotypic frequencies of ABO blood groups is O> B>A>AB. The decreasing order of allele frequency in Yadav is O (0.6300)> B (0.2447) and A (0.1252). In case of Rh (D) blood groups 96% were positive and 4% were negative. The allele frequencies were recorded 0.8 for D and 0.2 for *d* (Table 2).

**Corresponding Author :* pradipk14@yahoo.co.in

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Table 1. Distribution of ABO blood group and their allelic frequencies among the Yadav caste population (Backward caste) (Number of samples analysed = 200)

Phenotype	Observed Number	Percentage	Allele frequencies
O	80	40%	0.6300
A	34	17%	0.1252
B	73	35.5%	0.2447
AB	13	6.5%	-

Table 2: Distribution of the Rh (D) blood group and their allele frequencies among Yadav caste population (Backward caste) (Number of samples analysed = 200)

Phenotype	*Observed Number*	*Percentage*	*Allele Frequencies*
Rh(D)	192	96%	0.8
Rh(d)	8	4%	0.2

Usually, the distribution of ABO blood group varies from one population to another. In many other studies, blood group O has been found to be the most common blood group like- Caucasians (Seeley et al, 1998), Western European population (Adeyemo and Soboyejo, 2006) and Pakistani population (Adeyemo and Soboyejo, 2006). The distribution of allele frequencies of ABO and Rh (D) blood groups of Yadav population (B C) of Jaunpur district are found to be similar to that observed for other backward caste population of India (Rao et al., 2003; Reddy and Reddy, 2005; Prabhakar et al., 2005; Rai et al, 2008). The Rh (D) distribution also varies within any group of population. In this study, the percentage of Rh (D) positive was 96% and that of Rh (d) negative was found to be 4%. Over he years, the Rh blood group system has been distributed among any population to keep the frequency of Rh (D) negative very low since clinical situations could arise through Rh incompatibility.

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DIVERSITY OF *RICCIA* (MICH.) L. IN WAGAD REGION (BANSWARA AND DUNGARPUR DISTRICTS) RAJASTHAN, INDIA

B. L. Chaudhary and S. Rana

Department of Botany, Mohanlal Sukhadia University, Udaipur - 313 001

Abstract

Eight species belonging to single genus *Riccia* distributed all over the Wagad region have been collected from Banswara and Dungarpur districts of Rajasthan in fertile as well as vegetative stages. *Riccia gangetica* Ahmad and *R. billardieri* Mont. *et* Nees are the most dominant species represented in maximum collection sites. All belongs to the family Ricciaceae.

Key words : Banswara , Dungarpur, *Riccia*, Rajasthan.

INTRODUCTION

Rajasthan is located in the northwestern part of the subcontinent. It is bounded on the west and north-west by Pakistan, on the north and north-east by the states of Punjab, Haryana, and Uttar Pradesh, on the east and south-east by the states of Uttar Pradesh and Madhya Pradesh, and on the south-west by the state of Gujarat. The Tropic of Cancer passes through its southern tip in the Banswara district. The state has an area of 342,239 square kilometers and lies between Latitude 23° 3'N and 30° 12' N, and Longitude 69° 31'E and 78° 17' E at height of 578 meters above Mean Sea level. The climate of Rajasthan is of great extreme with sudden change in temperature, precipitation and wind.

The Wagad region of Rajasthan known as 'Humid Southern plain' falls in southern physiographic region of the state inhabited predominantly by scheduled tribes having very low socio-economic status. The Wagad region comprises Banswara and Dungarpur districts of Rajasthan covering Six sub divisions, Nine tehsils, Thirteen panchayat samities, Six towns and having in all 2326 villages. It covers an area of 8922 km^2 constituting about 2.6 % of the total geographical area of the state, thus forming small climatic zone of the state. The boundaries of the Wagad region falls between 23° 11' to 24° 01' North latitudes and 73° 21' to 74° 47 East longitudes, in which the Banswara district is situated between 23° 11' to 23° 56' North latitudes and 73° 58 to 74° 49' East longitudes and Dungarpur district between 23° 20' to 24° 01' North latitudes and 73° 21' to 74° 23' East longitudes. The Wagad region is extreme southern part of the state and is surrounded by Ratlam district of Madhya Pradesh in the east, Sabarkantha of Gujarat in the west, Panchmahal district of Gujarat in south and in north it is surrounded by two districts of Rajasthan i. e. Udaipur and Chittorgarh. (Map-1)

Due to high rainfall, averaging around 950 mm per annum resulting in high humidity, it is one of the richest spots of Angiospermic vegetation in general and Bryophytic in particular. It includes a variety of trees, shrubs, herbs, climbers and grasses. The subtropical evergreen forest of Banswara consists of mixed tree growth with *Tectona grandis* L. f .nom cons. as a predominant species followed by *Anogeissus latifolia* (Rxb. *ex* DC.) Wall. *ex* Guill. & Perr., *Diospyros melanoxylon* L. Roxb., *Madhuca indica* J.F.Gmelin, *Dendrocalamus strictus* (Roxb.) Nees and *Ficus religiosa* L. A perusal of the literature reveals that no work has been done on the Bryophytic flora of Banswara and Dungarpur districts of Rajasthan.

MATERIAL AND METHODS

Extensive and intensive collections of *Riccia* species has been done by visiting various places throughout the Banswara district during September-October 2003-2004. All the specimens were numbered and properly processed. Identifications were done with the help of available literature (Ahmad, 1942, Pande and Udar, 1957, Srivastava, 1964, Bapna, 1969, Bapna and Kachroo, 2000, Tanveer, 2005. Khinchi, 2007, Bhagora, 2007.) The collected specimens were placed in FAA, habit and habitats of each specimen in the field were noted. The voucher specimens are in the Herbarium, Department of Botany, M.L. Sukhadia University, Udaipur.

**Corresponding Author* : s.rana@rediffmail.com

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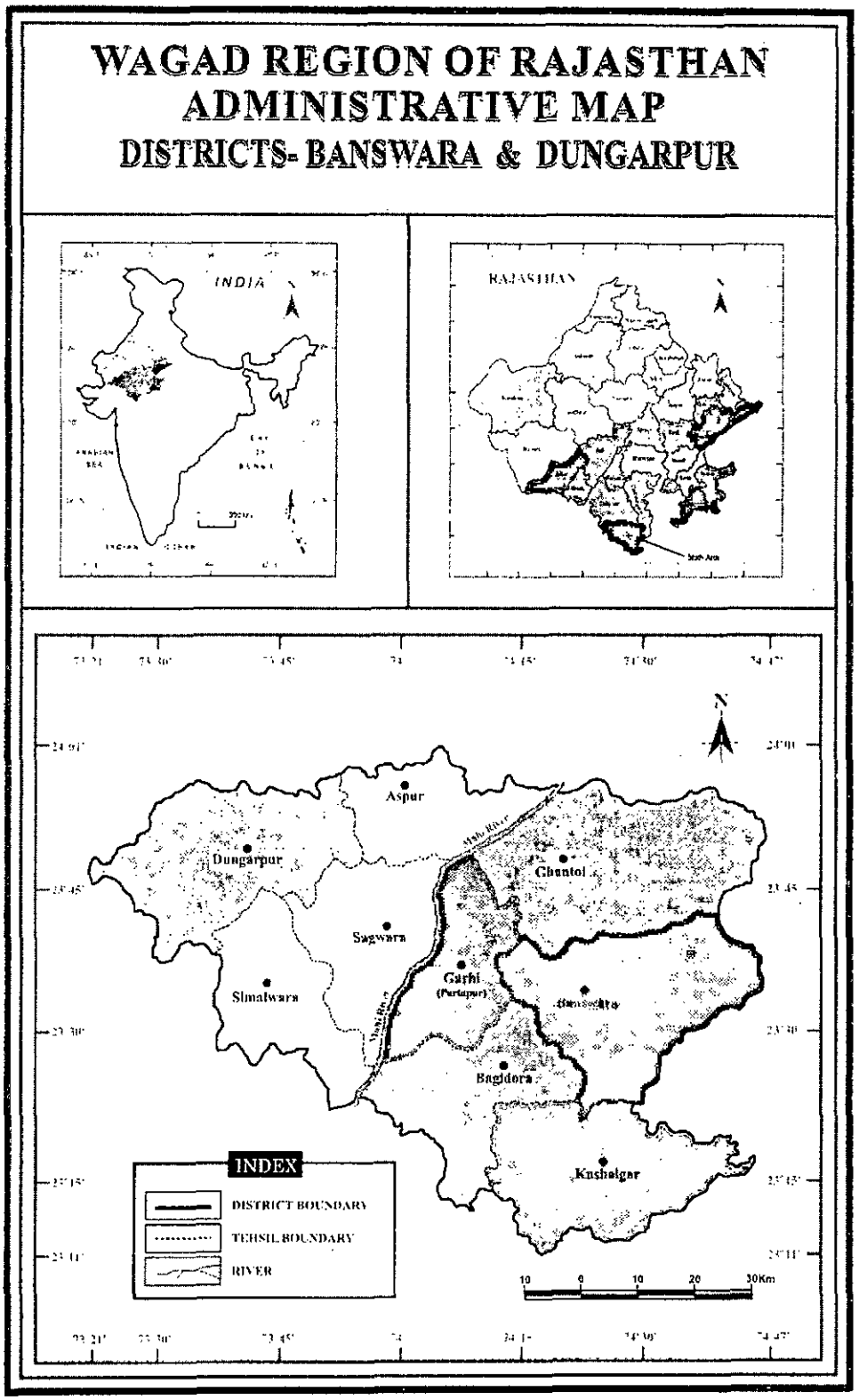

WAGAD REGION OF RAJASTHAN
ADMINISTRATIVE MAP
DISTRICTS- BANSWARA & DUNGARPUR
INDIA
RAJASTHAN
N
Aspur
Dungarpur
Ghantol
Sagwara
Garhi
(Partapur)
Simalwara
Bagidora
Kushalgar
INDEX
DISTRICT BOUNDARY
TEHSIL BOUNDARY
RIVER
10 0 10 20 30Km

Map-1

OBSERVATIONS

Class : **Hepaticopsida**
Order : **Marchantiales**
Family : **Ricciaceae**
Genus : ***Riccia***

Key to the species

1	Chlorophyll-bearing layer consisting of vertical filaments surrounding narrow vertical air space.	2
1	Chlorophyll-bearing layer consisting of irregular chambers separated by one celled thick walls.	6
2	Plants with cilia.	***R. melanospora***
2	Plants without cilia.	3
3	Plants dioecious.	***R. discolor***
3	Plants monoecious.	4
4	Spores winged.	***R. aravalliensis***
4	Spores unwinged.	5
5	Thalli bluish green, about 3 times broader than high, spores 85-135 µm black, 10-16 reticulations.	***R. gangetica***
5	Thalli green, about 4-6 times broader than high, spores 85-150 µm reddish brown, 6-7 reticulations.	***R. billardieri***
6	Plants dioecious.	***R. frostii***
6	Plants monoecious.	7
7	Thalli very broad, cruciate or in rosettes and spongy, spores up to 90 µm, dark brown.	***R. crystallina***
7	Thalli narrow, repeatedly branched, spores 70-100 µm, dark brown.	***R. plana***

***Riccia melanospora* Kash.**, Liverw. Himalayas Punjab pl.1: 94. 1929.

(Plate 1, Fig. B_1-B_6)

Monoecious. Plants overlapping and crowded, bright green or blue green, rarely isolated or forming irregular rosettes.

Thallus small 2-4 mm long and 1-2 mm broad, simple or once dichotomously branched; lobes oblong-ovate, narrow groove at apex, broad, flat or concave in the posterior region; wings usually turned upwards, cilia few, pink, restricted to the margin, up to 110 µm long or cilia absent. Ventral surface convex; margin purple or black. Scales large, purple, extending beyond the margin of the thallus, 840 µm long. Rhizoids tuberculate 20 µm wide and simple 24 µm in width. Cross section semi-circular, twice as broad as high; epidermal cells hyaline, oval, rounded or angular, 145-160 µm in diameter; air spaces narrow; assimilatory filaments 5-10 cells high; ventral tissues compact 10-14 cells high. Sex organs in 2-3 rows along the median line. Antheridial papillae small, hyaline, slightly projecting, 30-40 µm above the thallus surface; archegonial neck 252 µm long. Capsule prominent on dorsal surface, bulging out as dark specks of average 490 µm in diameter. Spores dark brown, opaque at maturity, winged, reticulate, 60-80 µm across outer face, reticulations small 9-16, wing 3-6 µm wide usually imperfect in mature spores with crenate margin. Tri-radiate mark faint or indistinct.

Field notes : Plants grow in exposed places on moist soil or rocks or on gravel paths. Their growth is better on calcium soils. Plants appear with the advent of rains and become dominant in some places. Usually found in

association with *R. billardieri, R. gangetica*, mosses and blue green algae, sometimes with *Anthoceros erectus.*

Locality : Government College Campus (alt. 200m), Banswara Club (alt. 250m), Bhandariya Hanuman Temple (alt. 300m), Way to Saredi (alt. 350m), Peepalkhunt Hilage (alt. 500m), Kagdi Fall (alt. 500m), Madar Hill (alt. 550m), Gupteshwar Temple Paloda (alt. 250m), Behind Mahi Rest House (alt. 300m). (Map-2)

Distribution : Hoshiarpur, Konsa, Kashmir, Pauri, Lucknow, Bhopal, Coimbatore, Rajasthan; Pakistan.

***Riccia discolor* Lehm.** and Lindenb. Pugill. 4: 1. 1832.

(Plate 1, Fig. A_1-A_7)

Dioecious. Plants overlapping in dense patches, very rarely forming irregular rosettes, Thalli green, once or twice forked; lobes oblong. Female plants larger than the male plants, up to 15 mm long and up to 7 mm broad, with a median groove all along the length of the thallus. Male thalli smaller, 2 to 8 mm long and 2.5 mm broad, usually with a groove which is narrow at apex and flat, behind. Margin purple and entire, often bent downwards. Epidermal cells thin walled, hyaline, oval or rounded and papillate. Thallus up to four times as broad as high; air spaces narrow, assimilatory filaments 6-8 cells high, ventral surface bears simple and tuberculate rhizoids; rhizoids sometimes harbour mycelium. Ventral scales small, semi-lunar, overlapping, deep pink, projecting beyond the thallus margin. Antheridia 1-3, in median rows, globular or slightly elliptic, antheridial papillae colorless or pink, projecting above the surface of the thallus, 185-295 µm long. Archegonia in the medium furrow, neck up to 95 µm, projecting above the surface of the thallus, turning violet in the middle after fertilization. Capsules in 1-2 rows black at maturity, spores dark brown, 80-120 µm in diameter, reticulate, 6-10 areoles on the outer face, tri-radiate mark inconspicuous.

Field notes : Plants grow on moist soil or rocks in exposed situations, usually overlapping, found associated with other species like *Riccia gangetica* Ahmad and *Riccia billardieri* Mont. et Nees.

Locality : Government College Campus (alt. 200m), Banswara Club (alt. 250m), Peepalkhunt Hilage (alt. 500m), Kagdi Fall (alt. 500m), Bhandariya Hanuman Temple (alt. 300m), Gupteshwar Temple Paloda (alt. 250m), Behind Mahi Rest House (alt. 300m), Peepalkhunt Bhatiya Tank (alt. 450m), Madar Hill (alt. 550m). (Map-2)

Distribution : Nainital, Mussoorie, Pauri, Guwahati, Shillong, Jorhat, Kamkhaya hills, Satpuras, Saugar, Pachmarhi, Coimbatore, Mangalore, Agumbe, Gersoppa falls, Rajasthan, Gujarat, Nepal, Sri Lanka, Pakistan, Myanmar, Uganda and Congo.

***Riccia aravalliensis* Pande et Udar,** J. Indian bot. Soc. 36: 248. 1957.

(Plate 1, Fig. C_1-C_5)

Monoecious, plants small, overlapping, sometimes in complete rosettes, glaucous green above, concolorous below. Thalli up to 3 mm. long, 1-1.5 mm. broad, 2-3 dichotomously branched, segments linear ovate, truncate or rounded at apex. Ventral scales prominent, large and overlapping, dark purple, not projecting beyond the margin. Rhizoids smooth walled and tuberculate. Dorsal groove narrow and deep near the apex, shallow behind and almost disappearing in the posterior region. Cross section 2-3 times as broad as high. Air chambers narrow and columnar, walls unistratose. Ventral surface strongly convex, sides ascending steeply to the acute margin. Antheridial ostioles conspicuous. Sporophyte embedded in the tissue of the thallus, prominent dorsally. Spores tetrahedral, 80-125 µm, areolate on the outer face with only 3-6 large areoles, inner faces vermiculate between the arms of the triradiate mark, winged, wing margin usually up to 8 µm broad, rarely broader, margin undulate, triradiate mark very prominent.

Field notes : The plants were found growing on moist soil under exposed places. Usually associated with *Riccia gangetica* and mosses.

Locality : Kadeliya Fall (alt. 400m) and Peepalkhunt Bhatiya Tank (alt. 450m)**(Map-2)**

Distribution : Pauri, Garhwal and Rajasthan.

***Riccia gangetica* Ahmad**, Curr, Sci.11: 433. 1942.

(Plate 1, Fig. D_1-D_6)

Monoecious. Plants bluish green overlapping in patches or forming beautiful, large well defined rosettes. Thalli 1-3 times dichotomously branched; 2 to 14 mm long and 1-3 mm broad; dorsal median groove prominent; lobes ovate or linear. Apex emarginated or obtuse; rhizoids dense, simple and tuberculate. Scales hyaline or purple, stout or thin, may or may not extend beyond the margins. Epidermal cells hyaline, oval or spherical; thallus 2-3 times as broad as high; compact tissue 9-10 cells thick. Antheridia and archegonia in 2-3 rows median line. Antheridial papillae, hyaline or pink, 150-180 µm, projecting above the surface of the thallus. Archegonial neck slightly projecting above the surface. Capsule up to 550 µm in diameter, prominent dorsally, dehiscence by rupturing of the tissue above, spores, tetrahedral,

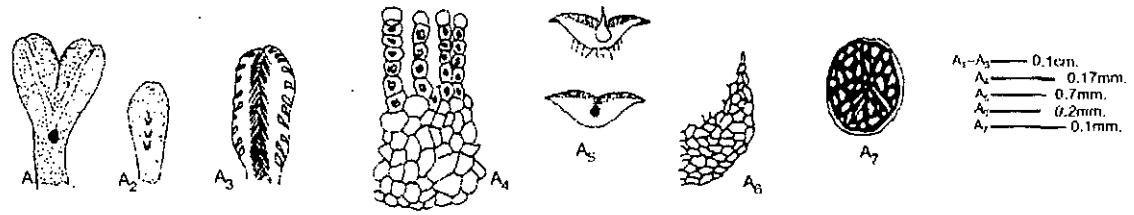


Fig. A_1–A_7 ***Riccia discolor*** **Lehm.**
A_1 Female thallus; A_2 Male thallus; A_3 Thallus in ventral surface; A_4 Portion of C.S. of thallus: A_5 C.S. of thallus various planes; A_6scale; A_7Spore.

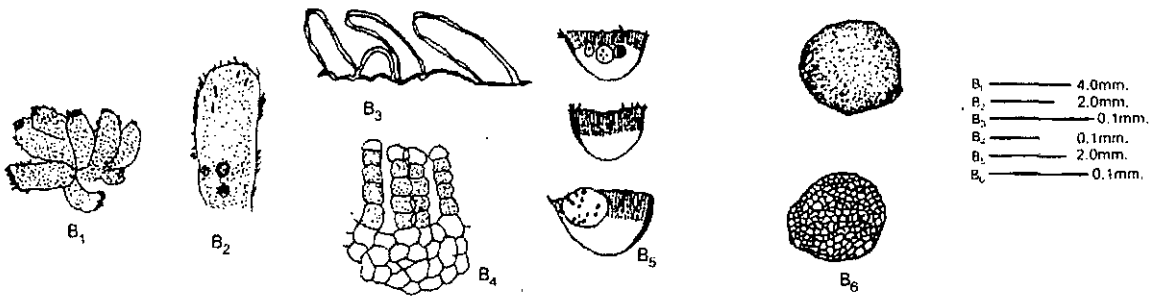


Fig. B_1–B_6 ***Riccia melanospora*** **Kash.**
B_1.Thallus habitat; B_2.Thallus with sporophyte at margin; B_3.Cilia; B_4.Portion of C.S. of thallus; B_5 C.S. of thallus various planes; B_6 Spores.

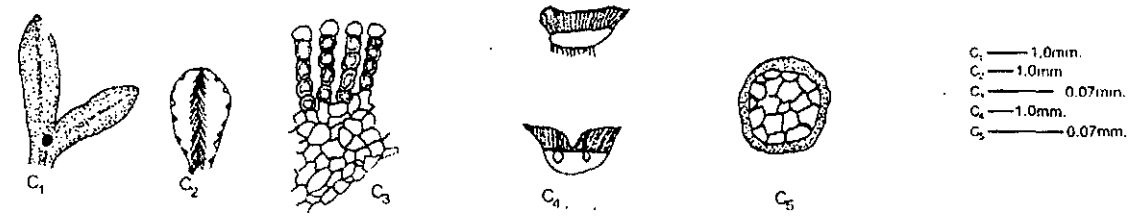


Fig. C_1-C_5 ***Riccia aravalliensis*** **Pande *et* Udar.**
C_1.Thallus Dorsal view; C_2. Thallus ventral view; C_3. Portion of C.S. of thallus; C_4. C.S. of thallus at various planes; C_5. Spore.

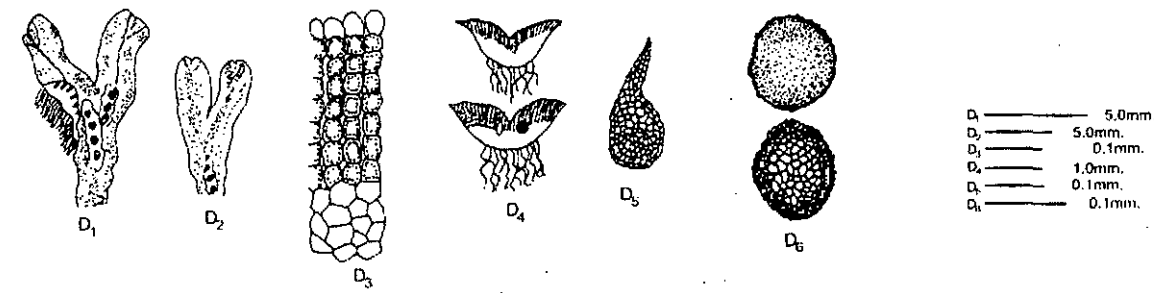


Fig. D_1–D_6 ***Riccia gangetica*** **Ahmad**
D_1–D_2. Thallus with sporophyte; D_3. Portion of C.S.of thallus; D_4. C. S. of thallus at various planes; D_5. Scale;D_6.Spores.

Plate 1

dark brown to black at maturity, 115-135 µm in diameter reticulations small 10-15, margin dentate or crenate.

Field notes : Plants grow on moist shady or exposed soil, on rocks, on coarse gravel soil, usually found associated with *R. billardieri, R. discolor* and *Anthoceros* species.

Locality : Government College Campus (alt. 200m), Banswara Club (alt. 250m) , Bhandariya Hanuman Temple (alt. 300m), Way to Saredi (alt. 350m), Ransagar Tank (alt. 150m), Vaijoda Forest Area (alt. 250m), Sagwara (alt. 300m), Kushalgarh (alt. 350m), Baitalab Tank (alt. 150m), Garhi (alt. 200m), Tripura Sundari (alt. 300m), Kagdi Fall (alt. 500m), Gupteshwar Temple Paloda (alt. 250m), Behind Mahi Rest House (alt. 300m), Madar Hill (alt. 550m), Kadeliya Fall (alt. 400m), Peepalkhunt Bhatiya Tank (alt. 450m), Aspur near a tank (alt. 200m), Salakeshwar near Anaas River Bank (alt. 400m), Dungarpur on old walls of a house (alt. 300m), Mahi Dam near banks of river (alt. 200m), Andeshwar on walls of a old house (alt. 350m). (Map-2)

Distribution : Western Himalayas, Garhwal, Assam, Shillong, Uttar Pradesh, Madhya Pradesh, South India, Nilgiri hills, Khandala, Rajasthan, Gujarat; Java.

***Riccia billardieri* Mont. et Nees,** Syn. Hep. 602, 1846; Udar, Curr, Sci. 26: 20. 1957.

(Plate 2, Fig. E_1-E_5)

Monoecious. Thalli pale green to dark or bluish green, *usually overlapping, forming dense patches, sometimes* forming irregular rosettes or found singly and spreading on open spaces. Thallus simple or 1-3 times rarely 4-5 times dichotomously branched; up to 20 mm long up to 10 mm broad, lobes ovate-oblong with prominent groove at apex and shallow behind. *Apical notch distinct;* obtuse or emarginated apex; margin purple entire and upturned, sometimes bent downwards. Ventral surface purple, convex and bear prominent scales which are overlapping and curved over the margins. Scales purple, one cell thick, semi lunar, up to 1.2 mm long. In plants growing in humid habitats the scales sparse and widely separated not extending beyond the margins. Rhizoids smooth-walled and tuberculated. Epidermal cells hyaline, oval, spherical or slightly irregular. Cross section 3-5 times as broad as high, assimilatory tissue up to 11 cells, air spaces narrow, ventral tissue compact, 6-7 cells high, parenchymatous. Antheridia in 2-3 rows, antheridial papillae long violet or hyaline, prominently projecting above the surface of the thallus, up to 295 µm long. Archegonia usually occur singly. Capsules embedded in 1-3 rows, greenish when young and dark brown to black at maturity, rarely projecting slightly on the dorsal surface. dehiscence by the decay of the overlapping tissues. Spores tetrahedral, reddish brown to dark brown often 70-126 µm in diameter, regularly reticulate, with 3-9 reticulations, angles of reticulations extend in prominent projections, capped by undulating membranes, tri-radiate mark inconspicuous.

Field notes : The plant grows under various habitats e.g. on moist ground shady places, on exposed situations, on moist soil or rocks, on compact and coarse granite sand, *on old walls, on banks of streams.* According to the habitat variations species show different associations. It was found to grow intermingled with *Riccia gangetica, R. discolor,* species of *Anthoceros, Notothylas, Targionia, Asterella* and *Plagiochasma, Hydrogonium consanguineum, Semibarbula orientalis, Bryum* species and *Selaginella* species. On dry soil the thallus is short, stunted, thick and stout, and usually the apical portion is bent or curved downward probably to protect the growing point against heat.

Locality : Government College Campus (alt. 200m), Banswara Club (alt. 250m) , Kagdi Fall (alt. 500m), Bhandariya Hanuman Temple (alt. 300m), Saredi (alt. 350m), Near Anaas River Bank (alt. 400m), Bagidora (alt. 350m), Bhiluda Sagwara (alt. 300m), Seemalwara (alt. 250m), Aspur near a tank (alt. 200m), Paloda near a tank (alt. 250m), Kushalgarh Bagaicha (alt. 600m), Ransagar Tank (alt. 150m), Vaijoda Forest Area (alt. 250m), Sagwara (alt. 250m), Kushalgarh (alt. 350m), Baitalab Tank (alt. 150m), Garhi (alt. 200m), Tripura Sundari(alt. 300m), Madar Hill (alt. 550m), Kagdi Fall (alt. 500m), Behind Mahi Rest House (alt. 300m), Peepalkhunt Bhatiya Tank (alt.450m), Mahi Dam near banks of river (alt. 200m), Dungarpur at several places (alt.300m.), Andeshwar on walls of a old house (alt. 350m). (Map-2)

Distribution : Western Himalayas, Punjab, Assam, West Bengal, Uttar Pradesh, Madhya Pradesh, South India, Rajasthan, Gujarat; Sri Lanka, Pakistan, Java, Sumatra, Celebes, Moluccas, Japan and Africa.

***Riccia frostii* Aust.,** Torrey Bull. 6: 17. 1875.

(Plate 2, Fig. F_1-F_6)

Dioecious. Plants overlapping or forming beautiful rosettes. Male thalli, light red or pinkish, small 3-5 mm, rarely 8 mm long and 1-4 mm broad. Female plants green, larger than male, up to 4-10 mm long and 1.5-3 mm broad, sometimes 4-6 mm broad, forming compact rosettes or sometimes overlapping, thallus simple or branched, lobes linear to oblong, a narrow mid dorsal sulcus in male plants, female plants flat, sulcus absent. Smooth walled rhizoids numerous and tuberculated

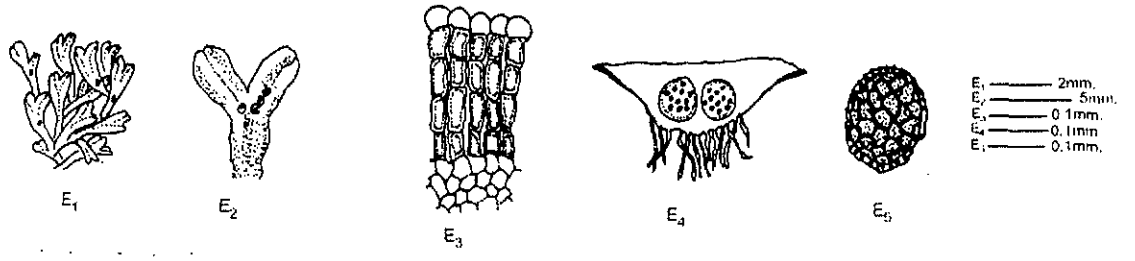


Fig. E_1–E_5 ***Riccia billardieri*** **Mont *et* Nees.**
E_1. Thallus Habit; E_2. Thallus enlarged view; E_3. Portion of C.S.of thallus E_4. Portion of C.S. of thallus from sporophyte region; E_5 Spore.

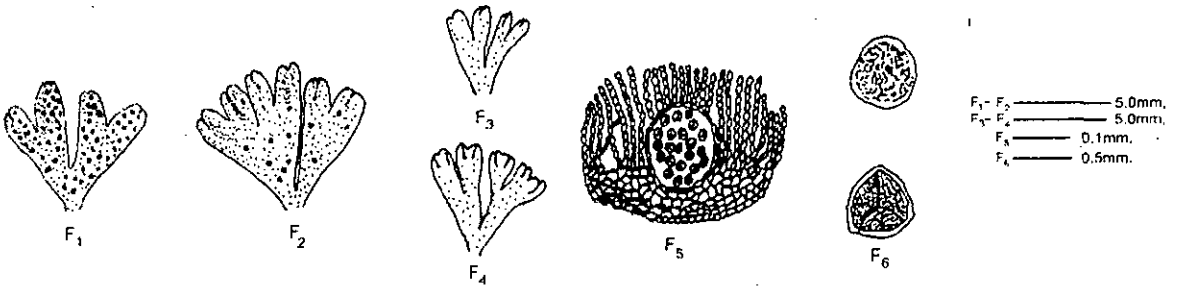


Fig. F_1–F_6 ***Riccia frostii*** **Aust.**
F_1- F_2 Female thallus habitat; F_3- F_4 .Male thallus;F_5. Portion of C.S.of thallus through capsule; F_6. Spores

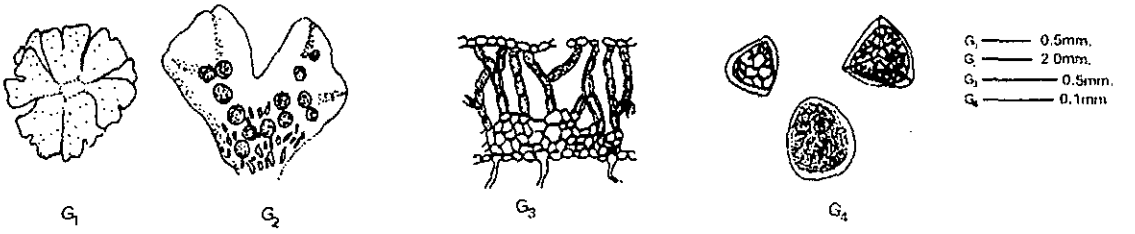


Fig. G_1–G_4 ***Riccia crystallina*** **L.**
G_1.Habit; G_2. Thallus with sporophyte; G_3 . Portion of C.S. of thallus: G_4. Spores.

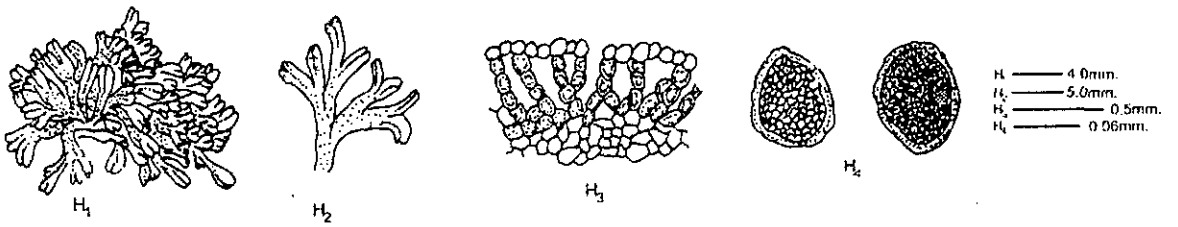
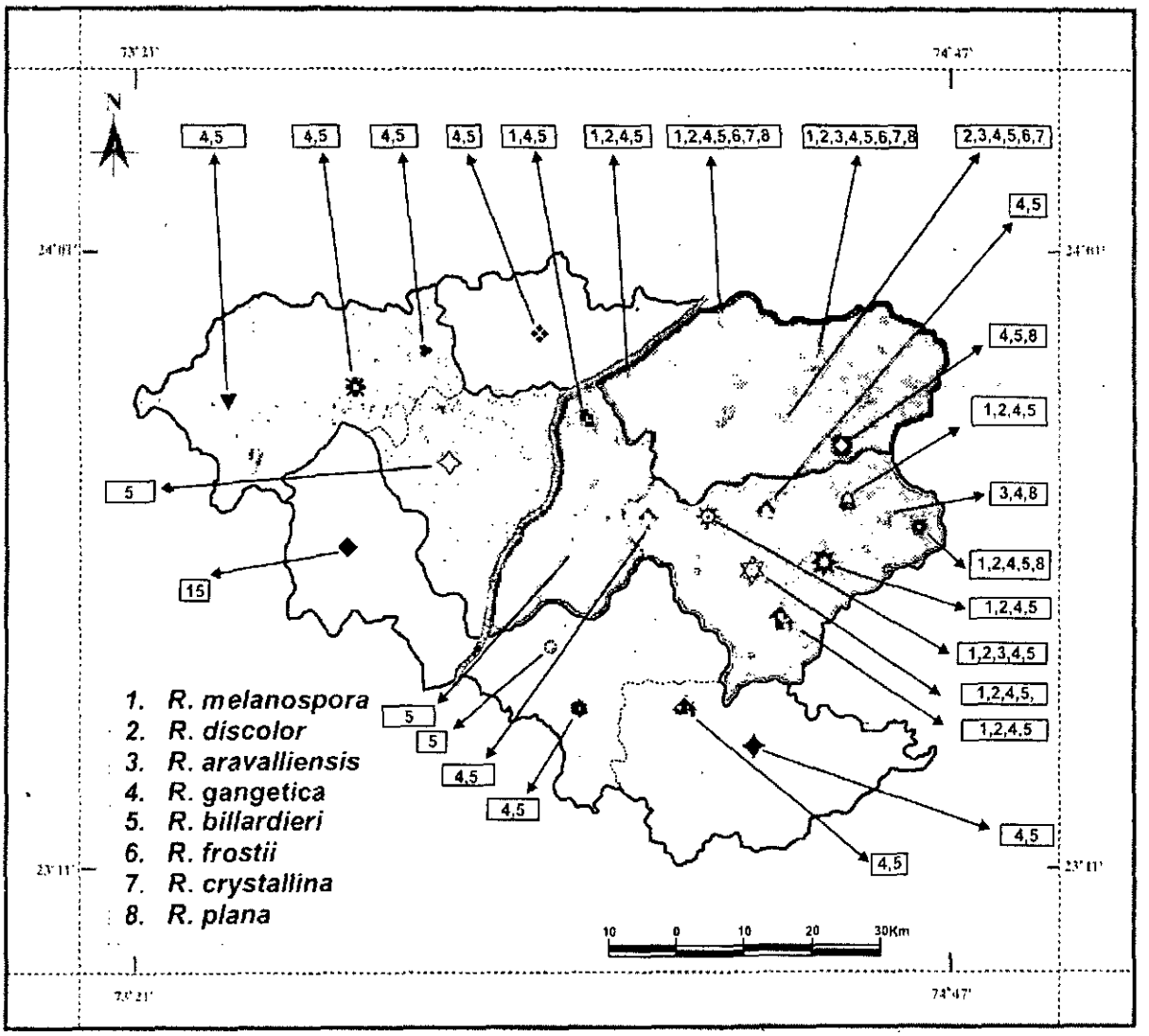


Fig. H_1–H_4 ***Riccia plana*** **Taylor.**
H_1–H_2. Habit; H_3. Portion of C.S.of thallus;H_4. Spores.

Plate 2

WAGAD REGION OF RAJASTHAN

Showing distribution of various species of *Riccia* in different localities of Banswara and Dungarpur districts



▼ Dungarpur ◆ Seemalwara ✱ Vaijoda Forest Area ❖ Aspur ◘ Hilage ○ Bagidora
Ran Sagar Tank ★ Bhiluda ★ Paloda ▮ Saredi ❄ Garhi ◆ Sagwara ◇ Mahi Dam
✱ Salakeshwar ✦ Kushalgarh ☼ College Campus ✱ Andeshwar ✿ Baitalab Tank
Bhandariya Hanuman ☼ Kadeliya ○ Kagdi Fall ✶ Bhatiya Tank ↑ Tripura Sundari
✲ Mahi Rest House Forest 🔔 Madar Hill ✡ Banswara Club ❀ Peepalkhunt Forest

MAP 2

rhizoids rare. Scales not detected. Cross section 2-3 times as broad as high, air chambers elongated; epidermal cells hyaline, oval, 40 µm x 28 µm; thin walled, assimilatory zone of loose filaments, compact tissue 5-7 cells thick.

Antheridia in 2-3 rows on dorsal region, cylindrical, 196 µm x 125 µm, antheridial papillae pink, projecting prominently, 72 µm above the thallus surface. Archegonial neck not projecting above the surface of the thallus, 182 µm long. Sporogoniuim numerous, prominent dorsally, in 2-3 rows along the mid dorsal line, up to 700 µm in diameter, embedded in the tissue of the thallus, spores brown to dark brown, tetrahedral with granular contents, 52-70 µm in diameter, the inner face more or less similar to outer face, tri-radiate mark distinct, wings up to 6 µm wide and entire.

Field notes : Growing on moist soil or alluvial deposits along the bank of streams and river. Plants can be recognized in the field as they form beautiful distinct male and female rosettes, sometimes, male and female plants intermingled; the male plants usually small, with reddish tinge whereas female plants are green. Fruiting usually in winter.

Locality : Peepalkhunt Bhatiya tank (alt. 550m). (Map-2)

Distribution : Western Himalayas, Punjab, Sikkim, Assam, Bihar, Bengal, Uttar Pradesh, Gujarat, South India, Rajasthan; East and West Pakistan, South America, North America, Europe, Africa, Egypt and Turkey.

***Riccia crystallina* L.,** Spec. Plant. 1138. 1753.

(Plate 2, Fig. G_1-G_4)

Monoecious. Plants usually forming well defined rosettes, 2-3 cm in diameter, sometimes overlapping when crowded or in patches. Thalli flat and dichotomously branched, dorsal surface with a broad median groove and margin turned upward; sometimes adventitious branches arising laterally along the margin; overlapping thalli are firmly adherent to each other; lobes spreading, up to 8-10 mm long, 3-4 mm broad; ventral surface convex. Rhizoids numerous in the median region, simple and tuberculate, 21 µm wide; scales rudimentary, near the apex. Thallus 3-4 times as broad as high; air chambers polyhedral or clavate, larger on flanks and smaller in centre, communicating with outside by indefinite pores; air chambers bounded by 10-15 cells; the partition walls one celled thick and bear chloroplasts; epidermal cells oval, hyaline, 115 µm x 85 µm; compact tissue 5-6 cells thick. Antheridial papillae hyaline, 374 µm projecting above thallus surface. Archegonial neck 175 µm long or more; rarely archegonia in a group of two. Sporophyte pulling ventrally, 220 µm in diameter; spores dark brown, tetrahedral, winged, incompletely reticulate, up to 90 µm-110 µm in diameter, areoles 3-5, incomplete on outer face, reticulations incomplete on inner face also, wing 6-9 µm wide, densely crenate; tri-radiate mark distinct.

Field notes : The species is usually growing in winter, on moist soil, in gardens, river-banks or cultivated soil, sometimes associated with *Riccia* species and mosses.

Locality : Peepalkhunt Bhatiya tank (alt. 550m). (Map-2)

Distribution : Western Himalayas, Eastern Himalayas, Bengal, Madhya Pradesh, Uttar Pradesh, South India, Rajasthan; Nepal, East-West Pakistan, South-West Africa, Britain, Europe and North America.

***Riccia plana*, Taylor,** J. bot. London 5: 414. 1846.

(Plate 2, Fig. H_1-H_4)

Monoecious. Thalli light green or grayish green, densely crowded and overlapping, sometimes forming complete or incomplete rosettes. Thallus up to 15 mm long and 2-4 broad, several times dichotomously branched, lobes obcuneate and divergent, distinct apical notch and anterior sulcus, upper surface flat with many polygonal areas, sometimes thallus with a distinct median groove and older part of the thallus shows a tendency to become pitted. Ventral scales colorless, near the apex, exceedingly small and difficult to detect. Rhizoids simple and tuberculate. Thallus often 2-2.5 times as broad as high; dorsal region of loose net work of irregular wide polyhedral air chambers, separated usually by one or two layered lamellae stretching in all directions and bearing chloroplast; air chambers open on the exterior by well defined pores; compact tissue 6-8 cells high. Epidermal cells hyaline, spherical or oval up to 165 µm in diameter. Antheridia and archegonia produced in considerable number and not confined to the median region of the thallus. Antheridial papillae, colorless, transparent, 100 µm to 150 µm, even up to 200 µm, projecting above the surface of the thallus. Archegonial neck up to 240 µm long at maturity, upper colorless part collapses after fertilization, basal part yellowish brown. Sporophyte prominent, bulging ventrally, often varying from 410 µm to 500 µm, rarely up to 570 µm in diameter. Spores light to dark brown, tetrahedral, 90 to 110 µm in diameter, reticulate, areoles 9-10 across outer face, each 5-8 µm wide; walls of reticulum on inner face imperfect, with short, truncate, usually simple spines arising from them; areoles papillose; tri-radiate mark

distinct; wing 7-9 µm thick, broader at angle with one oval or irregular slit or perforation, outer edge finely erose or crenate.

Field notes : Plants found on moist soil near the banks of streams or along water paths. Young thalli visible soon after the beginning of rainy season, usually fruiting from end of July to September; though in plains growing near moist and shady places, sporogonium may be found up to the end of October; otherwise most of the thalli disappear from the more exposed situations. The ripe sporogonia abundant on large thalli are hardly visible on dorsal surface. In favorable conditions plants show luxuriant growth and thalli are quite large, whereas thalli are shorter under drier habitats. The thalli usually dry up before the spores are shed and their liberation is by disintegration of the thallus. The method of spore distribution is imperfect and water seems to be the main carrier for their distribution. Living plants of *R. plana* were brought to the laboratory and kept moist in Petri dishes. They were found to have grown erect, thallus becomes thin and ribbon shaped-as observed in *R. billardieri*. Usually associated with the species are *Phaeoceros laevis, Fissidens diversifolius* and *Funaria hygrometrica*.

Locality : Kagdifall (alt. 500m), On the way to Mahi Dam (alt. 350m), Bhandariya Hanuman Temple (alt. 400m) and Kadeliya Fall (alt. 400m). (Map-2)

Distribution : Mangalore, Western Ghats, Bhopal, Rajasthan; Canary Island, Africa and Australia.

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IMPLICATIONS OF PTC BITTER TASTE RECEPTOR GENETIC POLYMORPHISM IN HUMAN HEALTH AND DISEASE

Krishan Sharma

Department of Anthropology, Panjab University, Chandigarh – 160 014

Abstract

Variation in the perception of bitter tastes has been associated with eating behaviour, like reduced acceptance of some foods and rejection of bitter compounds. Recent observations have implicated two common haplotypes of PTC gene in the determination of bitter compound–tasting ability. PTC tasting ability has been used extensively as a classic genetic marker in anthropological studies. The recent researches done in the Department of Anthropology at Panjab University, Chandigarh has found linkage of PTC gene with diseases like epilepsy and susceptibility to motion sickness. New hypotheses have been proposed to explain these associations. The work on genetic sensitivity to PTC and food preferences is ongoing. A sensory based approach emphasizes individual differences in taste sensory perceptions and food likes/ dislikes. This offers an additional strategy for diet planning because food preferences may affect food consumption patterns and in turn health. Beside taste, food consumption may also be dependent on cost and convenience. The differential preference of individuals to salty and sweet eatables is attributed to individual hedonic perceptions found in humans. Screening of populations for PTC taster status has been recommended because of its importance in health and disease.

Key words: BMI, body fat, disease susceptibility, food preferences, health, PTC taste gene, population variations.

INTRODUCTION

Diets rich in vegetables and fruits have been linked with lower rates of heart disease and cancer (Lichtenstein 1998; Beecher 1999). Nutrition scientists have advocated the inclusion of a large chunk of raw vegetables in our daily diet and recommended at least five servings per day of these as the key dietary strategy for the prevention of cancer and other chronic diseases (Steinmetz and Potter 1996). But we come across many people who do not like to eat raw vegetables and some other food items and these food choices have been linked with their taste perception.

Taste perception is one of the important chemosensitivity of the oral cavity, located not only on the lingual surface but also on the palate, epiglottis, pharynx and larynx. This sensitivity is also expressed in oesophagus, stomach and small intestine. This sense is normally stimulated by direct contact with chemical molecules or ions in solutions and substances as they are taken into mouth. Most familiar of these taste senses are: sweet, sour, bitter, salty. In addition to these traditional taste categories, a fifth category termed "umami" has been used for the taste of monosodium glutamate and related compounds used in oriental cooking. The taste of these materials is outside the salty taste suggesting a separate category. These sensory responses serve important role in dietary choices made by individuals.

Sweet taste is considered palatable and attractive stimulus that may lead to a larger intake of food items whether or not one is hungry. When hungry, the intake would further increase. When salt is needed, there is increased intake of salt. These taste senses determine food choices. Sweetness is associated with readily available calories from carbohydrates, whereas, bitterness serves as a warning signal against ingestion of potentially toxic substances and subsequent aversion of food compounds with similar taste. Taste bitterness is observed in a variety of plant foods, such as cabbage, cucumbers, beans, peas, potatoes, pumpkins, lettuce, spinach, turnips (Rousseff 1990).

One of the most widely studied individual differences in the genetically determined sensitivity to bitter taste is for the ability to taste compounds that contain an N-C=S (thiocyanate) group such as phenylthiocarbamide (PTC) and 6-n-prophylthiouracial (PROP). These chemicals taste bitter to many, but some either cannot taste them or require high concentration to recognize its bitter taste.

Taste Sensory Biology and Genetics

The sense of taste is determined by the taste buds that are composed of modified epithelial elements clustered together in a barrel-shaped opening to the oral surface

*Corresponding Author : anthro@pu.ac.in

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through a small pore at the top. Filaments or microvilli of the tips of these elongated cells project into the taste pore. There are approximately ten thousand taste buds in humans. A majority of the mammalian taste bud cells have a total life span of about 10 days. When the taste afferents to the tongue are cut, the entire taste bud degenerates to be reconstituted when the sensory nerves regenerates and reach the epithelial surface. Each taste bud is made up of 50-150 receptor cells. Each receptor cell in a taste bud responds best to one of the basic tastes, but it can respond to the other tastes though the strongest response will be towards a particular taste. The middle and basal portions of these cells are in contact with nerve fibres of the underlying connective tissue (Pfaffman 1978). There are two cranial nerves that innervate the tongue and are used for taste: the facial nerve (cranial nerve VII) innervates the anterior two-third of the tongue and the glossopharyngeal nerve (cranial nerve IX) innervates the posterior one-third of the tongue. The vagus nerve (cranial nerve X) carries taste information from the back part of the mouth. The cranial nerves carry taste information to the brain stem called the nucleus of the solitary tract, from where it goes to thalamus and then to the cerebral cortex. In man, bitterness is best perceived at the rear of the oral cavity; saltiness and sweetness is best at the tip and edges of the tongue, but sour sensitivity is widely distributed. Taste perceptions of sour and salty substances are mediated by depolarizing taste receptor cells (TRCs) through direct interaction with ion channels (Herness and Gilbertson 1999). In contrast, amino acids, sugars and other compounds that are perceived as sweet and bitter are mediated through G-protein coupled receptors (GPCRs), all of which are expressed in taste cells within taste buds on the tongue (Gilbertson *et al.* 2000; Smith and Margolskee 2001).

A lot of research is being done in the field of biology of bitter taste perception. Bitter tastants include amino acids and peptides, ureas and thioureas (PROP and PTC), sulfimides (saccharine), esters and lactones, terpenoids, phenols and polyphenols, etc. (Brieskorn, 1990). A large chemical diversity in chemical compounds suggests the existence of multiple bitter-taste receptors. The first major initiative to understand the molecular genetics of bitter-taste sensitivity came when Hoon *et al.* (1999) identified two proteins expressed in the apical microvillae of bitter taste receptor cells. These receptors are exposed to the oral cavity through a small opening called the taste pore (Hoon *et al.* 1999), where they are positioned to come into contact with the many compounds that enter the mouth. Each of these compounds represents a potential ligand, capable of binding to a receptor and stimulating bitter-taste perception. These receptors are capable of responding to a diversity of plant toxins (Bufe et al. 2002, 2005; Behrens et al. 2004; Pronin et al. 2004; Nelson et al. 2005; Soranzo et al. 2005). These small proteins mostly having less than 400 amino acids are encoded by a large family of trans-membrane G protein-coupled receptor genes named TAS2Rs (or T2Rs) (Chandrashekar et al. 2000; Shi et al. 2003).

T2Rs were expressed in all taste buds of circumvallate and foliate papillae (Chandrashekar et al. 2000). Although T2Rs were rarely expressed in fungiform papillae, those fungiform taste buds that did express T2Rs usually had a full repertoire of different receptors, suggesting that each cell may be capable of recognizing multiple bitter tastants. This is consistent with the observation that humans are capable of recognizing diverse bitter substances but not always distinguishing among them (Brieskorn 1990). TAS2R genes do not contain introns in their protein-coding regions. Twenty five functional TAS2R genes and eight pseudo genes have been identified from human genome sequences mapped to chromosomes 5, 7 and 12 (Shi *et al.* 2003). Studies on rodents have shown that TAS2R genes are also expressed in the stomach and small intensive (Wu *et al.* 2002).

Modifiers of PTC Taste Genotype-Phenotype

Since the chance discovery of PTC trait in humans about 77 years ago (Fox 1931), it has been accepted that this ability is inherited through a single locus (Blakeslee 1932). The early studies segregated PTC/PROP tasters from nontasters on the basis of their tasting of PTC or PROP crystals or filter paper soaked in PTC/PROP solution. Later studies showed that the thresholds at which people can taste serially diluted PTC solutions (solution number 1 being the most concentrated and solution number 14 being the most diluted were distributed bimodal) the first distribution belonged to nontasters and second to tasters (Hartman1939; Harris and Kalmus 1949). Because of individual differences in PTC thresholds, the most investigators believed in its complex features and proposed that certain subject-specific environmental and cultural factors may alter the phenotype; and many explanations have been forwarded to explain the genetics of PTC thresholds (Guo and Reed 2001; Sharma 2008). Sharma et al. (2008) found that further categorization of PTC taste thresholds into nontasters and weak tasters, medium tasters, strong/super tasters was more informative in many biological situations.

[PTC Taste Gene

The phenotypic ability to taste PTC bitter is vested in the DNA sequence diversity in the TAS2R 38 gene on human chromosome 7q 35-36 (Kim *et al.* 2003; Dryana *et al.* 2003). Three residues account for the genetic variation of PTC receptors in humans: the dominant P88, A262 and V297 (Proline/Alanine/Valine) as the taster phenotype; the recessive A, V, I (Alanine/Valine/ Isoleucine) at the same positions as the nontaster phenotype. The major taster and nontaster haplotypes differ from each other by the above three amino acid substitutions and there are no premature stop codons, frameshifts, insertions, deletions, or other type of mutations (Drayna *et al.* 2003; Kim *et al.* 2003; Wooding *et al.* 2004; Kim *et al.* 2005).

Population Variations in PTC Taste perception

The ability to taste PTC/PROP has been extensively studied in human populations across continents and several anthropological significant trends have been noted. The prevalence of PTC nontaster phenotype *among Caucasian populations of Western Europe and* North America is approximately 30% (Allison and Blumberg 1959). Low frequency of nontasters is a characteristic feature of native populations of West Africa (~3%) and Americas (~ 0 to 15%) and also the Asiatic (6-23%) populations (See Guo and Reed 2001). In India, Mongoloid populations residing along the Himalayas from the western end to the eastern end tend to have frequency of non-testers less than 20%. In the plains of Punjab, Haryana, Uttar Pradesh, Bihar, the frequency of non-taster varies between 25% and 40%. Among the tribal populations of Central India, the frequency of non-taster phenotype is very high varying between 40-60% (see Singh *et al.* 1994 for references and frequency data). PTC taste blindness is so rampant in tribal populations of Central India that Sharma et al (2002) found fewer individuals having PTC taste perception threshold of 10 or more in Konds of Orissa. It is likely that this PTC taste insensitivity to bitter substances might have conferred some sort of survival advantage to these tribal populations of Central India. Many of these cultures have developed food preparation practices which help them to overcome the bitter taste of many edibles.

These broad trends are apparent, but large differences in the frequency of non-testers in different populations living in a same geographic area or same population living in different areas are also observed. These differences may be attributed to factors like founder effect, genetic drift, natural selection or different methodologies employed to asses non-taster-taster phenotypes. In many studies nontasters were segregated on the basis of their tasting PTC crystals, while others used bimodal distribution of detection thresholds for PTC solutions. Wooding et al. (2004) analyzed patterns of DNA sequence variation at TAS2R38 in a sample of Africans, Asians, and Europeans. They *found nucleotide diversity at TAS2R38 significantly* greater than expected. In addition, levels of differentiation at this locus was lower than average for humans (*FST=0.056* among continents), indicating that the high nucleotide diversity cannot be explained by differences among populations. As first suggested by Fisher *et al.* (1939), these patterns were interpreted by Wooding et al. (2004) as an evidence for the balancing natural selection that is being maintained in human populations. Chimpanzees and humans share variable sensitivity to PTC but the molecular basis of this variation has arisen twice independently in the two genera (Wooding *et al.* 2006).

PTC Taste, Food Preferences and Health

The ability to taste PTC has long been debated to have protective value in rejecting bitter poisonous substances (Boyd, 1950). There is now definite proof that TAS2Rs are directly involved in the interaction between mammals and their dietary sources. The dietary changes resulted in the evolution of the proteins. There was a significant change in hominid diet during human evolution (Harris 1992, Leonard 2002). The diet changed from raw food to cooked food with the invention of fire and food preparation techniques that have been mastered by different cultures for the detoxification of the poisonous substances in the food articles. Detoxification of poisonous foods that started about 800,000 years ago (Goren-Inbar *et al.* 2004) by controlled use of fire and other food processing *techniques triggered a functional selection relaxation* on TAS2R genes over the years. However, still balanced genetic polymorphism is persisting in human populations.

PTC/PROP are chemically related to the isothiocyanates and goitrins, which are naturally present in cruciferous vegetables such as cabbage, broccoli, Brussel sprouts, turnips, kale, cauliflower, mustard green (see Drewnowski and Gomez-Carneros, 2000). When these goitrogenic compounds are eaten in large amounts, these compounds interfere with iodine metabolism, producing thyroid enlargement and goiter like symptoms. Before the wide spread use of iodized salt, endemic goiter was a significant health problem in many isolated parts of the world where iodine was scarce (see Green,

1974). It has been consistently reported that the incidence of the thyroid deficiency disease is relatively rare among PTC tasters and this has been attributed to their being avoiding cruciferous vegetables (Green 1974; Drewnowski and Rock 1995). In studies, based on checklists of food names, PTC/PROP tasters have reported more food dislikes than did non-tasters (Fischer et al 1961; Fischer and Griffin 1964). Apart from green and cruciferous vegetables as reported above, PTC or PROP sensitivity has been linked to food dislikes for rhubarb, sauerkraut, beer, coffee, brown bread and various sharp cheeses (Fischer et al 1963; Fischer and Griffin 1964; Forrai and Bankovi 1984). PROP tasters have also been reported to have reduced acceptance of naringin solutions, soy products and Japanese green tea (Drewnowski *et al.* 1997; Akella *et al.*, 1997).

The persistence o PTC nontaster genotype has been explained by the advantage it provides in certain specific environmental conditions. For example, Davis (1978). linked PTC insensitivity with excessive use of coffee among certain cultures. He argued that insensitivity to bitter substances might confer a surviving advantage to the people using maize or corn based staple diet. Corn has a low tryptophan content, which is compensated by the therapeutic levels of niacin present in roasted coffee that the people consume in greater amounts. Katz (1982) has argued that many cultures have developed food preparation practices which help to overcome the low-content of niacin in their staple diet. For example, treatment of maize with an alkali solution liberates niacin from an undigested segment and improves amino acid quality of the digestible fraction of food.

A challenge to the above view point is also being raised. It is argued that despite the evidence of likes or dislikes for raw vegetables among PROP tasters, this sensitivity has not shown a very significant impact on the consumption of cruciferous vegetables (Krondl *et al.* 1983; Niewind *et al.* 1988) or on the consumption of vegetables and fruits (Mattes and Labov 1989). Moreover, raw vegetables are not preferred food in most cultures. Detoxification of food items through various cooking practices has long been practiced in all cultures. Consumer food choices are driven primarily by the demands of taste, cost, and convenience (Glanz *et al.* 1998). Aversion to vegetables and foods may come due to various other reasons like unpleasant gastrointestinal effect in some people. Cultural-specific hot and cold effects have been associated with various food articles in all cultures. Individuals also differ in their hedonic perceptions like pleasantness or unpleasantness that may result in acceptance or rejection of various food articles and beverages. In selected foods and beverages, a certain degree of bitterness is expected. In coffee, beer, and wine, bitterness is paired with a desirable attribute (Rozin 1986; Mattes 1994; Guinard *et al.* 1996). The threshold for what is or is not acceptable may vary from one person to another because individual taste response to bitter varies enormously. Inherited taste factors, compounded by sex and age, add an extra layer of complexity to the acceptance of bitter plant foods by the consumer. Doty (1986) has documented many studies showing cross-cultural/ethnic differences in taste preferences and aversions from hedonic perspectives. Bartoshuk *et al.* (1998), Mennella *et al.* (2005) and Chang *et al.* (2006) have also reported a close relationship between PTC/PROP taster status and recognition threshold for sucrose, sodium chloride and quinine. Duffy *et al.* (2004) found that greater bitterness from 3.2mm PROP was a significant predictor of greater ethanol taste intensity and less alcohol intake and these effects were separate from age and sex.

Goldstein *et al.* (2005) found that BMI was 6.2 units higher in nontaster women compared with supertaster women (29.7 vs. 23.5, respectively; $p < 0.05$) and body fatness ($p < 0.01$) and triceps skinfold thickness ($p < 0.05$) were also higher in these women. The relationship between PTC genetic polymorphism and food preferences is being investigated in this region because cruciferous vegetables are enormously consumed used in northwest India. A recently submitted dissertation for master's degree by Chaudhary (2007) under my supervision investigated these aspects in adolescent Gujjar boys. Gujjar boys showed that their likeness for raw cabbage ($r = -0.35$; <0.01), turnip ($r = -0.35$; <0.01) decreased with increase in PTC taste sensitivity; while it increased for food items tasting sweet ($r = 0.55$; <0.01), salty ($r = 0.26$; <0.01) and sour (0.19; <0.05) with increase in PTC taste sensitivity as revealed by results of Spearman rank correlation of PTC threshold score and food choices. Stature of PTC tasters was higher on an average than that of nontasters. On the contrary, nontasters had greater body fat than tasters. However, the differences between the two were not statistically significant.

PTC Taste and Susceptibility to Diseases

There are a number of studies in the literature on the existence of associations or lack of associations between PTC taster status and diseases and traits. The examples include diabetes; eye diseases, gastrointestinal ulcers, thyroid disorders, schizophrenia, depression, personality characteristics, mental function,

growth variations, malignant tumours and susceptibility to diseases (see Guo and Reed 2001 for references). Some salient findings along with some recent studies done in the department of Anthropology, Panjab University would be reviewed. These associations may be explained on the basis of chance factors in some cases, but many others may be genuine and could occur either because the taster locus is in linkage disequilibrium with other loci that predispose such people to a disease or because the PTC locus has pleiotropic effect or the disease process may itself may mediate with the disease (Guo and Reed 2001; Sharma 2005; Sharma et al 2008).

In the case of nontasters, it has been hypothesized that an impaired bitter compound–tasting ability should result in a lifelong increase in exposure to a host of classically recognized coronary heart disease (CHD) risk factors (Tepper 1998; Tepper and Ullrich 2002) including a preference for fatty foods and an associated risk profile of body composition and lipid profile (Duffy *et al.* 2004). Similar risk is expected due choice of sweet and fatty foods or due to excessive use of alcohol by PTC nontasters. Individuals with PTC nontaster and taster haplotypes do show a difference in the prevalence of diabetes, but the greater prevalence of diabetes in tasters is not consistent with previously reported dietary preferences of tasters and nontasters, which would predict an association in the opposite direction (Tepper 1998; Tepper and Ullrich 2002; Duffy *et al.* 2004). On the contrary, Timpson *et al.* (2005) found no strong relationship between TAS2R38 haplotypes and either CHD traits or eating behaviour. While the study of Thompson *et al.* (2007) found confirmed relationships between genetic variation and bitter compound tasting ability in a large sample, and suggested that *TAS2R38* variation might also be associated with intermediate tasting ability. They however observed that antisocial behaviour, social class and depression showed no consistent relationship with the distribution of taste test scores. Alcoholism has been reported to be associated with PTC nontaster status in some studies (Di Carlo and Powers 1998), but not in all studies (Kranzler *et al.* 1996). Orrego *et al.* (1994) have found that PROP retards alcohol-induced liver disease.

The studies done at Panjab University, Chandigarh reveals a very curious relationship for the first time between PTC taste sensitivity and epilepsy (Sharma 2005). This study also explored the genetic susceptibility and prevalence of epilepsy in twins. Proband concordance rate in monozygotic (MZ) twins was four times higher than that in dizygotic (DZ) twins (0.67 vs. 0.17). Three of 15 (20%) affected twin kinships had epileptic first-degree relatives. These findings indicated significant underlying genetic susceptibility to epilepsy with the Holzinger's heritability estimate being 0.45. The prevalence of epilepsy was similar in MZ (45.45), DZ (45.11) twins, and their non-twin siblings (47.60). In the general population from various nationalities, the mean prevalence rate of epilepsy varied from 5 to 17 per 1000. The appreciably higher prevalence rate in twin kinships could be attributed to peculiar development factors associated with the twinning process or the intrauterine environment of mothers having tendencies to bear twins. Of the genetic markers, PTC locus seemed to be associated with the susceptibility to epilepsy. The allele frequency of non-tasters (t) seemed greater in epileptic twin kinships (0.71) than that in the general population (0.53). The frequency of non-tasters was similar in MZ and DZ twins and singletons: 27.3%, 26%, and 27.7% respectively. The PTC data on the general population was based on a sample of 278 individuals.

To explain this association, Sharma (2005) framed the hypothesis that intake of vegetables belonging to the genus *Brassica*, e.g., cabbage, cauliflower, turnip, *Brassica* leaves, increases manifold during the winter season in this region. In fact, these vegetables are eaten almost daily. The non-tasters tend to eat these vegetables in greater quantity and frequency. Because of presence of goitrogenic substances in these vegetables, non-tasters and less-sensitive tasters of this region under go greater thyroid stress. Consequently, they are more prone to neurological injuries/infections than tasters who were more buffered and had an adaptive advantage because thyroid hormone stimulates the development of neurons (brain cells) in the central nervous system and speeds up both the brain's growth rate as a whole and the differentiation of its specific centers and pathways. They further argued that the non-taster fetuses might be at greater risk of neurological damage by naturally occurring thyroid inhibitors in the diet of non-taster mother. In such a compound situation, they visualized greater risk of cerebral palsy in the non-taster developing fetuses, which made them more susceptible to epilepsy. These hypotheses were further strengthened by investigations extended to a large sample of 400 epileptic patients (200 idiopathic and 200 symptomatic) and 100 normal healthy individuals serving as controls (Pal *et al.* 2004). The PTC threshold distribution was bimodal as expected. The number of non-tasters among idiopathic epileptics (35.5%) and symptomatic epileptics (32.5%) was significantly higher

than controls (20%). The relative incidence of non-tasters in idiopathic and symptomatic epilepsies was 2.20 and 1.93 respectively. Some counter arguments that may interfere with the above hypotheses may also be forwarded here. Taste disorders are also believed to be caused by drugs used in the treatment of epilepsy. Damage to certain areas of the brain like brain stem, thalamus and cerebral cortex is also linked with taste problems. However, such factors were taken into account while forwarding these hypotheses.

Sharma *et al.* (2008) have reported another very interesting relationship between susceptibility to motion sickness (SMS) and genetic sensitivity to PTC taste. The odd ratio of motion sickness (MS) susceptible to MS non-susceptible was found to be 1:1.7 among PTC non-tasters and weak/medium-tasters, but the trend reversed among super sensitive PTC tasters in whom the odd ratio was 2:1.This evidences led to the framing of a number of hypotheses. First, alleles at TAS2R38 locus through collusion with other TAS2R genes might be affecting the neural threshold of a person that triggers a panic reaction to hostile motion. Second, TAS2R38 gene may be a sensitive genetic marker correlated with the neural sensitivity of a person that differ from individual to individual. Human sensory system processes diverse sensory inputs received from time to time as humans are exposed to various diverse postnatal experiences that include cultural, biological and environmental. As true for PTC taste sensitivity, susceptibility to motion sickness also decreases with increasing age due to habituation/acclimatization. These observations lend support to the purposed hypotheses interlinking these two separate attributes through some neurological pathways which may be genetically or biologically inter-related. Explaining the genesis of motion sickness on the basis of a threshold model, Sharma and Aparna (1997) found sensitivity to smell/bad odour, sex of an individual and equilibrium disorientation as important determinants of motion sickness. Genetic factors associated with these neurological impulses/receptors determined how a person would respond to panic situation created by a hostile motion (see Sharma *et al.* 2008).

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HISTOLOGICAL EFFECTS OF MONOCROTOPHOS ON PERINUCLEOLAR, CORTICAL ALVEOLI AND VITELLOGENIC STAGES OF OOCYTE OF *CYPRINUS CARPIO COMMUNIS* L. PRIOR TO FERTILIZATION

***M.S. Johal, Sarabjeet Kaur, and Y.K. Rawal**

Department of Zoology, Panjab University, Chandigarh -160 014

Abstract

***Cyprinus carpio communis* L.** were acclimatized in laboratory condition and seven different developmental stages of oocytes were recognized. The median lethal dose was found to be 0.38ml/L and the fish was then exposed to sub lethal concentration of 0.11ml/L of monocrotophos for 60 days. The fishes were sacrificed on 30th, 45th and 60th days of exposure by cervical dislocation and ovaries were fixed in Bouins in order to detect the histological alterations in oocyte under the effect of monocrotophos.The ovary was processed in different grades of ethanol, embedded in paraffin wax and stained with Eosin and Haematoxylin. This treatment revealed histological atrophies like comparative decrease in yolk globules and cortical alveoli on 30th, 45th and 60th days as compared to the normal fish. The vacuolization in cytoplasm was apparent in the vitellogenic stage of oocyte development. Other atrophies like decreased gonadosomatic index, granular texture of cytoplasm, increased number of atretic and wrinkled oocytes were also observed.

Key Words: *Cyprinus carpio communis* L., monocrotophos, oocyte, ultrastructure.

INTRODUCTION

The use of pesticide has increased with growing awareness about their utility in the agriculture production, post harvest technology and welfare of mankind. The pesticide contamination of water resources has affected the non-target aquatic organisms especially the fish both indirectly, through breaking the biological chains and directly producing toxic stress and chemical changes in the water quality. The pesticides even when applied in restricted areas are washed and carried away by rains and flood to water bodies altering its physicochemical properties causing poisoning, oxygen depletion and mass mortality of aquatic organisms. As ovaries perform the dual functions of producing eggs and hormones, therefore, any such change in the environment certainly effects the physiology and reproductive potential of the fishes. The pesticides are known to cause the histopathological effects on the ovary of fishes (Sahai, 1987). However, little efforts have been made in ascertaining the exact modulation and compensatory mechanism in the reproductive physiology of fishes.

In the present study, an attempt has been made to study the histological effects of monocrotophos on the different developmental stages i.e. perinucleolar, cortical alveoli and vitellogenic stages of oocyte of *Cyprinus carpio communis* L. when exposed to sub lethal dose of monocrotophos for 30 ,45 and 60 days.

MATERIAL AND METHODS

The live specimens of the *Cyprinus carpio communis* L. having the average length of 15.00 cm (±2 SD), average breadth of 9.00 cm (± 2SD) cm and average weight of 80 gm (± 5 SD) were collected from a private fish farm at Fatehgarh Sahib, Punjab and acclimatized under laboratory conditions for fifteen days. A static acute toxicity bioassay (APHA, 1998) of Hilcron 36SI, Monocrotophos (36% w/w Monocrotophos active ingredient and 64% w/w other ingredient) manufactured by Hindustan Insecticide Ltd has been performed to determine the 96 hr LC_{50} value which came out to be 0.38 ml/L of water. The physico-chemical characteristics of the water like pH, temperature, dissolved oxygen, alkalinity were recorded. To study the effects of pesticide on different developmental stages of ovary, three groups of six female fishes each were exposed to 0.11 ml/L (1/ 3rd of LC_{50} value), dose of monocrotophos during the month of August to November, 2007. The water in the control tank and water containing pesticide of the exposed fishes were changed daily during experimental period of 60 days. Fishes were fed daily with floating type food pellets (32% protein, 4% fat, 10% ash and 9% moisture) to avoid the effects of starvation.

Fishes from treated and control waters were sacrificed

*Corresponding Author : johalms45@gmail.com
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on 30th, 45th and 60th days of exposure by cervical dislocation. The ovaries were dissected out, weighed and fixed in Bouins fluid for 24 hours. After fixation samples were dehydrated in series of ethanol, embedded in paraffin wax, sectioned at 4-6 μm and stained with Eosin and Haematoxylin. The sections were covered with DPX mounting medium adopting the standard histological method (Gurr, 1962).

RESULTS AND DISCUSSION

Female fish like most vertebrates, suspend meiosis in diplotene stage until ovulation.(Sathyanesan, 1961; Al-Dahan and Bhatti, 1979; Wallace and Selman, 1983). Fish oocyte growth follows a similar general pattern in most teleosts. Oogonia give rise to immature oocytes with multiple peripheral nucleoli. These perinucleolar oocytes then undergo primary vitellogenesis resulting in the accumulation of mucopolysaccharides in the cortical alveoli (Khoo, 1979). The oocyte enlarges and its zona radiata thickens as vitellogenic yolk is deposited (Deniel, 1993). The nucleolus migrates to the animal pole prior to the breakdown of nuclear membrane (Yamamoto, 1956). Hydration preceeds ovulation and the appearance of these hyaline oocytes is the indication of imminent spawning (West, 1990). The follicles collapses after the oocyte has been released to form structures called post ovulatory follicles (POFs) which are the indicators of recent spawning and are not thought to persist for a long period.

The ovaries pass through a number of developmental stages which can be identified by visual assessment of their colour, vascularization and appearance of eggs (Santurtun *et al.*, 1998). Gross examination of the paired ovary of common carp, *Cyprinus carpio communis* L. has revealed that the fish contains seven developmental stages of oocytes following the classification given by Kesteven (1960) which include oogonia stage, chromatin nucleus stage, early perinucleolar stage, cortical alveoli stage, vitellogenic stage, germinal vesicle migration stage and germinal vesicle breakdown stage. It has been observed that in contrast to the ovaries of the control group, the histological appearance of monocrotophos exposed fish were quite different.

The oocyte in the perinucleolar stage also developed vacuolization in the cytoplasm exhibiting poor staining (Fig.1D). This resulted in the shifting of centrally located nucleus which is the characteristic of this stage. The number of nucleoli at periphery of nucleus was not that prominent as in the control group (Fig.1A). Moreover, the number of nucleoli were less as observed on 30th and 45th day and least on 60th day (Figs.1B, 1C, 1D) which may be due to the poor staining tendency as described earlier. Such effects have been reported in DDT treated *Sarotherodon mossambicus* ovary by Shukla and Pandey (1985). Parallel to this, formation of vacuoles, necrosis, expansion of hepatocytes of liver of common carp was depicted on pesticide exposure (Sharma and Sharma, 1994).

The decline and dissolution of lipid yolk globules and cortical alveoli at cortical alveoli stage (Figs.1F, 1G, 1H) as well as in vitellogenic stage were marked very clearly in the present study. Similar effect was reported in the ovary of *Heteropneustes fossilis* (Hazarika and Das, 1998). The clear difference in the quantity of appearance of cortical alveoli was observed in normal and treated fishes (Figs.1E,1F,1G,1H). The decrease in the cortical alveoli with increase in exposure period of pesticide was apparent.

In the oogonia stage of oocyte development, it was found that oogonia undergo degeneration and deformities (Figs.2F, 2G) in shape. A decline in gonadosomatic indices, diameter and number of different oocyte in treated common carp along with damage to peritoneal lining (Rastogi and Kulshrestha, 1990) were observed. The vacuolization of oocytes was observed which was comparatively more on the 60th day of treatment as compared to that on 30th and 45th days of exposure of monocrotophos (Figs.2A,2B,2C,2D). Some interfollicular spaces (Fig.2G) were observed in the ovary which probably formed due to shrinkage of oocyte. These results are in conformity with the earlier observations of Srivastava and Srivastava (1994) on *Heteropneustes fossilis*.

The non ovulated mature eggs degenerate in ovary. Degeneration process of the ovarian oocytes and their resorption into the system is widely known as Follicular Atresia. In Teleosteon species occurrence of atretic oocytes is a common phenomenon of prespawning, spawning and post spawning ovaries (Guraya *et al*, 1975; Guraya 1986, 1993). On the other hand it has been found that environmental stress (Kling, 1982) and temperature are main causes of follicular atresia. Monocrotophos induced toxic stress resulting in follicular atresia (Fig.2F) was also detected in common carp ovaries.

In the vitellogenic stage, increase in vacuolization and dissolution of yolk granules occurred with the increase in period of exposure which was maximum on 60th day of monocrotophos treatment (Figs.2B, 2C, 2D). This is somehow related to the decline in lipid concentration in liver of the fish. The elevated level of cholesterol in ovary

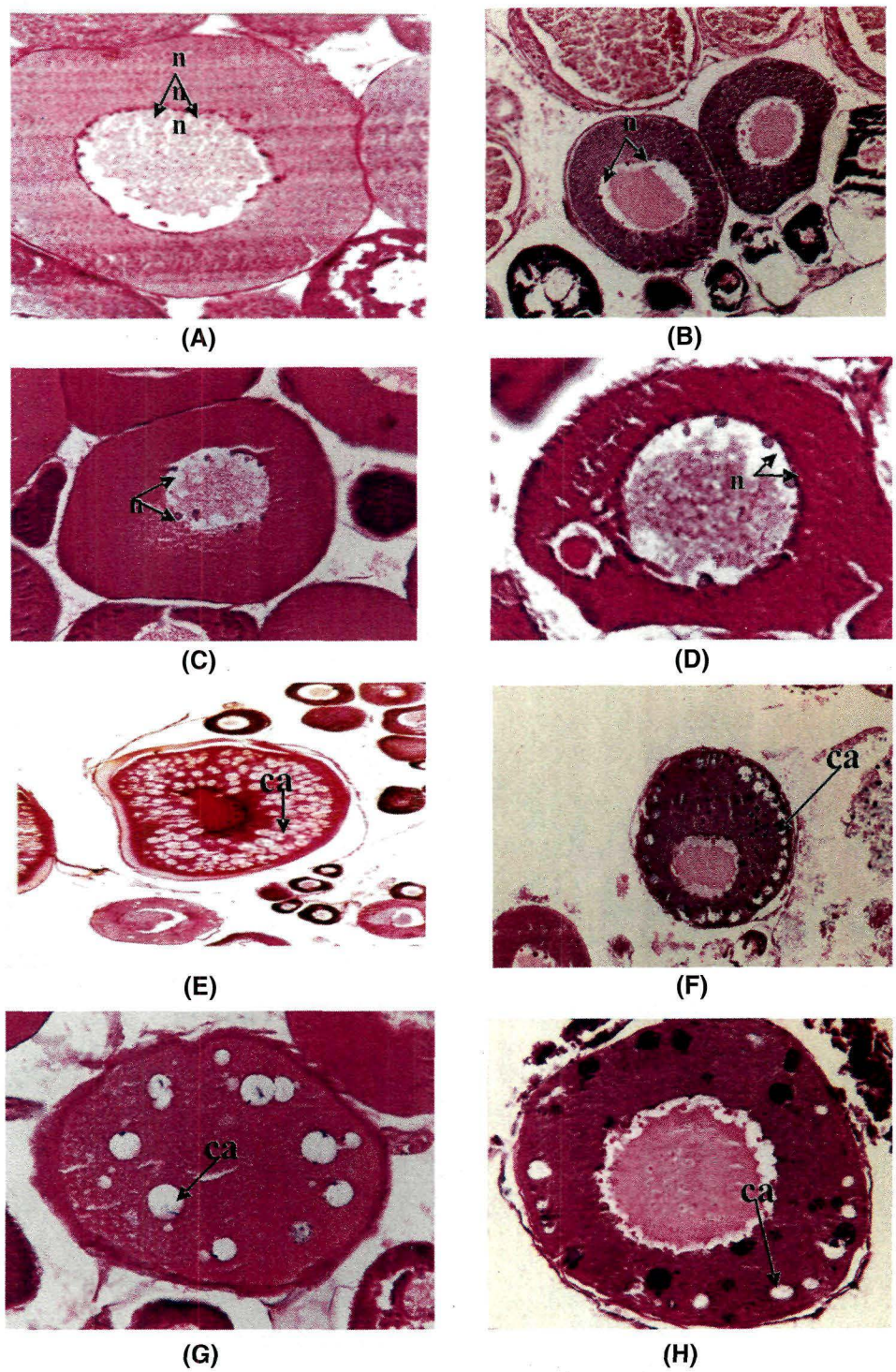

Fig.1: (A) 40X, Normal perinucleolar stage (B) 10X, Perinucleolar stage on 30th day showing lesser nucleoli (C) 40X Perinuclear stage on 45th day showing few nucleoli (D)40X Perinucleolar stage on 60th day showing decreased appearance of nucleoli and slight vacuolization (E) 20X Normal cortical alveoli stage (F) 20X Less cortical alveoli on 30th day (G) 40X Lesser cortical alveoli on 45th day(H) Few cortical alveoli on 60th day. ca-corticalalveoli.,n-nucleoli.,o-oocyte., v-vacuole.

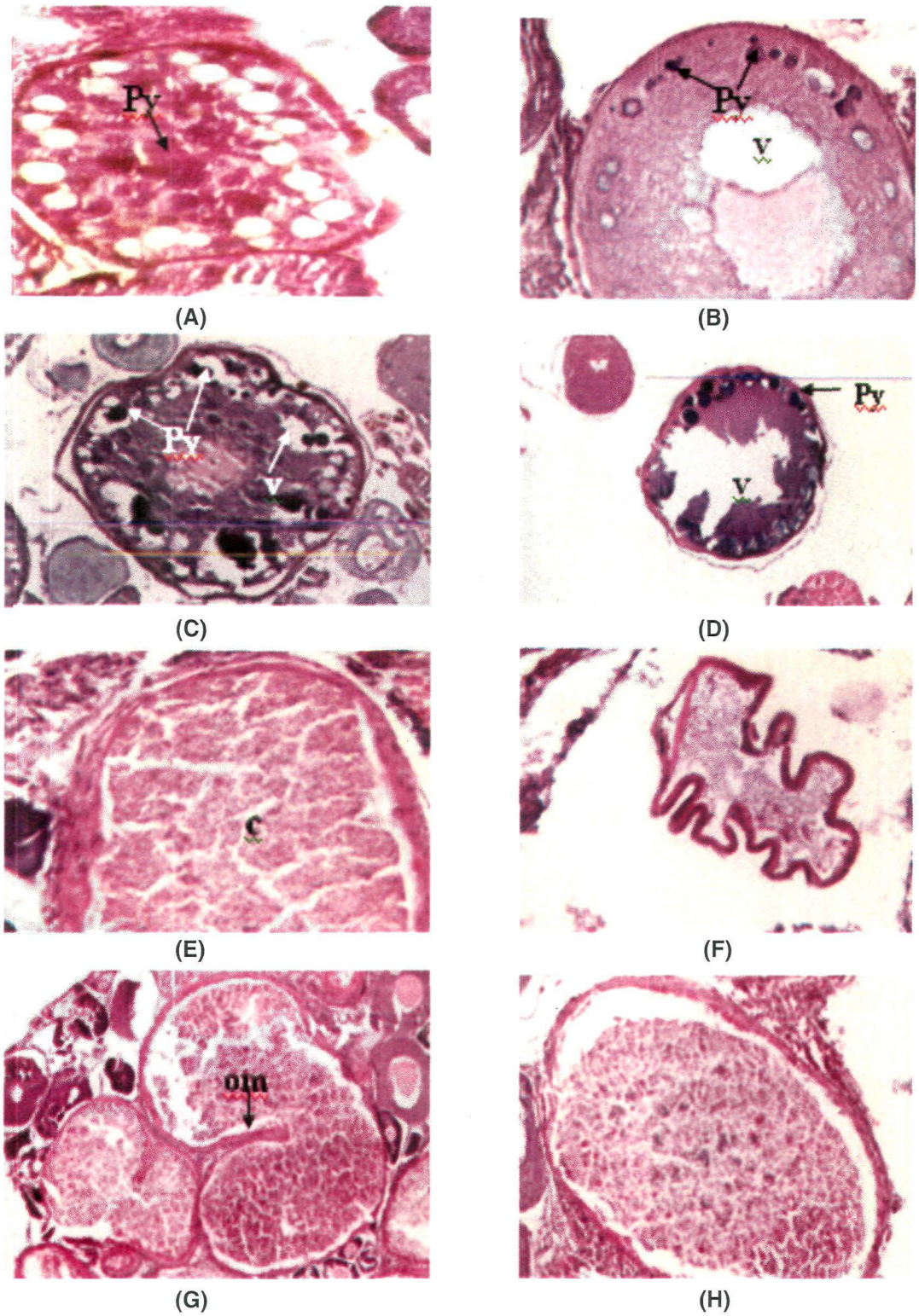

Fig.2: (A) 20X Normal vitellogenic stage (B) 20X Vitellogenic stage on 30th day showing vacuolization and decreased protein yolk granules (C)20X Increase in vacuolization with decreased protein yolk on 45th day (D)20X Very less protein yolk and large vacuole on 60th day (E) 40x Granular texture of cytoplasm on 30th day(F) 40X Degenerating oocyte on 60th day (G) 10X Dissolution of oocyte wall on 60th day (H) 20X Shrinkage of ooplasm forming gap near membraneon 45th day. v-vacuole.,c-cytoplasm.,om-oocyte membrane., py-protein., v-vacuole

in response to pesticide apparently reflects the reduced rate of its utilization for steroid synthesis in ovary (Singh and Singh, 1980). Due to increase in cholesterol level, a decrease in ovarian activites and total gonodotrophin concentration in *Heteropneustes fossilis* has been reported earlier (Singh and Singh, 1978a, 1979). Pesticides induce decline in liver lipid Synthesis (Singh and Singh 1978b; Singh and Singh, 1980; Murty and Devi, 1982). This is associated with decreased production of NADPH due to the decreased activity of glucose-6-phosphate dehydrogenase (G-6-PD) (Singh and Sahai, 1985). An inhibition of activity of G-6-PD has also been reported in *Cyprinus carpio* following exposure to carbetex (Dragomirescu *et al,* 1975).

The dissolution of the oocyte wall was observed in different stages of development which was almost the same in the ovary upon exposure to 30th, 45th, and 60th days of exposure (Fig.2G), whereas, the control group showed clear demarcation of theca layer, zona radiata and granulosa in these stages.

In the germinal vesicle migration stage there were deformities in the shape of oocytes at all intervals of exposure period.

It is also observed that the appearance of gap near the membrane (Fig.2H), deformed atretic oocytes (Fig.2F) and appearance of granular texture of cytoplasm (Fig.2E) in the treated fishes was apparent.

Generally the first type of yolk inclusion to accumulate in the developing oocyte is lipid yolk, in form of distinct lipid droplets, marking start of endogenous vitellogenesis (Shackley and King, 1977). In the present study the protein yolk accumulation occur after and concomitant to lipid yolk accumulation (Fig. 2E). The protein yolk is exogenous in origin, the protein yolk precursor having been identified as vitellogenin (Wallace, 1978). The hepatically derived vitellogenin is specifically sequestered by developing oocytes under gonadotrophic control (Wallace and Selman, 1983). Thus, present finding of reduced protein yolk globules (Fig. 2D) in vitellogenic stage of oocyte in ovary, reduced vittellogenin in blood plasma and gonadotrophic hormones are all interrelated to each other.

Most interesting feature of present study is the reduction in enzymatic parameters, hormones and proteins required for oogenesis which might be responsible for the observed atrophies. Gonadal changes are regulated by varied titer of gonadotrophic hormone and the atresia of follicles is due to lack of sufficient endogenous gonadotrophin as growth of follicle is principally dependent on the level of gonadotrophin. There is a strong evidence that pesticide effects the functioning of steroid enzyme system in the gonads of *Cyprinus carpio* (Kapur *et al.*, 1978).

Significant observations in present study are severe damage to peritoneal lining; vacuolization of cytoplasm of oocyte; damage to yolk vesicles in maturing oocytes; disintegration of cortical alveoli and yolk globules in mature oocytes in the developmental stages of oocyte of *Cyprinus carpio communis* L. on exposure to monocrotophos.

The oocyte in the perinucleolar stage developed poor staining tendency due to vacuolization leading to decreased appearance of nucleoli. The appearance of the cortical alveoli and vitellogenic yolk decreased in the oocyte with the increase in the exposure period of monocrotophos.The deformities in oocyte shape, dissolution of oocyte wall, wrinkled oocytes, granular texture of cytoplasm were other atrophies apparent upon exposure to monocrotophos. Thus, gonadotoxic impact of monocrotophos induced deleterious changes on ovaries of common carp, which certainly affect the fertility and productivity of the fish population.

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PROTEIN REQUIREMENTS OF INDIAN MAGUR, *CLARIAS BATRACHUS* FINGERLINGS BY USING PROCESSED SOYBEAN AS THE MAIN PROTEIN SOURCE

Meenakshi Jindal

Department of Zoology and Aquaculture, CCS H. A. U., Hisar – 125 004

Abstract

Ten diets with varying protein levels (35, 38, 40, 42 and 45%) were formulated by using fishmeal (FM) and processed soybean (PS) as the major protein sources. *Clarias batrachus* fingerlings were fed twice daily for 100 days @ 5% body weight. Studies have revealed that growth performance (in terms of live weight gain, specific growth rate and growth per cent gain), nutrient retention (protein efficiency ratio, apparent protein digestibility), accumulation of carcass protein and fat were significantly ($P<0.05$) high in the groups fed on diet containing 40.25% protein, irrespective of protein source, however, the values were high for the diets containing PS as the protein source. Further, the fingerlings fed on PS based diet having 40.25% protein also excreted significantly low ($P<0.05$) ammonical nitrogen (NH_4-N) and ortho-phosphate (o-PO_4) in the treated water in comparison with the fingerlings fed on FM based diets. Thus, it is evident from these studies, that PS based diet at 40.25% protein level appears to be optimum for maximizing the growth of *C. batrachus.*

Key words: ammonical nitrogen, fishmeal, growth, protein levels, ortho-phosphate.

INTRODUCTION

Fish nutrition has become one of the most important components for aquaculture development today. Food and feeding costs generally constituting the highest operating costs of aquaculture enterprises. It is no surprise that fishmeal (FM) is the most expensive protein source in aquaculture feeds. Therefore, animal proteins can be replaced by plant proteins in catfish feeds without affecting growth and feed efficiency (Jindal, 2007). Many plant proteins such as soybean, canola, moong, guar etc. offer considerable promise in this regard owing to their low prices and market availability. Due to worldwide dominance of soybean and its appreciation as quality protein, several workers have attempted to replace FM with soybean in diets formulated for several fish species (Jindal *et al.*, 2007a, b; Robinson and Menghe, 2007, Jindal *et al.*, 2008a, b, c).

Some of the advantages regarding Indian magur are that its flesh is tasty, and has less spines. It has medicinal and therapeutic value, as it has iron, copper, vitamin B_{12} and unsaturated fatty acids in sufficient amount, which helps in making blood. Moreover, its flesh is more digestible, for which it is prescribed to patients during convalescence and to lactating mothers. It can be cultured in small and shallow ponds (where carp culture is not possible), as it can gulp atmospheric air due to presence of air breathing organs. Further, it can be cultured in monoculture or in polyculture with carps, due to its non-piscivorous nature. It fetch high market price than carps. Keeping these points in view, the experiments were performed in this catfish, *Clarias batrachus.*

Fish do not have a specific protein requirement but rather a definite requirement for essential amino acids that comprise proteins. Keeping in view the essentials of a balanced diet, the present investigation was designed to provide some information on growth responses, digestibility and nutrient retention in the fingerlings when fed on a diet containing 5 different levels of proteins obtained through the incorporation of two protein sources such as 1. Processed soybean (plant origin) used as the main protein source 2. Fishmeal (animal origin) used as the reference protein source. Knowledge of protein and energy requirements is useful for obtaining optimum growth. Since water pollution is another important and limiting factor, which affects growth and survival of a species, therefore, the effects of diets on post prandial diurnal excretory patterns of ammonical nitrogen (NH_4-N) and ortho-phosphate (o-PO_4) in the treated water was also studied.

MATERIAL AND METHODS

Preparation of Experimental Feed

Groundnut oil cake, rice bran, fishmeal and soybean

*Corresponding Author : mypshya@rediffmail.com
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seeds were procured from the local market of Hisar. However, the raw soybean contains many anti-nutritional factors (ANFs) especially lectin, phytohaemoglutinin, anti-vitamins and protease (trypsin) inhibitors, which interfere with appetite, absorption and metabolism. Therefore, before incorporating in diets soybean seeds were heat processed (121°C, 15 lb for half an hour) to remove ANFs (Garg *et al.*, 2002).

All the ingredients were thoroughly ground. The proximate composition of all the ingredients was done following AOAC (2000) prior to the preparation of diets (Table 1). Ten different diets (diets 1-5, Fishmeal, FM based; diets 6-10, processed soybean, PS based) were formulated with varying protein levels of 35, 38, 40, 42 and 45%. The ingredient composition and proximate analysis of all the ingredients is presented in Table 2.

Experimental Design

Fingerlings of *C. batrachus* were obtained from Sultan Singh Fish Seed Farm, Nilokheri, Haryana, India. After initial acclimatization in the laboratory, the fingerlings (mean weight 5.21 ± 0.09g) were randomly distributed @ 10 fish per aquaria (30L capacity) in replicates of two for each dietary treatment. Aquaria were kept in the Fish Laboratory, Department of Zoology and Aquaculture, CCS, HAU, Hisar, where the temperature was maintained at 25 to 28°C with lighting schedule of 12 hr. dark and 12hr. light. Fingerlings were fed twice daily at 9:00 a.m. and 4:00 p.m. @ 5% body weight per day for the whole experimental duration of 100 days. Fish were bulk weighed at every 20th day interval and the feeding rates were adjusted accordingly. Fish were exposed to their respective diet for 4 hr. during each ration, thereafter; the uneaten feed was siphoned out, stored and dried separately for calculating the daily feed consumption. The faecal matter voided by the fish was also collected from each aquaria separately and dried at 60°C for subsequent determination of digestibility (Spyridakis *et al.*,1989). At the termination of experiment, fish from all the treatments were weighed individually and processed for carcass composition.

ANALYTICAL TECHNIQUES

The feed ingredients, experimental diets, faecal samples

Table 1: Proximate analysis (% dry weight basis) of the ingredients.

Ingredients	Proximate composition (%)					
	Crude Protein	Crude Fat	Crude Fiber	Total Ash	Nitrogen Free Extract	Gross Energy (KJg^{-1})
Groundnut Oil Cake (GNOC)	35.266 ± 0.005	6.250 ± 0.003	6.000 ± 0.005	7.000 ± 0.000	45.496 ± 0.006	18.607 ± 0.003
Rice Bran (RB)	14.100 ± 0.005	10.066 ± 0.005	11.003 ± 0.005	20.556 ± 0.003	44.440 ± 0.005	14.906 ± 0.007
Fish Meal (FM)	42.926 ± 0.002	10.996 ± 0.003	3.493 ± 0.003	29.653 ± 0.003	12.930 ± 0.001	16.713 ± 0.000
Processed Soybean* (HPS)	43.733 ± 0.008	25.603 ± 0.000	4.496 ± 0.003	3.796 ± 0.000	22.370 ± 0.001	24.298 ± 0.001

* Raw soybeans were hydrothermically processed in an autoclave at 121°C at 15 lbs for 30 min. to remove anti-nutritional factors (ANFs) (Garg *et al.*, 2002).

All values are mean ± S.E. of means of 3 observations

Table 2: Ingredient composition and proximate analysis (% dry weight basis) of 10 compounded diets (diets 1-10) with different protein levels (35, 38, 40, 42, 45%).

	FM based diets (Protein %)					PS based diets (Protein %)				
	1 (35)	2 (38)	3(40)	4 (42)	5 (45)	6 (35)	7 (38)	8 (40)	9 (42)	10 (45)
Ingredients (%) Groundnut Oil Cake (GNOC)[a]	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	57.9
Rice Bran (RB)[b]	18.0	10.0	5.0	1	-	17.5	9.8	7.6	0.7	-
Fish Meal (FM)[c]	15.0	23.0	28.0	32.0	35.0	-	-	-	-	-
Processed Soybean (PS)[d]	-	-	-	-	-	15.5	23.2	28.4	32.3	35.1
Binder[e]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Chromic Oxide (Cr_2O_3)[f]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mineral premix and amino acids (MPA)[g]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Proximate Analysis (%) Crude Protein	35.00	38.00	40.25	42.00	45.50	35.00	38.5	40.25	42	45.5
Crude Fat	5.5	6.3	7	9	8.5	7	10.5	9.5	11	12
Crude Fiber	3.5	4	3.5	5	4.5	6.5	6	7.25	6	5
Ash	9.15	8.5	7.3	5.95	6.65	9.05	8.45	6.5	6.8	7.15
Nitrogen Free Extract (NFE)	46.85	43.2	42.95	38.05	34.85	42.45	36.55	36.5	35	30.35
Gross Energy KJg^{-1}	18.48	18.88	19.65	20.01	20.09	18.32	19.52	19.53	20.28	20.71

a, b – used as basic feed ingredients
c - used as the reference protein source of animal origin
d - used as the main protein source of plant origin
e - used is Carboxyl methyl cellulose to make the diets water stable
f - used as an external indigestible marker for estimating apparent digestibility.
g - added to supplement the diets with minerals and amino acids. Each Kg contains Copper - 312mg; Cobalt - 45mg; Magnesium - 2.114g; Iron -979mg; Zinc - 2.13g; Iodine 156mg; DL-Methionine - 1.92g; L-lysine mono hydrochloride - 4.4g; Calcium 30% and Phosphorous - 8.25%

and fish carcass (initial and final) were analysed (AOAC, 2000). Chromide oxide levels in the diets as well as in the faecal samples were estimated spectrophotometrically (Furukawa and Tsukhara ,1966).

Live weight gain (g), growth percent gain, specific growth rate (SGR, $\%d^{-1}$), protein efficiency ratio (PER) and gross conversion efficiency (GCE) were calculated using standard methods (Steffens,1989). Apparent nutrient digestibility (APD) of the diets were calculated (Cho *et al.*, 1982) as follows:

$$APD = 100 - \frac{100 \times \%\ Cr_2O_3 \text{ in diet} \times \%\ \text{nutrient in faeces}}{\%\ Cr_2O_3 \text{ in faeces} \times \%\ \text{nutrient in diet}}$$

The energy contents of the diets and fish were calculated using the average caloric conversion factors of 0.3954, 0.1715 and 0.2364 KJg^{-1} for lipid, carbohydrate and protein respectively (Henken *et al.*, 1986).

Water Quality Parameters

Water samples for the determination of water quality parameters were obtained in replicates from each treatment at 20 days interval. Water temperature (°C) was recorded daily using digital thermometer and pH, conductivity and dissolved oxygen were monitored using multiline F-set-3 (E. Merck Ltd., Germany). All other parameters were determined (APHA, 1998).

At the end of feeding trials, water samples from each aquarium were collected at 2h interval for the estimation of excretory levels of ammonical nitrogen (NH_4-N) and ortho-phosphate (o-PO_4) following APHA (1998) and calculated as follows:

$$\text{Ammonical nitrogen excretion } (mgg^{-1}BWd^{-1}) = \frac{NH_4\text{-N } (mgl^{-1}) \text{ in water}}{\text{fish biomass (g) per L of water}}$$

$$\text{Ortho-phosphate production } (mgg^{-1}BWd^{-1}) = \frac{\text{o-}PO_4 \ (mgl^{-1}) \text{ in water}}{\text{fish biomass (g) per L of water}}$$

RESULTS AND DISCUSSION

Water Quality Parameters

The water quality characteristics of different aquaria stocked with *C. batrachus* fingerlings fed on different dietary protein levels (35.0 to 45.0%) based on reference FM diets (1-5) and main PS based diets (6-10) are shown in Table 3.

The data showed that DO ranged from 4.01 to 5.00 mg/l. The pH remained alkaline (7.3 to 7.8). The water temperature fluctuated between 24.5 and 26°C. Low DO values in the aquaria where the fish were fed on 40.25% dietary protein, irrespective of the protein source, clearly indicates its utilization by the growing fish. Further, DO values were found much low in aquaria where the fish were fed on diet containing PS as the main protein source. These results are in agreement with those of Kalla *et al.*, 2004 , Jindal *et al.*, 2007a ,b and Jindal, 2008a, b.

Post-prandial excretory levels of ammonical nitrogen (NH_4-N) and ortho-phosphate (o-PO4)

The excretion of NH_4-N and o-PO_4 were observed to decrease significantly ($P<0.05$) with an increase in the dietary protein level up to 40.25% (Table 3), but above this level excretion of NH_4-N and o-PO_4 increased. These observations showed that the limits of digestibility of protein in *C. batrachus* is up to 40.25% and above this level, the proteins in the diets are deaminized and are excreted as ammonia in aquaria water, which polluted the water and resulted in decreased growth of fish. These present findings are in broad agreement with those of Kalla *et al.*, 2004, Jindal *et al.*, 2007a, b and Jindal, 2008a, b,.

Further, significantly Low ($P<0.05$) values in NH_4-N excretion and daily amount of o-PO_4 production in the effluent water were clearly observed in the fish fed on diets containing protein from plant origin in comparison to those fed on diets containing FM. This finding further supports high retention of nutrients in the fish fed on plant origin protein. The use of plant protein as a mean to reduce nitrogen and phosphorous content in water has already been suggested by many workers (Garg *et al.*, 2002, Jindal and Garg 2005, Jindal *et al.*, 2007a, b and Jindal *et al* ., 2008a, b, c).

Irrespective of the protein level and source, peak values of NH_4-N excretion occurred at 8hr of post feeding (Fig. 1) and of o-PO_4 at 6hr of post feeding (Fig. 2). These peaks indicated the time at which the fish excrete NH_4-N and o-PO_4 at its maximum. These peaks also showed that when fish were fed with diets, then at start the excretion rate was low, but as the time passed out excretion started increasing up to a limit *i.e.* the peak time and after that excretion again started decreasing. These peaks also showed the time at which maximum absorption of nutrients from feed took place. These results were in agreement with those of Jindal (2007, 2008a,b), Kalla *et al.* (2004), Jindal and Garg (2005), Robinson and Menghe (2007) and Jindal *et al.* (2007 a, b).

Growth Parameters

Survival in different treatments was high and varied between 89 to 96%. Irrespective of the protein source (FM or PS), growth performance (in terms of live weight gain, specific growth rate and growth per cent gain), nutrient retention (protein efficiency ratio, apparent protein digestibility) values showed a progressive and significant ($P<0.05$) increase with each increase in the dietary protein level up to 40.25% (Table 4). With further increase in the dietary protein levels, a significant ($P<0.05$) decrease in most of the growth and digestibility parameters were observed. On the other hand, digestibility of soybean containing diet at 40.25% protein

Table 3: Water quality parameters of different aquaria stocked with *C. batrachus* fingerlings fed on FM and PS based diets at different dietary protein levels.

Parameters	FM based diets (Protein %)					PS based diets (Protein %)				
	1 (35)	2 (38)	3 (40)	4 (42)	5 (45)	6 (35)	7 (38)	8 (40)	9 (42)	10 (45)
Dissolved oxygen (DO) mgl^{-1}	4.400 ± 0.115	4.200 ± 0.125	4.166 ± 0.006	4.633 ± 0.008	5.000 ± 0.115	4.363 ± 0.008	4.189 ± 0.115	4. 011 ± 0.115	4.600 ± 0.118	4.900 ± 0.120
pH	7.8 ± 0.003	7.6 ± 0.002	7.5 ± 0.003	7.3 ± 0.000	7.3 ± 0.003	7.4 ± 0.003	7.6 ± 0.002	7.7 ± 0.003	7.4 ± 0.003	7.6 ± 0.003
Water temperature (°C)	25.0 ± 0.000	25.6 ± 0.000	24.5 ± 0.000	25.0 ± 0.000	25.0 ± 0.000	25.3 ± 0.166	25.3 ± 0.166	25.5 ± 0.166	25.8 ± 0.166	25.5 ± 0.288
Conductivity micro (μ) mhos cm^{-1}	0.500 ± 0.001	0.540 ± 0.002	0.480 ± 0.001	0.493 ± 0.000	0.513 ± 0.001	0.493 ± 0.001	0.453 ± 0.000	0.550 ± 0.002	0.430 ± 0.001	0.540 ± 0.002
Free Carbon dioxide (Free CO_2) mgl^{-1}	16.40 ± 0.115	16.43 ± 0.008	16.86 ± 0.120	17.20 ± 0.115	17.03 ± 0.003	17.40 ± 0.115	16.20 ± 0.105	16.60 ± 0.120	17.40 ± 0.115	17.60 ± 0.119
Total alkalinity (mgl^{-1})	220.00 ± 5.773	212.00 ± 2.309	207.33 ± 1.764	247.33 ± 3.712	246.66 ± 1.764	252.66 ± 1.764	244.66 ± 2.404	229.33 ± 2.906	214.00 ± 2.309	225.33 ± 2.906
Total hardness (mgl^{-1})	219.33 ± 1.764	212.00 ± 1.155	226.66 ± 1.764	224.00 ± 2.309	249.33 ± 4.807	226.66 ± 2.404	215.33 ± 1.764	254.66 ± 2.404	236.00 ± 2.309	210.00 ± 2.309
Ammonical nitrogen (NH_4-N) excretion (mg/100BW of fish)	0.724 ± 0.000	0.632 ± 0.001	0.316 ± 0.000	0.499 ± 0.001	0.406 ± 0.002	0.708 ± 0.000	0.569 ± 0.001	0.245 ± 0.002	0.361 ± 0.001	0.392 ± 0.000
Ortho-phosphate (o-PO_4) excretion (mg/100BW of fish)	0.573 ± 0.002	0.509 ± 0.001	0.406 ± 0.002	0.423 ± 0.001	0.474 ± 0.001	0.522 ± 0.000	0.454 ± 0.000	0.383 ± 0.003	0.404 ± 0.001	0.434 ± 0.002

* - All values are mean of ± S.E. of mean of 3 observations

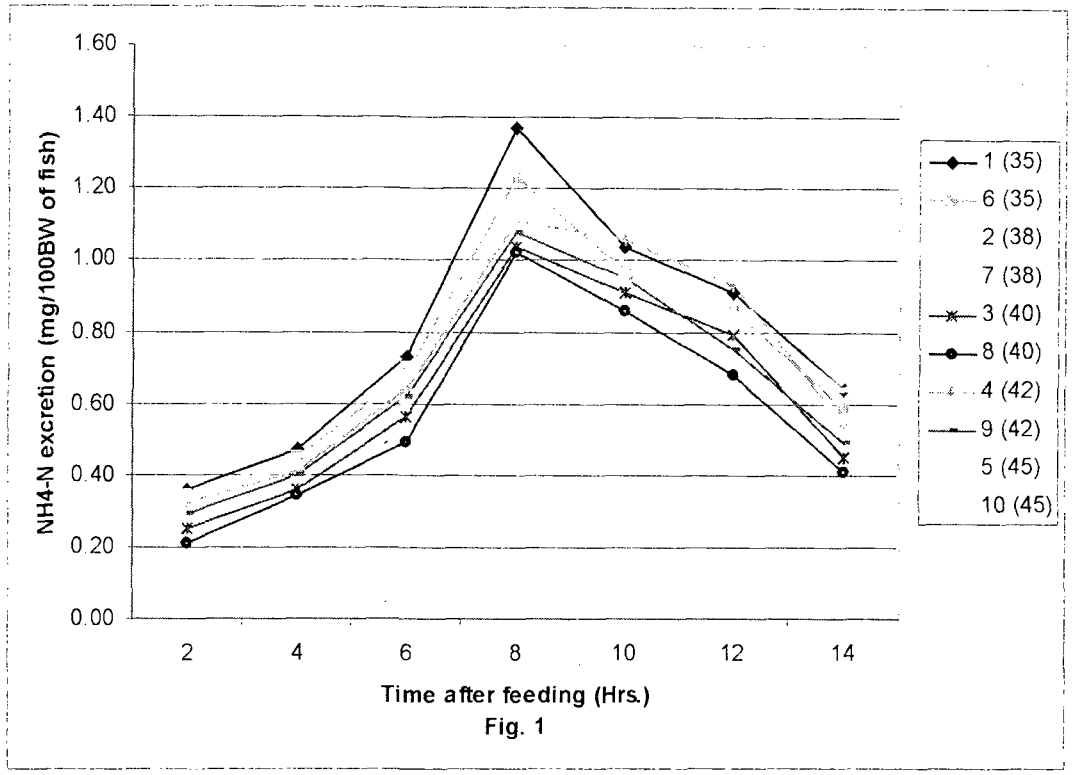

Fig. 1: Comparative diurnal pattern of Ammonical nitrogen (NH_4-N) excretion in treated waters of aquaria stocked with *C. batrachus* fed on diets 1 - 10 (1-5 -FM based & 6-10 processed soybean based)

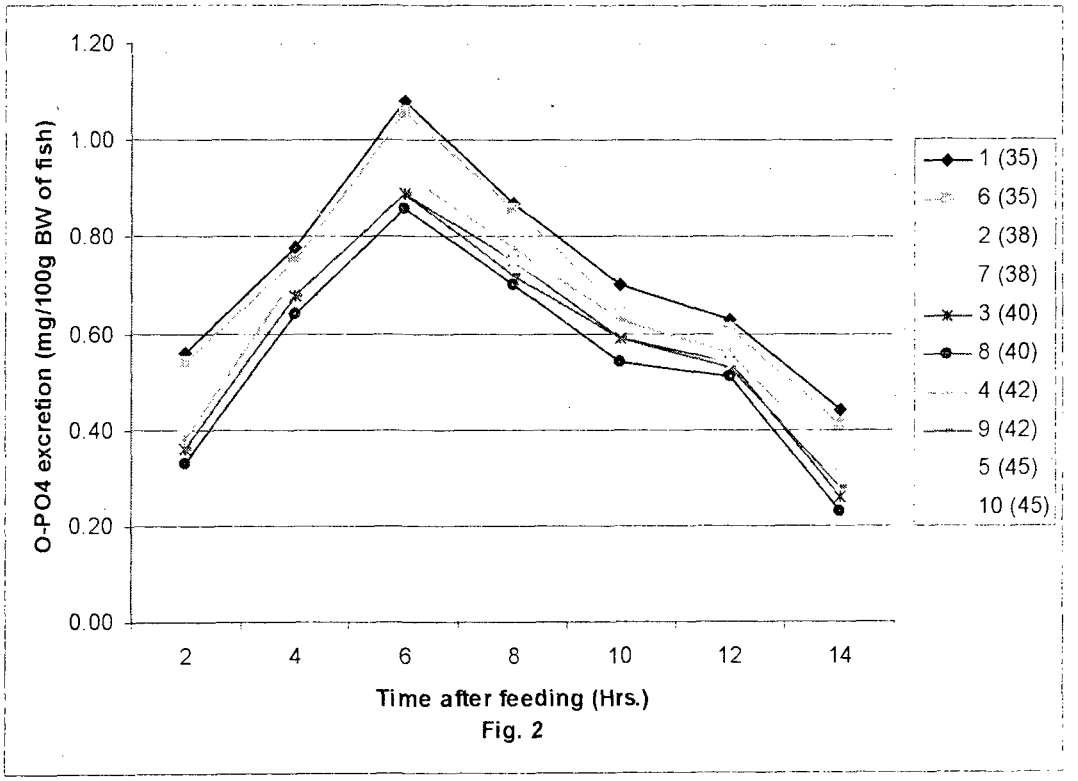

Fig. 2: *Comparative diurnal pattern of Ortho-phosphate (o-PO_4) excretion in treated waters of aquaria stocked with C. batrachus fed on diets 1 - 10 (1-5 -FM based & 6-10 processed soybean based)*

level was 87.58% and FCR was 2.8, while the digestibility of FM containing diet at 40.25% was 84.54% with concurrent FCR values of 2.9. These results indicate that *C. batrachus* appears to be better equipped to digest and absorb nutrients from plant feedstuffs.

The present findings on protein levels in practical diets for *C. batrachus* are in broad agreement with those reported for *Channa punctatus* (Jindal and Garg, 2005, Jindal *et al.*, 2007a, b and Jindal *et al.*, 2008a). Growth depression in response to high dietary protein levels has also been observed in *Mugil cephalus* (Kalla *et al.*, 2004); *C. mrigala* (Jose *et al* ., 2006) and *H. fossilis* (Jindal ,2008b).

Protein levels above optimum requirements resulted in decreased growth rates because of reduction in dietary energy available for growth due to energy spent for deamination and excretion of excess absorbed amino acids (Jindal, 2008a, b) or due to the inhibitory effects of high dietary protein on the production / release of digestive enzymes such as protease etc. (Jindal, 2007).

A comparative live weight gain (g) in different dietary treatments (1-10) having dietary protein levels (35-45%) are shown in Fig. 3.

Proximate Carcass Composition

The data on carcass composition (Table 5) indicates that the fish fed on PS based diets had high retention of protein, fat and energy in comparison to the fish fed on FM based diets at similar protein levels. Further, accumulation of carcass protein paralleled with that of weight gain, indicated that growth was mainly due to the accumulation of protein. These results are in agreement with those of Jindal and Garg (2005) and Jindal *et al* . (2007a, b) and Jindal (2008a, b).

The growth and digestibility parameters were found to be negatively correlated with NH_4-N excretion and o-PO_4 production but, positively correlated with protein accumulation in the fish carcass (Table 6). These results are in agreement with those of Kalla *et al* . (2004), Jindal and Garg (2005), Jindal *et al.* (2007a b) and Jindal *et al* .(2008a,b, c).

CONCLUSIONS

Better performance of *C. batrachus* fingerlings when fed on PS based diets in comparison to the fish fed on FM based diets, may indicated that heat treatment reduced ANFs in soybean and also profoundly improved the

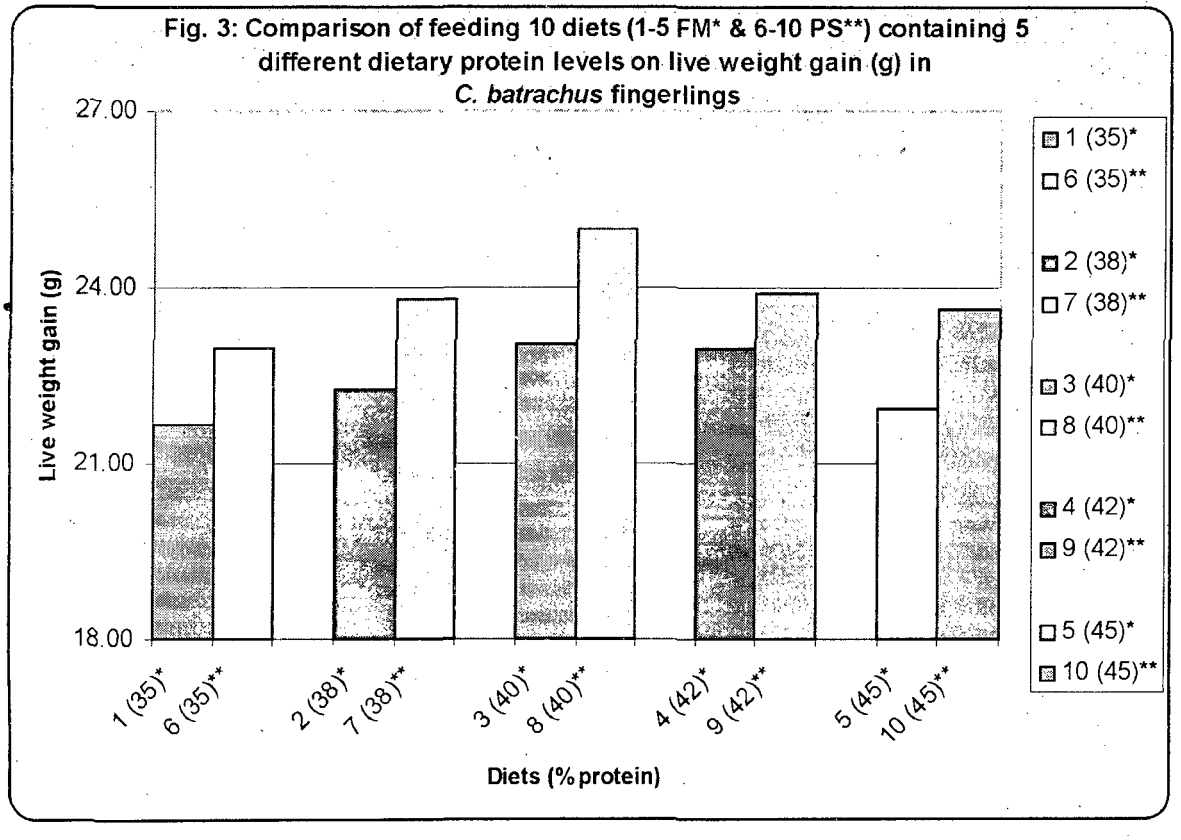

Fig. 3: Comparison of feeding 10 diets (1-5 FM* & 6-10 PS) containing 5 different dietary protein levels on live weight gain (g) in *C. batrachus* fingerlings**

Table 4: Effect of FM and PS based diets at different five dietary protein levels on growth performance, digestibility and nutrient retention in *C. batrachus* fingerlings.

Parameters	FM based diets (Protein %)					PS based diets (Protein %)				
	1 (35)	2 (38)	3 (40)	4 (42)	5 (45)	6 (35)	7 (38)	8 (40)	9 (42)	10 (45)
Survival (%)	89	92	90	95	92	90	94	95	96	93
Live Weight gain (g)	21.675 ± 0.005	22.275 ± 0.006	23.030 ± 0.210	22.965 ± 0.265	21.945 ± 0.002	22.980 ± 0.002	23.815 ± 0.000	24.985 ± 0.505	23.885 ± 0.125	23.625 ± 0.135
Fish length gain (cm)	7.350 ± 0.005	7.400 ± 0.000	7.900 ± 0.100	7.450 ± 0.150	7.700 ± 0.100	7.550 ± 0.005	7.700 ± 0.000	8.200 ± 0.100	7.900 ± 0.000	8.000 ± 0.000
Growth % gain in BW	403.74 ± 4.394	413.89 ± 2.024	440.845 ± 12.930	409.576 ± 20.314	411.331 ± 9.942	408.19 ± 9.674	421.190 ± 4.462	459.243 ± 3.294	429.315 ± 11.778	437.243 ± 8.050
Growth /day % BW	1.356 ± 0.004	1.337 ± 0.002	1.375[c] ± 0.012	1.343 ± 0.002	1.345 ± 0.001	1.347 ± 0.001	1.342 ± 0.000	1.372 ± 0.000	1.364 ± 0.001	1.393 ± 0.002
Specific growth rate SGR (% d^{-1})	0.717 ± 0.004	0.702 ± 0.002	0.733 ± 0.001	0.707 ± 0.018	0.708 ± 0.008	0.711 ± 0.001	0.706 ± 0.000	0.731 ± 0.001	0.723 ± 0.002	0.747 ± 0.000
Food Consumption/day %BW	3.969 ± 0.004	3.978 ± 0.013	4.003 ± 0.016	4.012 ± 0.003	3.999 ± 0.001	3.982 ± 0.001	4.011 ± 0.000	3.964 ± 0.001	3.983 ± 0.001	3.975 ± 0.003
Feed Conversion ratio (FCR)	2.987 ± 0.001	2.974 ± 0.015	2.911 ± 0.003	2.987 ± 0.004	2.973 ± 0.002	2.937 ± 0.000	2.900 ± 0.001	2.888 ± 0.001	2.919 ± 0.002	2.853 ± 0.000
Protein efficiency ratio (PER)	0.647 ± 0.000	0.612 ± 0.001	0.611 ± 0.003	0.558 ± 0.000	0.514 ± 0.000	0.338 ± 0.003	0.626 ± 0.001	0.637 ± 0.000	0.592 ± 0.003	0.549 ± 0.002
Gross conversion ratio (GCE)	0.342 ± 0.001	0.335 ± 0.001	0.343 ± 0.004	0.334 ± 0.000	0.336 ± 0.003	0.342 ± 0.005	0.334 ± 0.015	0.346 ± 0.001	0.342 ± 0.002	0.350 ± 0.000
Apparent protein digestibility (APD) %	81.680 ± 0.250	82.830 ± 0.008	84.545 ± 0.185	82.900 ± 0.004	80.045 ± 0.004	82.910 ± 0.005	84.455 ± 0.155	87.580 ± 0.008	86.290 ± 0.004	85.755 ± 0.003

* Mean with the same letter in the same column are not significantly (P>0.05) different
* All values are Mean ± S.E. of mean of three observations;
* - All values are mean of ± S.E. of mean of 3 observations

Table 6: Relationship between water quality parameters and growth parameters in *C. batrachus* fed on diets 1 – 10.

Diets	DO mg/l	Excretory wastes		Growth parameters				Fish carcass protein (%)
		NH_4-N (mg/100g BW of fish)	o-PO4 (mg/100g BW of fish)	Wt. gain (g)	Growth % gain in BW	FCR	APD	
1 (35 % FM)	4.40	0.72	0.57	21.67	403.74	2.98	81.68	20.03
6 (35 % PS)	4.36	0.71	0.52	22.98	408.19	2.93	82.91	20.66
2 (38 % FM)	4.20	0.63	0.51	22.27	413.89	2.97	82.83	20.76
7 (38 % PS)	4.18	0.57	0.45	23.82	421.12	2.90	84.45	21.55
3 (40 % FM)	4.16	0.32	0.41	23.03	440.84	2.91	84.54	21.28
8 (40 % PS)	4.01	0.24	0.38	24.98	459.24	2.88	87.58	22.52
4 (42 % FM)	4.63	0.49	0.42	22.96	409.57	2.98	82.90	20.41
9 (42 % PS)	4.60	0.36	0.41	23.88	429.32	2.92	86.29	21.32
5 (45 % FM)	5.0	0.41	0.47	21.94	411.33	2.97	80.04	19.85
10 (45 % PS)	4.9	0.39	0.43	23.63	437.54	2.85	85.75	20.73

quality and acceptability of feed. These results also highlight that after heat treatment, soybean can be used as an alternative dietary protein source for *C. batrachus* fingerlings and, thus, can help in replacing FM from the diets. Further, the decrease in NH_4-N excretion and o-PO_4 production in the receiving water with the use of plant proteins in feeds has important implications on the management of highly intensive fish farming system. Therefore, the use of processed soybean (at optimal dietary protein level 40.25%) is suggested as an eco-friendly dietary protein source in the diets of *C. batrachus* fingerlings. Such a replacement with plant protein will not be only cost effective, but certainly would reduce excretion of nitrogenous wastes and total organic matter, possibly also of phosphorous, and alleviate pollution problems in intensive aqua-cultural systems.

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PLANT RESOURCES OF ARUNACHAL PRADESH

R.C. Srivastava

Botanical Survey of India, P.B. 127, Itanagar - 791 111

Abstract

The paper throws light on the plant resources of Arunachal Pradesh. It provides an account of the ,environmental conditions, dominant types of vegetation, medicinal plants, primitive taxa, endangered taxa, endemic taxa, crops, oil-yielding trees, ornamental plants,plants of ethnobotanical importance and other economically important plants.The conservation strategies have also been discussed.

Key words: Plants, Resources, endemic, endangered,medicinal, ethnobotany,Arunachal Pradesh.

INTRODUCTION:

The erstwhile 'NEFA' (North Eastern Frontier Agency) is the 24th State of the India, now known as 'ARUNACHAL PRADESH'. Spread over an area of 83743 sq km, it is situated between the geographical limits of 26° 28′ and 29° 30′ N and 90° 30′ and 97° 30′ E. It is bounded in the north by Mc-Mohan Line, in the east by China and Myanmer, in the south by Nagaland and Assam and in the west by Bhutan. It is the largest (in area) state among N.E.States. The capital town of Arunachal Pradesh , Itanagar situated at an altitude of 539 m , is located at 93° East longitude and 27° North latitude in the Lower Subansiri District and has been named after a historical fort, the "ItaFort , built in 14-15th century. Arunachal apart from having an important place in Hindu Mythology finds mention in the ancient literature , like in the "Kalika Purana" and "Mahabharata". The place is supposed to be the "Prabhu Mountains" of the Puranas. It is said that sage Parashuram washed away his sins here. This legendary place in the lower reaches of Lohit river is now a pilgrimage centre called "Parasuram Kund" where a large number of people from different walks of life come to have a holy dip on 'Makar Sankrantii' day. "Malinithan", a place in East Siang District, has rich granite sculptures belonging to 14-15th century depicting Indra on elephant 'Airavata', Suryhen chariot and 'Nandi'. According to logical legends, it is here Krishna married Rukmini.Krishna and Rukmini were welcomed here by Parvati with garlands, and Parvati thus acquired the name 'Malini' and the place subsequently named 'Malinithan'. Over 400 years old Monastery of Mahayana Buddhism is situated in Tawang District at an altitude of about 3,100 m. Built in 17th century the place is the focal point of spiritual life of the Buddhists and houses more than 500 Buddhist priests. It is also the birth place of the Dalai Lama the VIth.

The State has been divided into 16 districts viz. Upper Siang, Tawang, West Kameng, East Kameng, Lower Subansiri, Upper Subansiri, West Siang, East Siang, Upper Dibang, Lower Dibang, Lohit, Changlang, Tirap, Papumpare, Anjaw, Kurung-Kumey.

Arunachal Pradesh has generally a rugged terrain characterized by hill ridges and valleys. The ridges are either parallel or in opposite direction and in between the hill ridges, wide or narrow, deep or shallow valleys exist. The hills gradually rise from south to north with an east-west orientation. The elevation ranges from 200 to 7756 m along the Tibet-China border.Based on the tribes inhabiting a particular area, Arunachal Pradesh was earlier divided into the five sub-areas viz.Aka Hills, Abor Hills, Daffla Hills,Miri Hills, and Mishmi Hills.

Physiographically the Himalayan ranges in Arunachal Pradesh can be divided into 3 divisions viz. '*Siwalik and the Foothills*' which runs along the southern border of Arunachal Pradesh along the longitudinal valleys of Kameng, Subansiri, Siang, Dibang and Lohit. The area has a more or less flat topography and gradually merges with the plains of Assam in the northern part of Brahmaputra valley; '*Lesser Himalayas*', rising from the Assam plains, the 'Siwaliks' attain a sudden rise and merge into Lesser Himalayan ranges in the north. This division has comparatively lower altitudes (upto 800 m) along river valleys. The '*Greater Himalayas*' is the dominant division of the state. Peaks reaching as high as 7,000 m and more are located in this division. Some of the known peaks of this division are : Gorichen (7,300 m) , Kangto (7,090 m), Namcha Barwa (7,756 m), Kulangri (7,544 m) and Chomo Lhari (7,344 m).

Geographically Arunachal Pradesh may be divided into three zones viz. the Sub-Himalayas, the Lesser

*Corresponding Author : rcs_bsi@yahoo.

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Himalayas and the Greater Himalayas.

The 'Sub-Himalayan Zone' consists of Neogene Mallassic Sediments (Siwalikhs) whereas the Lesser Himalayas comprises Upper Proterozoic to Lower Palaeogene shelf sediments Bomdila Group, Buxa-Miri Formations, and the Greater Himalayas has been characterized by para and ortho metamorphites and acid to intermediate igneous intrusions from Precambrian to Tertiary age (Sela Group, Siang Group, Lumla Formation etc). These zones are controlled by the distinct structural features called'Main Boundary Fault' (MBF), " Main Central Thrust" (MCT) and the "Lohit and Mishmi Thrusts".

Drainage

There are numerous streams and rivers dissecting the varied topography of Arunachal Pradesh. Main watershed system of the state is constituted by eleven rivers which are fed through rain water or through melting snow at the sources. These rivers receive water of all other substantial streams and rivulets and are finally drained to the westerly flowing Brahmaputra. Main rivers in the state are : Kameng, Subansiri, Siang, Lohit, Tirap, Dirang and their tributories include Kamlang, Sissini, Kamala, Dikrong, Ranga, Noa-Dihing and Namphuk (Buri-Dihing) ,etc. 'Digaru' a tributory of 'Lohit river' is called as 'Pagla river' for its ferocity in changing courses and causing irrrepairable damages to the villages located along its course. But after the summer, it thurns as a life giver, faciliating many economic activities.

Soil

In major parts of the state, the soil is rocky. These rocks are of Himalayan type mainly shales, schists and conglomerates. In general the soils are acidic due to heavy rainfall and are rich in humus with higher percentage of nitrogen because of dense and rich vegetational cover. These soils have thick layer of organic matter as a result of accumulation of huge quantities of rotting/ decaying plant materials. The erosion and deposition by rivers has resulted in sandy to sandy-loam, clayey soil mixed with heterogeneous matrix in some places. Sometimes soil mixed with mica is also found in river belt regions, whereas in some places the sedimentary nature of the soil can be observed. The soil in the foothill regions may be sandy or loamy or mixed, while it is clay alluvium with rich organic content in the plain areas or in the valleys.The cultivation on the hill slopes plays an important role in the rapid depletion of the organic matter from the surface layers of the soil as it is washed away due to heavy and prolonged rainfall, and as a result these slopes gradually loose their fertility.The soil in higher regions is dark brown to yellowish brown in colour and somewhat coarse textured. It may be coarse sandy loam to loamy sand while the subsoil is loamy or clayey loam. These soils are well drained and granular.

Climate

Broadly the state has cold humid climate. Based on the monsoon, there are 4 seasons which sometimes orvelap one another:- Winter (Jan. to Feb.); Premonsoon: (March to May); Monsoon ; June to Sep. and Postmonsoon : Oct. to Dec.

The average mean maximum and minimum temperature is 29.5^0 C and 17.7^0 C in subtropical humid regions and 21.4^0 C and 2.4^0 C in cold humid regions. Generally December, January and February are the coldest months whereas, July and August are the warmest months and the maximum temperature is normally $\pm$ 30^{0}C. However, sometimes the temperature rises as high as 35^0 C during summer month in the plains and broad valleys.

Average annual rainfall in the humid subtropical regions is about 2,972.7 mm while it is 2,086.9 mm in cold humid regions. East Siang and neighboring areas of Lohit receive the highest rainfall, whereas West Kameng experiences the least annual rainfall.

People & Culture

Arunachal Pradesh is the land of 26 major tribes and 110 sub-Tribes viz: Aka, Apatani, Ashings, Bagins, Boris, Digarumishmis, Minyongs, Monpas, Nishis, Noktes, Padams, Sherdukpens, Singphos, Tagins, Tangsas, Wanchos, Yobins, etc.

The *Monpas, Membas* and *Sherdukpens* of Tawang and West Kameng follow Mahayan sect of Buddhism. Their villages have richly decorated "Gompas". They breed yaks, mountain goats and practice terrace cultivation. *Khamtis* and *Singphos* of the eastern part of the state follow Hinayana sect of Buddhism and are said to have migrated from Thailand, and Myanmer long ago. *Adis, Akas, Apatanis, Bagins, Tagins, Nishis, Mijis, Tangsas*, etc., worship sun and moon god called *Donyi-Polo* and *Abo-Tani* are the believed original ancestors for most of these tribes. Nokte people practice elementary form of 'Vaishnavism'.

The different tribes inhabiting in different parts of the state lead an intricate life totally dependent on the forest resources, and all requirements ranging from food, fuel, fodder, medicine, cordage and various other domestic needs are met by the local vegetation.

People of Arunachal Pradesh are traditional craftsmen having deep aesthetic sense. They master a variety of crafts like weaving carpets, rugs, garments of vivid colours and exquisite patterns, painting, pottery, wood carving, cane and bamboo furniture, household goods, and other attractive and decorative articles.

PREVIOUS WORK

I. Floristic Survey Work :

Lt. R.Wilcox and Captain Bedford visited Mishmee Hills (Mishmi) in Arunachal Pradesh during their Survey of Assam and the neighbouring countries in view of geographic discoveries on the N.E.Frontier (1825-1828), but it was only Griffth who botanised this region for the first time. His '*Flora of Mishmee Hills*' was based on the collections made by him during October-December, 1836 following more or less the route of Wilcox and Bedford. The account deals with 900 species of flowering plants and 22 species of ferns and fern allies. Thomas J.Booth undertook horticultural explorations between 1840-1850 from Bisnath (Assam) into the hills of Daphlas (Daffla or Nyishi) situated at the south-eastern corner of Bhutan and described some *Rhododendrons* from this area. With the advent of 20th century, the plant explorations in the region gained momentum which resulted in the publication of some important floristic accounts such as, "*Botany of Abor Expedition*" by I.H.Burkill (1924-1925); "*Botanical Expedition in the Mishmi Hills*" by Kingdon Ward (1929-1931); "*Lohit Valley*" by Kingdom -Ward (1953); "*A sketch of the vegetation of Aka Hills*" by N.L.Bor (1938) etc. In 1941, K.P.Biswas published "*The Flora of Aka Hills*" based on the collections of N.L.Bor for a period of 3 years (1931-1934) which includes 1549 species of Angiosperms, 9 species of Gymnosperms and 58 species of ferns and fern allies.

The work of U.N.Kanjilal, Chief Commissioner of Assam came in to light only after his death in 1928, when P.C.Kanjilal with A.Das, C.S.Purakayastha and R.N.De of the Forest Department of Assam published the 'Flora of Assam' during 1934-1940. Fifth volume on grasses is by N.L.Bor (1940). This work is still regarded as a major floristic account so far as the flora of this region is concerned. G.K.Deka of the Forest Department of Assam who later on joined the Botanical Survey of India, explored some parts of Kameng district mainly the foothills in 1951. K.Srinivasan in early 1955 surveyed along the Rupa Valley. In the late 1955, R.S.Rao undertook plant exploration along the Rupa Valley and Dirang Valley, Apatani Valley and surrounding areas of Subansiri District. A.K. Das, Hue Tag and coworkers of R. G. University, Doimukh (Arunachal Pradesh) have also made appreciable field surveys in the state.Singh (2001)reported on agrobiodiversity in Arunachal wherein he enlisted 16 species of *Dioscorea*; 21 land races of *Oryza sativa,* 17 indigenous fruits, 8 cultivars of large cardamom, and 33 cultivars of *Citrus*.

After the establishment of the Eastern Circle of Botanical Survey of India at Shillong in December 1955, various parts of Arunachal Pradesh viz., Kameng, Subansiri, Siang, Lohit, Tirap, etc., were surveyed by R.S.Rao (1955-59, 1973: Kameng, Subansiri, Siang, Tirap); G.Panigrahi (1957-59: Kameng, Subansiri, Siang, Tirap); J.Joseph (1957-1958, 1964,1969: Kameng, Siang, Lohit); D.B.Deb (1961: Tirap); A.S.Rao (1964, 1969,1970,1973: Kameng, Siang, Lohit); A.R.K.Sastry (1964-66: Subansiri); C.L.Malhotra (1970-71: Subansiri); P.K.Hajra (1970,1973, 1976: Kameng); A. S. Chauhan, K.P. Singh & D.K. Singh (1983-1994: Namdapha) Rao & Verma (1977-79) have included specimens in their publications on monocots of N.E.India. 'Fern Flora' of the state (mainly based on collections from Changlang and Tirap) has been published by Singh & Panigrahi (2005).

S.N.Hegde and A.N. Rao, K. Haridasan, L.R. Bhuyan, S.P. Singh, G. Murtem of the Forest Department of Arunachal Pradesh also have conducted botanical surveys & exploration work. Hegde (1984), and A.N. Rao(1991-2008) have worked on Orchid Flora of the state.

After the establishment of Arunachal Pradesh Field Station unit of Botanical Survey of India at Itanagar in July 1977, R.M.Dutta, G.D.Pal, A.K.Baishya, Jagadish Lal, H.J.Chowdhery, S.K.Das, A.Pramanik, G.S.Giri, P. Chakraborty, B.K. Balodi, R.C.Srivastava, H.S.Mahapatra and Kumar Ambrish conducted survey work in some areas of Arunachal Pradesh. G. D. Pal surveyed the flora of Lower Subansiri District. B.K.Balodi worked on 'Flora of Tawang' but died before its completion.After his death, his work was compiled by H.S.Mahapatra. Mahapatra took two short field trips to Tawang and collected 250 field numbers during 2004-07. R.C.Srivastava collected 1072 f.n. from Tawang,West Siang(Mechuka,Tato,Yorlung), East Siang (Passighat), and Papumpare(Itanagar WLS) Districts during 2005-2009. Kumar Ambrish conducted seven filed tours in Upper Subansiri district and collected over 1000 species . R.K. Chowdhery made extensive collections from Upper Siang District and collected 1001 species. The herbarium specimens collected

during these field trips are deposited in ASSAM (Shillong), ARUN (Itanagar) and CAL (Howrah) herbaria of Botanical Survey of India.Preliminary work on cryptogams has been done by R.K. Gupta(2001),D.K.Singh *et al.* (2001), Singh & Bujarbarua(2001) and Bisht & Harsh(2001).

Collections of Late K.C. Sahni, H.B.Naithani and others of FRI,Dehradun who conducted survey & exploration work in Arunachal, are housed in DD herbarium at Dehradun in Uttarakhand state.

III. Ethnobotanical Survey Work :

Ethnobotany is the study of the different uses of plants in day to day life of the ethnic communities.Some appreciable attempts have made by following workers in this direction. Pal (1984) recorded 129 species of plants used by Nyishi, Apatani, Hill-Miri, Adi, etc ethnic communities of Arunachal Pradesh, out of which 112 uses are not known outside their tribal community. Pal(1992) published his observations on less- known interesting tribal uses of plants in Lower Subansiri district of Arunachal Pradesh wherein he recorded uses of 12 species of Ferns and 13 species of angiosperms.Thothatri and Pal (1987) also contributed to the ethnobotany of tribals of Subansiri district of Arunachal Pradesh.

Rawat and Chowdhury (1998) conducted studies on ethnomedicinal uses of 154 species (145 species of Angiosperms, 1 species of Gymnosperm, 7 species of Pteridophytes and one species of a fungus) in 'Nishi' and 'Apatani' ethnic communities of Arunachal Pradesh out of which 35 species were new claims of ethnomedicine: new uses and new mode of application of 60 species and recommended the scope of commercial exploitation of 8 species viz. *Abroma augusta, Centella asiatica, Eclipta prostrata, Paedaria foetida, Rubia manjith, Solanum nigrum, Terminalia belerica, Terminalia chebula*, in socio- economic development of the aborigines. Twenty -two species included in this study are used in Ayurvedic formulations as ethnomedicine.

Bhuyan (1999) recorded different uses of plants by Nishi tribe of Papumpare district. He reported the use of 86 species as medicine, 66 species as vegetable, 55 species as wild edibles, 6 species as beverage and local drink, 25 species as timber, 5 species as spice, 16 species for making furniture, 5 species for roofing, 12 species for cultural articles, 20 species as fuel, 23 species as fodder, 11 species in rituals, 1 species in magico-religious belief, 12 species as mythological and folklore, 10 species for making ornaments and 18 species for miscellaneous purposes. According to him, in addition to commonly used plants, the plants used by the local people living in different areas are : *Coptis teeta, Aconitum ferox, Podophyllum hexandrum, Panax pseudoginseng, Bergenia spp., Crassocephalum crepidioides, Clerodendrum colebrookianum, Solanum khasianum, S. torvum, Urena lobata, Houttuynia cordata* and *Musa* spp. as medicine; *Eleusine coracana, Oryza sativa, Zea mays and Saurauia roxburghii* as beverage/ drink;. *Terminalia myriocarpa, Morus laevigata, Michelia champaca, Phoebe goalparensis, Dipterocarpus macrocarpus, Pinus wallichiana,P. roxburghii, P. merkusii, Quercus rex, Gmelina arborea, Duabanga grandiflora* etc as timber ; *Illicium griffithii, Allium hookeri, Houttuynia cordata, Mentha arvensis,* etc as spices; canes,bamboos *(Bambusa tulda, B. pallida), Morus laevigata, Michelia champaca, Terminalia myriocarpa, Duabanga grandiflora, Pinus wallichiana, P. roxburghii, Phoebe goalparensis* for making furniture; *Clerodendrum colebrookianum, Zanthoxylum oxyphyllum, Z. armatum, Polygonum posumbu, P. perfoliatum, Pogostemon benghalensis, Solanum torvum, S. nigrum, Colocasia spp, Atylosia goensis, Artemisia indica, Amaranthus caudatus, A. viridis, Diplazium esculentum, Sarchochl amys pulcherrima, Eryngium foetidum* as vegetable. *Antidesma acuminata, Baccaurea sapida, Mangifera sylvatica, Polygonum chinense, Canes(fruits), Areca catechu, Garcinia cowa, G. pedunculata, Elaeocarpus floribundus, Citrus sp. Terminalia citrina, Dillenia indica, Madhuca butyraceoides* etc. are eaten. *Eleusine coracana and species of Cyathea (C.gigantea*)etc. are sources of food. *Imperata cylindrica, Livistona jenkinsiana, Saccharum sponteneum, Themeda villosa, Phyllostachys assamicus,* etc. are used for roofing houses. *Calamus tenuis, C. flagellum, C. floribundus, C. erectus, C. leptospadix. Daemonorops jenkinsiana, Bambusa tulda, B. pallida, Pinus wallichiana, P. roxburghii* etc. are used as cultural materials. . Leaves of bamboos, grasses, *Bauhinia purpurea, Eleusine coracana, Ficus dumosa, F. hispida, Themeda villosa,* species of *Musa, Saccharum, Thysanolaena, Carex, Oryza,* etc are used as fodder. *Calamus (3-4 species), Quercus rex, Q. lamellosa, Arundina graminifolia, Elaeocarpus sphaericus, Rhododendron sp., Pinus sp., Tsuga dumosa, Phlogopteris sp., Entada sp.*, etc are used in ritual/folklore/ mythological ceremonies. *Calamus erectus, C. tenuis, C. leptospadix, Daemonorops jenkinsiana, Bamboosa tulda, B. pallida, Dendrocalamus hamiltonii* etc are used as ornaments. *Sapindus mukorossi, Gymnocladus assamicus and*

Entada purseatha are used as detergent. Orchids, *Pinus sp., Cryptomeria japonica, Polyalthia longifolia* var. *pendula, Araucaria* spp., f,erns and other flowering plants, are used for decorative purposes. *Rubia manjith, Acacia catechu, Areca catechu, Viburnum foetidum, Eclipta prostrata* etc are used as dye. *Thysanolaena maxima and Sida rhombifolia* are used as broom.

Hui Tag and Das (2005) have reported the plants used by Hill Miri tribe in fisheries. Das & Hui Tag (2006) have reported the ethnomedicinal uses of 45 species of 'Khamti' tribe inhabiting Chongkam and Namsai circles of Lohit district.

Bisth and Murtem (1999) reported the inherited knowledge(i.e, various ways of identification, local names, taboos, recipes and indigenous methods of treating mushroom poisoning) of the people belonging to '*Hill-Miri*'(Nyishi) ethnic community about the 'Mushrooms' which are locally called as *Ende, Ende Dayak, Ambuk (Buluck), Imbuk, Hatur, Subre, Ingur,* etc. by the '*Nyishi*' people. The poisonous mushrooms are called '*Auy Hatar*' ('*Auy*' means ghost). Mushrooms collected and sold in local markets include *Auricularia auricula,Pleurotus spp.,Schizophyllum commune*, etc. These are collected from the forest, washed and then boiled with dried 'bamboo shoots' (called as '*Huyup*' or '*Hirchur*' in Nyishi) or chicken or fresh meat of wild or domesticated animals.The fungi eaten by ethnic people of Arunachal include *Auricularia auricula, Cantharllus cibaricus, Heracium ernaceus, Laetiporous sulphurus, Schzophyllum commune andSparassis crispa*.

Kohli (2001) recorded the inherited knowledge of '*Tani*', *Adi*, *Apatani* and *Nyishi* tribes of Subansiri district of Arunachal Pradesh, about 3 main substitutes for their staple food viz. Tashe (*Wallichia densiflora*), Tache (*Cyathea gigantea*) and Tabe (*Angiopteris evecta*); hunting aids viz. gum (used in bir traps) obtained from 8 species ; mild arrow poisons from '*Raring*' (*Polygonum hydropiper*), Bark of 'Ombeng – a creeper (*Zanthoxylum nitidum*) and Onger's leaves (*Z. rhetsa*); natural dyes obtained from seven species viz. stem of ' *Taming*' (*Rubia manjith*), leaves of '*Sankhi*' (*Symplocos paniculata*), leaves of '*Moru*' – a tree, bark of '*Sipon*' – a tree, bark of *Sinking Moling*, leaves of 'Sipon' – a tree, bark of Sinking Moling , leaves of *Engot* and fruits of '*Nimar*' tree. He also recorded the locally made instrument '*Tippo*' for weavging cloth and source of the yarn viz. '*Ampykokarmo*' or '*Sachcha*' seeds. The report indicates that Kohli did not get full cooperation from the local folk due to which he could not ascertain the scientific names of these plants.

In this context, it is worth mention that a well planned and time bound strategy has to be adopted for proper documentation of the inherited ethnic knowledge of all the 110 ethnic communities of Arunachal Pradesh, by involving the State Government and local people. This job has to be taken up on priority basis because after a decade or two, there may not be a single person to tell us about their ethnic knowledge.

In view of the above facts it is felt that it is the prime need of the time to establish a full- fledged multidisciplinary *Institute of Ethnobiology'* which will monitor all such ethnobiological researches and take care that such reports should be taken up seriously and the ethnic communities get their legitimate dues for sharing their ethnic knowledge which is their intellectual property.

The plants of ethnobotanical use recorded so far from Arunachal Pradesh are enlisted below. Botanical names are given in bold letters followed by vernacular names and uses by ethnic community.

1. **Aabacopteris lakhimpurensis** var. **hirta**

   Vern. Name: Adi: Ruhra

   Ethnic Uses: whole plant is used in worship of God during illness.

2. **Abelmoschus moschatus**

   Vern. Name: *Nyishi:* Tachusenghme

   Ethnic Uses: raw fibre from the fruits is used for weaving.

3. **Abroma augusta**

   Vern. Names: *Adi-* Yadukh; *Nyishi-* Yokhung

   Ethnic Uses: root-juice taken to increase appetite by *Nyishi* people. Decoction of stem bark is given twice a day for days in dysentery and vomitting by *Adi* and *Nyishi.*

4. **Abrus precatorius**

   Vern. Name: Nyishi-Raho

   Ethnic Uses: leaf and root-decoction is taken as abortifacient.

5. **Acacia concinna**

   Vern. Name : *Adi:* Riji

   Ethnic Uses : paste of pounded stem is thrown into stream to stupefy the fish which float up,facilitating an easy catch.

6. Acorus calamus

Vern. Name: Apatani: Kilatolyo

Ethnic Uses : paste of rhizome is applied on dislocated and swollen bones; also applied on wounds for quick healing.

7. Adhatoda zeylanica

Ethnic Uses: decoction of leaves and roots is used for speedy remedy of cough and cold, and bronchial trouble by *Nyishi* tribe.

8. Ageratum conyzoides

Vern. Names: *Nyishi & Apatani*: Pasho; Pasu-payou; *Adi*-Yabum

Ethnic Uses: Leaves are used by *Nyishi*people on swollen parts to relieve pain. Plant juice is applied twice daily in red eye (conjunctivitis). All the three tribes apply leaf-paste, leaf-juice on cuts and wound to check-bleeding and early healing. Plants are pounded and made into pills of the size of pea. One pill thrice a day is administered to cure blood dysentery.

9. Agrimonia pilosa var.**nepalensis**

Vern. Name: *Nyishi:* Taniom

Ethnic Uses: fruit juice is used as gum.Leaves are eaten after boiling. Its taste is bitter.

10. Ajuga macrosperma

Vern. Name: *Hill-Miri*: Namdunghor

Ethnic Uses: whole plant is taken as vegetable.

11. Allium hookeri

Vern. Name: Nyishi:Lahun

Ethnic Uses: pounded bulbs mixed with oil applied on throat and chest to cure cough and cold;also on wounds for healing. Ash of bulb with oil applied to cure rash or eruption of skin and other skin diseases.

12. Alocasia forniculata

Vern. Name: *Nyishi*-Kanjok

Ethnic Uses: fruits are used as fish-poison; powder of seeds with seeds of *Alpinia allughas* and *Datura metel* when taken causes madness.

13. Alpinia malaccensis

Vern. Name: *Adi*: Puprere; Apa.: Tili.

Ethnic Uses: fruits are edible, aromatic.

14. Alsotonia scholaris

Vern. Name: *Nyishi*-Taisan

Ethnic Uses: one teaspoonful white latex with equal quantity of water is given after delivery for recovery of health. Two to three drops of this latex is applied on skin eruption and abscesses upto 3 days for complete cure.Leaf-juice is applied thrice daily in headache. In stomach trouble and to control blood pressure dried bark and water (1:4) are given for 3-7 days.

15. Amaranthus gracilis

Vern. Name: *Nyishi*: Tai.

Ethnic Uses: leaves and fruits are eaten as vegetable.

16. Andrographis paniculata

Vern. Name: *Nyishi:*Chirata

Ethnic Uses: stem-juice is given in dysentery and for deworming.

17. Angiospteris evecta

Vern. Name: Nyishi: Nabay, Bom

Ethnic Uses: dilute aqueous extract of caudex/ rhizome is given in dysentery/ diarrhoea. Rhizomes are eaten as food by *Nyishi* people.

18. Anisomeles ovata

Vern. Name: Apa.: Narutami

Ethnic Uses: whole plant is crushed and made into paste and applied in mascular pain.

19. Artimisia indica

Vern. Name: Nyishi-Tapin Yame; Kukulu *(Apa)* Laglin *(Adi)*

Ethnic Uses: *Apatani* people eat boiled leaves to get relief from Asthma; aromatic smell of plant clears the nose blockade, when inhaled. Bath with diluted leaf-juice gives relief in itching and skin allergy. Juice of fresh leaves is dropped in eyes to cure redness of eye but is painful. Paste of leaves is applied on back, or leaves spread over bed give relief in back pain.

Fomentation by leaves gives relief in headache.

20. Artimisia nilagirica

Vern. Name: *Nyishi:* Tapingrami

Ethnic Uses : plant is used as cattle feed.

21. Artemisia parviflora

Vern. Name: *Nyishi:* Taping roming

Ethnic Uses : old people carry bunch of leaves on their back for 4-6 hours per day to get relief in back-pain.

22. Arundina bambusifolia

Vern. Name: *Nyishi:* Longbom

Ethnic Uses: plant is used for decoration during festivals.

23. Arundinaria callosa

Vern. Name: *Apa*: Tabyo; Adi: Bud- Buji

Ethnic Uses: bark is used to make very hard and durable rope.

24. Aspidopterys indica

Vern. Name: *Apa:* Taru; *Nyishi:* Tasa

Ethnic Uses: entire plant is crushed and boiled with water; the extract thus obtained is boiled further till the extract becomes thicker into a gum. The gum thus formed is used for catching birds.

25. Asplenium phyllitidis

Vern. Name: *Adi*: Patatak

Ethnic Uses: plants used in festival for decoration.

26. Asplenium simonsianum

Vern. Name: Adi: Patatak

Ethnic Uses: plants used in festival for decoration.

27. Athyrium latifolium

Vern. Name: *Nyishi*: Akalama

Ethnic Uses: tender shoots (cooked) eaten as vegetable.

28. Balanophora dioica

Vern. Name: *Nyishi*: Poyou

Ethnic Uses: juice from fleshy rootstock yields gum (locally called as " *potacapting- nene*") which is used for catching birds.

29. Baliospermum calycinum

Vern. Name: *Adi*: Gilgal

Ethnic Uses: leaves (cooked) are eaten as vegetable.

30. Baliospermum montanum

Vern. Name: *Nyishi:* Piriya

Ethnic Uses: leaves are cooked and eaten as vegetable.

31. Bambusa tulda

Vern. Name: Apa: Bije; Adi: Tabbe

Ethnic Uses: stem is used for making flute locally called '*eloo*'. It is used by priest during '*Dree*'festival. The sound is believed to keep evil spirits away.

32. Bauhinea variegata

Vern. Name: Pacham

Ethnic Uses: tender leaves and flowers (cooked) are eaten as vegetable.

33. Begonia episcopalism

Vern. Name: *Adi*: Sudum Meku

Ethnic Uses: Leaves (cooked) are eaten as vegetable, but the taste is sour.

34. Begonia roxburghii

Vern. Name: *Nyishi:* Baya, Babarai; *Apatani*: Bekhoo, Lukhu

Ethnic Uses: Nyishi people use roots, petioles and leaves in cold/fever/malaria; apply pounded leaves in itching; leaves and fresh whole plants are eaten by *Nyishi* as well as *Apatani* people.

35. Begonia observa

Vern. Name: *Nyishi:* Baya, Babarai; *Apatani:* Lukhu

Ethnic Uses: *Nyishi* people use roots, petioles and leaves in cold/fever/malaria; apply pounded leaves in itching; leaves are eaten by *Nyishi* as welll as *Apatani* people.

36. Begonia palmata

Vern. Name: *Nyishi*: Bayia

Ethnic Uses: Chutney is prepared from stem paste; also effective in cough/ cold. Stem is used *as vegetable.*

37. Berberis wallichiana .

Vern. Name: *Nyishi*-Madrak: Lobetree*(Apatani)*:*Apatani:* Tipetire

Ethnic Uses: paste of root-bark is applied on swollen parts of body to get relief from body pain. Spines are used for tatooming on chin and fore head. A mixture of rice- starch and *soot* is applied on the wound; rich-starch pierces the skin and soot gives the colour; tattoo locally called *'te'* is traditional custom.

38. Bidens tripartita

Vern. name: Nyishi: Nikampusi

Ethnic Uses: leaves are eaten (raw or boiled).

39. Blechnum orientale

Vern. Name: *Nyishi:* Lichalana

Ethnic Uses: pounded leaves and rhizome are applied on cuts and wounds for clotting blood and quick healing.

40. Brassiopsis glomerula

Vern. Name: *Nyishi:*Tago

Ethnic Uses: bolied fruits (5-6) are eaten in cough. Dry fruits are pounded and mixed with water and applied on skin eruptions and abscesses. Fruits are eaten as *'chatni'*.

41. Brassaiopsis speciosa

Vern. Name: *Nyishi:* Tago

Ethnic Uses: tender leaves are made in to a paste/ *chutney*. The leaves, though bitter in taste are taken with rice to cure diarrhoea, stomach-ache and throat pain, they are also treated over the flame and then used to foment the injured/ swollen parts 2 to 3 times a day to relieve pain.

42. Blumea fistulosa

Vern. Name: *Adi:* Rumdum

Ethnic Uses : leaves (cooked) are eaten as vegetable; boiled leaf is given in diarrhoea.

43. Boehmeria macrophylla

Vern. Name: *Nyishi:* Tatam tatnam

Ethnic Uses: ripe fruits are eaten by birds; also by children.

44. Calamus floribunda

Vern. Names: Apatani: Easoo; Nyishi: Taneso

Ethnic Uses: fruits are eaten.Stem is used for making basket locally called *nara* and hat called as *beopa*.

46. Callicarpa arborea

Vern. Name: *Nyishi and Adi:* Tato,Yalu, Yahorin

Ethnic Uses: tender branches are used as tooth-brush for relief in toothache. Paste of leaf or bark is applied on scorpion sting. Bark is used for skin diseases; also used as substitute for *Areca catechu* by old people.

47. Campylandra aurantiaca

Vern. Name: *Adi*: Dipa Talo

Ethnic Uses: pieces of rhizomes are taken as tonic and to cure stomach disorders. Considered to be aphrodisiac.

48. Canarium strictum

Vern. Name : *Apatani*- Dhuna; *Nyishi*- Singlu

Ethnic Uses : bark-juice is used against insect bite. Bark and resin of plants are burnt in and outside house for prevention of diseases like chicken-pox.

49. Carex cruciata

Vern. Name: *Nyishi:* Basar, Sodomplapa

Ethnic Uses: pounded seeds are applied on wounds; tender stem is eaten.

50. Carex filicina

Vern. Name: *Nishi*: Bahik

Ethnic Uses: raw seeds are eaten.

51. Carica papaya

Vern. Names: *Nyishi and Adi:* Omita

Ethnic Uses: 3-4 flowers are boiled and taken twice a day to improve hearing capacity.Boiled raw fruits with salt or ripe fruits are eaten to increase lactation in women.

52. Carlemania griffithii

Vern. Name: *Nyishi:*Hamkay

Ethnic Uses: plants –decoction is given thrice a day in cough.

53. Casearia vareca

Vern. Name: *Dafla*-Nelochang

Ethnic Uses: fruit-paste is taken in intestinal parasites. Fruit-juice is dropped in earache.

54. Centella asiatica

Vern. Name: *Apa*-Glankgkhako

Ethnic Uses: plants are eaten with salt and chilly as vegetable; said to be blood purifier and remedy for gastric; 10-15 leaves taken thrice daily cure abdominal pain and relief in constipation; fresh leaves and stem are taken to increase digestive power and promote appetite by Nyishi and Apatani tribes.

55. Chenopodium album

Vern. Name: *Adi:* Taye

Ethnic Uses: seeds are eaten; also used in preparing local drink, '*Apong*'. A paste of pounded seeds is added to boiled rice and water; mixture is kept for two days to increase the rate of fermentation.

56. Chlorophytum arundinaceum

Vern. Name: *Apatani*: Tale

Ethnic Uses: entire plant is taken as vegetable either raw or after boiling. It is used as a substitute for onion.

57. Chromolaena odoratum

Vern. Name: *Adi*: Telimbabo

Ethnic Uses: leaf-juice and paste is applied in fresh cuts and wounds to stop bleeding and to relieve pain. Fomentation with young leaves gives relief in headache and fever (Nyishi Tribe).

58. Cissus quadrangularis

Vern. Name: *Saru (Dafla/Nyishi)*

Ethnic Uses: powder of leaves and young shoots, mixed with water is taken in menstrual disorders. Stem-juice is dropped in ear-ache.

59. Citrus medica

Vern.Name: *Adi:* Jipin

Ethnic Uses: ripe fruits are eaten, sweet – tasted.

60. Clerodendrum colebrookianum

Vern. Names: *Adi*: Tapen; Nyishi: Polo-O

Ethnic Uses: tender leaves are taken as vegetable; leaf- decoction(3-4 teaspoonfull) twice daily is considered effective in reducing blood pressure.

61. Clerodendrum japonicum

Vern. Name: Nyishi: Poto-O

Ethnic Uses: Leaves (cooked) are eaten as vegetable.

62. Clerodendrum squamatum

Vern. Name: *Adi*: Tapen

Ethnic Uses: tender leaves are taken as vegetable.

63. Cnicus griffithii

Vern. Name: *Nyishi:* Tailobeo

Ethnic Uses: flowers are eaten.

64. Coix lachryma-jobi

Vern. Name: *Nyishi:*Tatang

Ethnic Uses: grains are used for preparing necklaces, used by girls.

65. Coelogyne pectata

Vern. Name: *Nyishi*: Tikhit

Ethnic Uses: dried pseudobulb is crushed and made into powder. The powder is then applied to burn injury; burning pain is relieved immediately and wound is healed up.

66. Colocasia affinis

Vern. Name: *Nyishi:*Maksar, Jangli Kachu

Ethnic Uses: 1 or 2 spathe(s) and inflorescence taken twice to cure cough, fever and tuberculosis. Juice of leaves and petioles are applied on itching.

67. Coniogramma fraxinea

Ethnic Uses : warm leaves are tied upon burn injuries by *Nyishi* people.

68. Coptis teeta

Vern. Names: *Adi, Nyishi :* Rinko; Idu- Aro; *Mishmi:*Tita

Ethnic Uses: rhizomes with water are eaten as tonic; also taken in fever, head ache and gastric by Adi and Nyishi people.

69. Coriolus versicolor

Vern. Name: *Nyishing* :Taying

Ethnic Uses: Nyishi people take decoction in dysentery.

70. Costus speciosus

Vern. Name: *Yachi:* bapi, Myonpobapi *(Nyishi)*

Ethnic Uses: rhizome and part of stem is eaten raw in snake bite; paste of rhizome and stem is applied at the place of snake-bite/ insect bite.Warm stem juice is applied on burning wounds twice daily.

71. Crassocephalum crepidioides

Vern. Names: *Adi:* Hogegain; *Apatani:* Gendattamang

Ethnic Uses: whole plant is eaten either fresh or boiled; leaf- juice is applied on cuts to prevent bleeding; pain is relieved and the wound is healed up quickly.

72. Crepis japonica

Vern. Names: Hill-Miri.: Rupjup Rubjup; *Adi*: Rum Dum

Ethnic Uses: entire plant is cooked as vegetable. Fresh leaves are eaten.

73. Curcuma caesia

Vern. Name: *Apatani:* Kali Haldi

Ethnic Uses: roasted rhizome is eaten by Apatani people at bedtime to get relief from cough and asthma.

74. Cyanodon dactylon

Vern. Name: *Nyishi:* Meedira Tasha

Ethnic Uses: paste or powder of plant is taken with water for regular menstruation; also in headache by *Nyishi* people.

75. Cyathula prostrata

Ethnic Uses: it is an ingredient of '*Tapyo*'- the '*Apatani Black Salt*'.

76. Cyathea andersonii

Vern. Name: Adi: Taste

Ethnic Uses: core is dried removing the stem – bark and grinded;powder thus obtained are used as substitute of wheat.

77. Cyathea spinulosa

Vern. Names: Adi: Tange; *Nyishi:* Tachi-tani

Ethnic Uses: stems after removing bark are fed to cattle.

78. Cyclogramma auriculata

Vern. Names: *Adi*:Ruktak; *Nyishi:* Akalama

Ethnic Uses : boiled tender shoot is eaten as vegetable.

79. Cyclosorus glandulosus

Vern. Name: *Apatani:* Riji

Ethnic Uses: whole plant is used in festivals.

80. Cyclosorus parasiticus

Vern. Name: *Adi:* Rukdik

Ethnic Uses: tender shoots(frond) are used for giving fomentation to the gout and rheumatis.

81. Debregeasia longifolia

Vern. Names: *Nyishi:* Tatamtanam; *Adi:* Jirepole

Ethnic Uses: tender leaves are boiled and taken orally as tonic; fruits are eaten by birds.

82. Dendrobium hookerianum

Vern. Name: *Hill-Miri.*: Tachee

Ethnic Uses: Yellow dye is obtained from flowers; flowers are made into paste and mixed with sufficient water; yarn or cloth is dipped in this mixture and kept for sometimes.

83. Dendrocalamus hamiltonii

Vern. Name: *Adi*: Ea

Ethnic Uses: tender shoot is used to prepare '*hiyup*', a sour-tasted pickle.Stem is used in religious and marriage ceremony; scape is locally called '*hipuk*' particularly used in marriage ceremony.

'*Beotop*', a kind of umbrella is made from scape by Nyishi people.

84. Dendrocalamus strictus

Vern. Names: *Adi:* Taok; *Apatani:* Eabing

Ethnic Uses: This is planted in house and in places of worship. It is believed to keep devil spirits away; plant is used in Meoko festival for decoration.Stem is used for making arrow. Bark is used as rope which is very hard.

85. Dendrocnide sinuata

Vern. Names: *Nyishi:*Podret, Pudrangta; *Apa:* Hathipata

Ethnic Uses: warm root-paste is applied on swollen muscles, injury and itching in Nyishi community. Its leaves with those of *Stephania glabra* (2:1) are bolied and 1-2 teaspoonful decoction is taken in fever and malaria in Nyishi community: Apatani people use the decoction of its leaves in urinal disorders and red-urine ; leaf-decoction is also given in dysentery in Apatani as well as Nyishi people.

86. Dichrocephala bicolor

Vern. Name: *Apatani.*: Pechikai

Ethnic Uses: tender plants are edible.

87. Dicranopteris linearis

Vern. Names: Adi: Ollo; *Nyishi:* Tapiu

Ethnic Uses: inner core of stem after removing bark are fastened on chest and belly for protection against arrow.

88. Dillenia indica

Vern. Name: *Nyishi, Apatani*:Jampa, Tenga

Ethnic Uses: fruit ash is given in stomachache in Nyishi community. Fresh fruits are eaten with salt by Apatani people in stomachache. Fruits are eaten and made in to pickles also.

89. Dioscorea bellophylla

Vern. Name: *Nyishi*: Yazeng

Ethnic Uses: tubers with hot water are given in fever, malaria, headache and dysentery.

90. Dioscorea hamiltonii

Vern. Names : *Apatani*: Engi; *Nyishi*: Serelake

Ethnic Uses: bulbils and tubers are cooked and taken as food.

91. Discorea bulbifera

Ethnic Uses : tubers with those of *Stephania glabra* are used in dysentery. Pounded tubers are rubbed on spots with burning sensation.

92. Diplazium esculentum

Vern. Names:Nyishi: *Hokapadma; Apatani:*Hokahmang

Ethnic Uses: young fronds are eaten as vegetable (cooked).

93. Dipteris wallichii

Vern. Name: *Nyishi:* Tapano

Ethnic Uses: fronds are hanged on bamboo -stick in paddy-field to keep away birds.

94. Drymaria cordata

Vern. Names: *Adi*:Kado kairo; *Hill-Miri*-Kaja Habo; *Nyishi*- Ropsik-Romnik, Kadokaro Sojang mariang

Ethnic Uses: leaf-juice is applied to skin diseases.Paste of whole plant mixed with bile of goat, boar or fish is applied on ringworm. Vapour of stem and leaf juice gives relief in sinus. *Adi* people mix 3-4 plants with fruits of guava and eat in gastric problem.

95. Dryopteris elongata

Vern. Name: *Hill-Miri* : Kaja Habo

Ethnic Uses : tender shoots are edible; entire plants are used in religious ceremony.

96. Eclipta prostrata

Ethnic Uses : *Apatani* people use plants on cuts and wounds; 3-4 plants with sugar and salt taken twice a day gives relief in dysentery and stomach pain.

97. Elaiagnus latifolia

Vern. Name: *Apatani*: Hari

Ethnic Uses: fruits are edible, sour-tasted.

98. Elastotema sessile

Vern. Name: Nyishi: Tatomung

Ethnic Uses: whole plant is considered as frog poison.

99. Elatostema platyphylla

Vern. Name: *Nyishi:* Hujee; *Adi:* Sakobadha

Ethnic Uses: fresh root-juice is used for vomitting.

100. Eleusine coracana

Vern. Names: *Adi*: Tami; *Apatani:* Sase

Ethnic Uses: country liquor '*Apong*' is made from the grains; ash of grain (*Tachoo*) is taken twice in cough, cold,congestion and for neutralising wine.

101. Elsholtzia blanda

Vern. Name: *Adi*: Bok Pomro

Ethnic Uses: tender leaves are crushed and made into paste with common salt and is

applied to old wounds of cattle to clear of pus and maggot.

102. Emblica officinalis

Vern. Name: *Nyishi & Apatani:* Amlaki ghoss

Ethnic Uses: fruits are edible and used as appetizer and freshness of mouth by both the tribes.

103. Engelhardtia spicata

Vern. Name: *Hill-Miri.:* Ripekam

Ethnic Uses: paste of pounded roots is used as fish-poison.

104. Entada purseatha

Ethnic Uses: seed-paste with mustard oil is used in bone fracture by *Nyishi* people.

105. Equisetum debile

Vern. Name: *Adi*: Isstape

Ethnic Uses: plant is used by the local priest in religious ceremony.

106. Erianthus rufipilus

Vern. Name: *Adi:* Pilu

Ethnic Uses: tender stem (culm) is eaten when one is thirsty while working in the jungle; entire plant is used in festivals for decoration.

107. Erigeron bonariensis

Vern. Names: *Adi and Apatani:* Daglentado

Ethnic Uses: vapour of leaves inhaled in sinus problems.

108. Eryngium foetidum

Vern. Names: Nyishi and Apatani: *Dhaniya Pat; Adi:* Hariyo

Ethnic Uses: paste of stem and leaves applied on forehead in headache. Seed-powder used in madness in *Adi* & *Apatani.* Leaves are used to make *chutney* with leaves of *Centella asiatica*.

109. Eurya acuminata var **euprista**

Vern. Name: *Nyishi:* Turku

Ethnic Uses: leaves are mixed with *Rubia manjith* plants and boiled . The extraction thus obtained is used as permanent dye.

110. Fagopyrum esculantum

Vern. Name: *Adi*: Amintatek

Ethnic Uses: leaves are cooked as vegetable. Ripe fruits are eaten.

111. Ficus auriculata

Vern Name: *Adi*: Hote

Ethnic Uses: ripe fruits are eaten.

112. F. elastica

Vern. Name: *Hill- Miri*: Sangri

Ethnic Uses: fruits eaten by birds;crushed fruits are thrown into brooks or streamlets to stupefy fish and makes them float up, helping an easy catch.

113. F. fistulosa

Vern. Names : *Apatani*: Mobopu; *Nyishi*: Longee

Ethnic Uses: plants are used as firewood.

114. F. hirta var. **roxburghii**

Vern. Name: *Adi*: Takchi

Ethnic Uses: fruits are given to pigs as food.

115. F. saemocarpa

Vern Name: *Nyishi:* Talasi

Ethnic Uses: latex is applied on warts and pimples.

116. Forrestia mollissima

Vern. Name: *Adi*: Tachar Parin

Ethnic Uses: entire plant is crushed and the juice is applied to the arrowhead to make it poisonous.

117. Galeola falconeri

Ethnic Uses: seeds are used in bee-keeping.

118. Garcinia pedunculata

Vern. Name: *Nyishi:* Mibia

Ethnic Uses: fruits are edible but sour in taste. One fruit is boiled in ½ litre of water and is given twice daily in dysentery and cough by *Nyishi* people.

119. Gerbera piloselloides

Vern. Name: Adi: Pangnesir

Ethnic Uses: leaves are used for giving hot

formentation to relieve rheumatic pain.

120. Gnaphalium affine

Vern. Names : *Apatani*: Miang ; *Adi*: Buli

Ethnic Uses: dried plants are used as fuel.

121. G. purpureum

Vern. Name: *Nyishi:* Tecep

Ethnic Uses: plants are eaten after boiling.

122. Grewia multiflora

Vern Name: *Adi*: Hakobangi

Ethnic Uses: stem bark is used as rope.

123. Globba multiflora

Vern. Name: *Nyishi:* Belah

Ethnic Uses: rhizomes are crushed and applied on injury or rubbed daily atbed ime in body pain and swollen muscles by *Nyishi* people.

124. Gynocardia odorata

Vern. Name: *Nyishi:* Tak

Ethnic Uses: pounded fruits mixed with water are used for extraction of teeth. Fruits are prohibited to be eaten by *Nyishi* people. Fruits pounded and mixed with water and used as poison for killing insects, worms and fishes.

125. Gynostemma pedata

Vern. Name: *Apatani:* Rikoh

Ethnic Uses: to get clear throat problems, *Apatanis* take mixture of *Tapyo* (Apatani black salt) and *Rikoh* along with less quantity of chilly and common salt (Kohli 1992). Dry seed powder is found to be anthelmintic (Kohli 1980); powder of stem or root about ½ teaspoon with water taken orally, twice daily is a remedy of cough and stomach troubles.

126. Gynura cusimbu

Vern. Name: *Apatani*: Kochibamang

Ethnic Uses: leaf- juice is taken orally as a preventive measure against worms..

127. Hydrocotyle javanica

Vern. Name: *Nyishi:* Barung

Ethnic Uses: whole plant is eaten raw against stomachache; also given raw after delivery by *Nyishi* tribe. *H. rotundifolia* is also used for the same.

128. Hedychium dekianum

Ethnic Uses: rhizome- paste or powder applied on injury and wounds for immediate healing and relief from pain by *Apatani*.

129. Hedychium gardnerianum

Vern. Name: *Nyishi:*Oyoulangoom

Ethnic Uses: flowers are used in festivals for decoration.

130. Hedychium gracile

Vern. Name: *Adi:* Bibu

Ethnic Uses: plant is offered to drive away evil spirit by local priest called 'Dundar', when a man is suffering from diseases.

131. Hedyotis scandens

Vern. Name: *Nyishi:* Hylibi, Reekhing

Ethnic Uses: pieces of stem (crushed or pounded) heated and applied against toothache by *Nyishi* people.The juice extracted from stem is applied as eye drop (1 or 2 drops at a time) against conjunctivitis and also used in cleaning of dust and gum from eyes. Twigs or stem piece (12-15 cm long) slowly heated over flame and used as tooth brush.

132. Hibiscus rosa-sinensis

Vern. Name: *Apatani:* Ghasphu; Dafla: Bat

Ethnic Uses: flowers mixed with leaves of *Michelia champaca* in the proportion of 1:2 are pounded together and is applied with water for washing of hairs to remove hair dust and dandruff; also used as hair tonic; flower-paste is taken in fever.

133. Houttuynia cordata

Vern. Names : *Nyishi:* Honya, Hongyea; *Apatani:* Siahamang

Ethnic Uses: *Nyishi* people use whole plant as condiment or improving appetite; 3-4 fresh plants are eaten twice daily in case of jaundice; 5-10 plants are kept inside the banana leaf and roasted; the roasted plants are taken twice daily to stop dysentery. *Apatani* people use the stem and leaves as vegetable; considered effective for providing good sleep and freshness of mind.

Plants are also used as condiment and sold in bundles (10-15 plants in one bundle); leaves are eaten raw as chutney.

134. Hydrangia robusta

Vern. Name: *Adi*: Takmi

Ethnic Uses: leaves are cooked as vegetable.

135. Hyptis suaveolens

Vern. Name: *Apatani*: Narutami

Ethnic Uses: leaf-juice or pounded tender twigs, is rubbed against skin disorders and itching; 3-4 drops of leaf-juice is mixed with water for taking bath against itching. Usually such bath is given to children for the treatment of cough and cold by *Apatani* people.

136. Impatiens latiflora

Vern. Name: *Nyishi:* Riong

Ethnic Uses: whole plant is mixed with *Torenia diffusa* in equal proportion and pounded and taken with water for recovery of fever/ intermittent fever and against headache.

137. I. racemosa

Vern. Name: *Nyishi*: Yemchee

Ethnic Uses: cooked leaves are served as vegetable.

138. I. scabrida

Vern. Name: *Hill-Miri*: Namcho

Ethnic Uses: entire plants are boiled and taken as vegetable; tender leaves are most preferable.

139. I. tripetala

Vern. Name: *Nyishi:* Leangm

Ethnic Uses: 3-4 plants are eaten either raw or boiled thrice daily after meal to promote appetite by *Nyishi* people.

140. Indofevillea khasiana

Vern. Name: *Nyishi:* Yazang pipe

Ethnic Uses: pounded or powdered roots and stems is taken with hot water (about 5 gm twice daily) against fever, headache, malaria and also for dysentery.

141. Ixora acuminata

Vern. Name: *Nyishi:* Dokmain

Ethnic Uses: fresh leaves (3-4 at a time) are eaten (raw/boiled) thrice daily as a remedy for headache and cooling of forehead.

142. Lasianthus longicauda

Vern. Name: *Apatani*: Santupaya

Ethnic Uses: fruit-extract is used as gum for praying birds.

143. Leea compactiflora

Vern. Name: *Nyishi*: Neelan

Ethnic Uses: flowers and berries pounded and tightly tied with the help of a cloth against snake bite and other insects.

144. Limacia oblonga

Vern. Name: *Adi*: Titmilie

Ethnic Uses: ripe fruits are edible, sweet.

145. Lindora neesiana

Vern. Name: *Nyishi*: Kuchu

Ethnic Uses: fruits are eaten by birds; also by children.

146. Litsea citrata

Vern. Name: *Adi*: Taier; *Apatani:* Santetero

Ethnic Uses: both ripe and unripe fruits are edible. It is used as substitute of spices during preparation of vegetables, curry and meat. Pickle is prepared from the fruit, fragrant.

147. L. cubeba

Vern. Names: *Nyishi:* Earking, Jayar; *Apatani:* Santero; *Adi & Tagin:* Tayer

Ethnic Uses: *Nyishi* people use pounded fruits and leaves mixed with water to be taken 2-4 tea spoonful twice daily in blood dysentery, stomach trouble and fever. Paste of leaves is also applied on fore head in case of headache. *Apatani* people eat fresh ripe or unripe fruits as a remedy for cold and cough and also for good sleep. Fresh fruits are edible and also used as spice; fruits and seeds are used as condiment. Seeds are alsochewed in case of thread worm infection.

148. L. salicifolia

Vern. Name: *Nyishi:* Tanyik Sangne, Hara, Taor

Ethnic Uses: pounded bark and mixed with water

is applied on bone fracture and tightly tied with a piece of cloth to set right the bone; paste obtained from pounded barks and administered twice daily against boils and abscesses; ripe fruits which are tasty and pungent are eaten.

149. Lobelia affinis

Vern. Name: *Hill- Miri*: Nimante

Ethnic Uses: leaves are cooked as vegetable.

150. Loropetalum chinense

Vern. Name: *Apatani*: Marri

Ethnic Uses: plants are used in religious ceremony.

151. Luffa cylindrica

Vern. Name: *Nyishi:* Hey

Ethnic Uses: leaves are used as vegetable.

152. Lycopodium clavatum

Vern. Name: *Adi:* Dogomiri

Ethnic Uses: entire plant is used in marriage ceremony for decoration.

153. Macaranga denticulata

Vern. Names: *Adi*: Yaduk; *Nyishi:* Hara

Ethnic Uses: leaves are used during religious and marriage ceremony; leaf-juice is applied on wounds.

154. Maesa chisia

Vern Name: *Nyishi:* Ohansomchangum

Ethnic Uses: hardwood is used for making spades to dig out *Dioscorea* tubers.

155. M. macrophylla

Vern Name: *Nyishi:* Tak Sangne

Ethnic Uses : 5-6 berries are eaten fresh thrice daily in case of any fever including malarial fever by *Nyishi.*

156. M. montana

Vern Name: *Nyishi:* Surana

Ethnic Uses: paste of leaves mixed with oil is rubbed against body pain.

157. Mahonia acanthifolia

Vern. Name : *Apatani*: Tamen,Taming

Ethnic Uses : ripe fruits are edible, sweet, tongue becomes black. Generally the tribal people use to select their sacred places near this plant.

158. M. napaulensis

Vern. Name: *Apatani:* Tamen, Taming

Ethnic Uses: juice extracted from crushed stems is applied for the treatment of itching and skin rushes. Stem juice is used as a local yellow dye as colouring agent. Fumes from boiling of stem are useful in conjunctivitis and eye troubles. Ripe berries are eaten by both the tribes.

159. Mallotus albus

Vern. Name: Fishkuri

Ethnic Uses : leaf- powder is used in fever and cold, one teaspoonful two times a day with water. Root –juice is useful in ear-ache.

160. Mastersia assamica

Vern. Name: *Nyishi:* Rading, Rem

Ethnic Uses: stem juice is applied on cuts, wounds and other injuries for immediate healing by the *Nyishi*; bark is used for making ropes. Its fibre is also used to make thread for fishing net.

161. Melastoma malabathricum

Vern. Name: *Apatani*: Akysanyi; *Nyishi*: Di-sengn, Dai-Hitae; Adi: Pudiraju

Ethnic Uses: fruits are edible; stem is used as tooth-brush; fruits cause shining of teeth; fruits offered to God for better yield of paddy.

162. Melia azedarach

Vern. Name: *Nyishi & Apatani:* Tapa Tale

Ethnic Uses : fresh bark pounded and applied twice daily against burning sensation till complete relief by both the tribes. About 3-6 leaves boiled in one bucket of water and is taken bath in case of itching (both the tribes).

163. Melothria heterophylla

Vern. Name: *Nyishi:* Yazang-pipe; Apatani: Kabomako

Ethnic Uses: 5-10 gm of pounded tubers are taken with one glass of hot water (very bitter in taste) against fever, malarial fever and headache; juice from fleshy roots is rubbed on itching skin till complete relief; fruit are edible. Local children are fond of these fruits.

164. Metathelpteris gracilescens

Vern. Names : *Nyishi:* Radak, Nipiati; *Adi:*Rudtak

Ethnic Uses: frond -juice applied on itching, Fronds are also useful in cuts for immediate healing. The pinnae are warmed above fire and tied with the help of a cloth to relieve body ache. Fronds are used in small quantity in preparation of local drink (*Apung*) by ethnic groups; fronds are kept over flame to make hot fomentation twice or thrice a day for two days to relieve body pain.

165. Michelia champaca

Vern. Name: *Apatani:* Salyo

Ethnic Uses : 3-4 fresh or dry seeds (raw or boiled) are eaten to improve the loss of appetite and liver disorder; leaves of the plant mixed with flowers of *Hibiscus rosa- sinensis* (2:1) and pounded together is applied with water for washing of hair to remove hair dust.

166. M. oblonga

Vern. Name: *Apatani*: Salyo

Ethnic Uses: parts used and uses are similar to *M. champaca.*

167. Mikania micrantha

Vern. Name: *Apatani:* Mantami; *Nyishi:* Tare

Ethnic Uses: *Apatani* people apply juice of stem and leaves in skin diseases, itching and skin allergy, 3-4 drops of juice mixed with water is used as germicides during bath. *Nyishi* people apply juice from leaves for healing of wounds, also apply on cuts to stop bleeding. Leaves are warmed above fire and kept on the eyes and repeated 4-times to cure any type of eye trouble; plants are used as a remedy for snake bite and scorpion sting. Leaves are used in itches and poulting wound in the different parts of the world.

168. Miliusa globosa

Vern. Name: *Dafla:* Tasenaung

Ethnic Uses: fresh leaves crushed and inhaled in headache.

169. Millettia cinerea

Vern. Name: *Apatani.*: Rolang

Ethnic Uses: stem is used as rope.

170. M. pachycarpa

Vern. Name: *Nyishi*: Hapuling

Ethnic Uses: roots are used as fish-poison.

171. Mitracarpus verticillatus

Vern. Name: *Hill-Miri*: Talu

Ethnic Uses: young shoots and leaves are boiled and taken as vegetable.

172. Molineria prainiana

Vern. Name: *Apatani*: Loli

Ethnic Uses: fresh leaves are used to tie over the lower abdomen of pregnant lady for relieving of labour pain, easy and quick delivery.

173. M. recurvata

Vern. Names: *Nyishi:* Doik; *Apatani:* Loli

Ethnic Uses: fresh leaves crushed and applied against body pain and labour pain by *Apatani* tribe; root juice is applied on cuts and wounds for early healing. Fruits are also eaten by *Nyishi* tribe.

174. Momordica dioica

Vern. Name: *Nyishi*: Keychasshi

Ethnic Uses: fruits are used as vegetable.

175. Morinda angustifolia

Vern. Name: *Nyishi:* Yacha

Ethnic Uses: 1-2 leaves just warmed over fire and is tied with a piece of cloth against body pain by Nyishi tribe. Root - juice taken for the remedy of cough.

176. Morus indica

Vern. Name: *Hill-Miri*: Latek

Ethnic Uses: fruits are edible.

177. Mucuna pruriens

Vern. Name: *Adi*: *Dimpa*

Ethnic Uses: stem- juice is applied on eyes to relieve pain and to cure diseases.

178. Murraya paniculata

Vern. Name: *Adi*: Nyibumtarum

Ethnic Uses: ripe fruits are edible.

179. Musa acuminata

Vern. Name: *Adi:* Kulu

Ethnic Uses: fruits are edible when ripe. Unripe fruits are used as vegetable.

180. M. sapientum

Vern. Names: *Adi*: Kulu; *Apatani & Nyishi*: Kol

Ethnic Uses: fruits and stem are taken as food. Fruits are eaten by pig; entire plants are used in all festivals.; juice of stem and leaves crushed and aplied over swollen feet and skin disorders.

181. M. velutina

Ethnic Uses: juice extracted from the stem is used in dysentery.

182. Mussaenda roxburghii

Vern. Name:*Adi*: Tangmeng

Ethnic Uses: leaves are cooked and served as vegetable.

183. Mycetia longifolia

Vern. Name: *Adi*: Tangmge

Ethnic Uses: leaves are cooked and eaten as vegetable.

184. Myrica esculenta

Vern. Name: *Apatani*: Baching

Ethnic Uses: juice extracted from pounded bark is applied on itching and skin eruptions. Sometimes juice is mixed with water and taken bath. Fruits are edible and sold in the market.

185. Nephrolepis cordifolia

Vern. Name:.*Nyishi:* Tapion

Ethnic Uses: stipes are used to make trap for catching birds in the paddy fields.

186. Ocimum basilicum

Vern. Name: *Apatani:* Nangpara

Ethnic Uses: leaves and inflorescence crushed with salt and water is taken in case of cholera.

187. Oenanthe javanica

Vern. Names: *Apatani*: Aguhama; *Nyishi:* Barn

Ethnic Uses: whole plant is eaten raw or cooked as vegetable.

188. Osbeckia nepalensis

Vern. Name: *Adi:* Pudirasa

Ethnic Uses: ripe fruits are edible.

189. O. nutans

Vern Names: *Nyishi:* Dai; *Adi:* Jikenemi

Ethnic Uses: ripe fruits are edible; an important plant used in all kind of festivals among *Adi* tribes.

190. O. stellata

Vern. Name: *Nyishi:* Didasa

Ethnic Uses: fruits are edible.

191. Otochilus porrecta

Vern. Name: *Nyishi:* Awaon

Ethnic Uses: Pseudobulbs and leaves pounded together and applied twice daily on burn injuries till complete relief.

192. Oxalis corniculata

Vern. Names: *Nyishi:* Sajang hobo; *Apatani:* Okhui hamang,Ohokhuhii; *Hill-Miri*:Phagiyup

Ethnic Uses: *Apatani* people use (raw/boiled) as vegetable the whole plant and said to promote appetite but it should not be taken with local drink '*Apung*'. *Nyishi* people apply juice of plant on cuts and injuries to stop bleeding; juice of leaves is used as eye drops(1-2 drops) for removal of dust from eyes or against redness of eyes; fruits are edible,sour, entire plant is eaten raw by Hill Miris.

193. O. debilis

Vern. Name: *Apatani:* O- Khui-hamang

Ethnic Uses: whole plant is used as vegetable either raw or cooked and is said to promote appetite but local drink '*Apung*' should not be taken with the plant.

194. Oxyspora paniculata

Vern. Name: Adi- Porkejale; *Nyishi*: Dasa

Ethnic Uses: stem is used as tooth brush (datoon), fruits are eaten for shining of teeth, flowers are offered to deites to get better yield of paddy; stem after removing bark is eaten.

195. Paederia foetida

Vern. Name: *Nyishi:* Tapinrimin; *Apatani:* Gandhali

Ethnic Uses: *Nyishi* people use plant as cooked vegetable due to foetid, which is very effective in gastric trouble. For storage the small tablets are made from powered leaves, mixed with water and dried in sun and stored in bottle. This tablet is

often used in gastric trouble.Fruits grinded and mixed with water and is applied against skin emiting bad odour particularly bad odour of armpit, abscesses and allergy. *Apatani* people use juice from the pounded leaves (in 1 to 2 tea spoonful mixed with boiled water twice daily for drinking) against gastric trouble. Boiled leaves and twigs are used as vegetable and is said to be effective for cleaning of stomach and also against stomach swelling and diarrhoea.

196. Pericampylus glaucua

Vern. Name: *Apatani*: Rukitaru

Ethnic Uses: stem is used as rope which is very hard and durable.

197. Perilla frutescens

Vern. Names: *Nyishi:* Tanam; *Apatani:* Timing

Ethnic Uses: seeds are edible but harmful if taken more is and develops cough. Oil from the seeds applied on forehead against headache and fever by *Apatani* people.

198. P. ocimoides

Vern. Name: *Nyishi:* Tanam

Ethnic Uses: paste of seeds is used to enhance the taste of curry-soup. It is used as a substitute of mustard oil or spices.

199. Phlogacanthus curviflorus

Vern. Name: *Nyishi:* Pilamola

Ethnic Uses: pounded flowers are used as condiment. About ½ tea spoonful is taken with meal twice daily for remedy of colic pain and also as purgative.

200. Ph. tubiflorus

Ethnic Uses: red flowers are mixed with fish curry considered good for relieving cough.Flowers are edible.

201. Physalis angulata

Vern. Name: Phuligach

Ethnic Uses: seeds (8-10) and fruits(8-10) are eaten raw in gastric trouble.

202. P. minima

Vern. Name: *Adi*: Bodopati

Ethnic Uses: juice extracted from crushed leaves (3-4) and fruits (1-2) is administered with water twice daily for atleast one week for remedy of gastric by *Adi* and *Apatani* people. Berries are edible.

203. Pilea bracteosa

Vern. Names: *Nyishi:* Gongi; *Adi:* Guge

Ethnic Uses: leaves are used as vegetable.

204. P. glaberrima

Vern. Name: *Nyishi:* Gugeo

Ethnic Uses: leaves are used as vegetable.

205. Pinus wallichiana

Vern. Names: *Nyishi:* Pusasan; *Apatani:* Tel ghos

Ethnic Uses: resin collected from live plants by piercing the stem is applied in cracks of heels usually during winter at bed time for one week.

206. Piper attennuatum

Vern. Name: *Adi:* Dolopann

Ethnic Uses: fresh leaves are mixed with tobacco leaves and used for smoking.

207. P. brachystachyum

Ethnic Uses: seeds used with honey for curing cough.

208. P. pedicellosum

Vern. Name:Nyishi.: Radhk

Ethnic Uses: leaves are used for giving hot fomentation for sprains. After application the affected portion is wrapped by the same leaves.

209. P. sylvaticum

Vern. Name: *Adi*: Rari

Ethnic Uses: leaves are used as vegetable.

210. P. trioicum

Vern. Name: *Nyishi:* Ridik; *Apatani:* Ridi

Ethnic Uses: leaves warmed above fire either covered locally or tied over with a piece of cloth against bodyache which mainly occurs due to tiredness by *Nyishi*. Roots are chewed by *Apatani* as a remedy for cough.

211. Plantago erosa

Vern. Names: *Apatani:* Mepi- hamang; *Adi:* Doni-hankang

Ethnic Uses: *Apatani* people use leaves either raw or boiled as vegetable and considered as remedy for constipation. It also improves digestion.

212. P. major

Vern. Name: *Nyishi:* Nido marto

Ethnic Uses: its leaves along with the leaves of *Pasu payou* are crushed and made into pills of the size of pea. One pill trice a day is given to cure blood dysentery; boiled leaves are eaten by *Nyishi* people.

213. Plectranthus japonica

Vern. Name: *Apatani*: Yode

Ethnic Uses: fresh juice obtained from the leaves applied externally on swollen parts and wounds resulting from insect bites.

214. Plumbago zeylanica

Ethnic Uses: root is said to increase digestion; promote the appetite and useful in dyspepsia, piles and skin diseases.

215. Polygonum alatum

Vern. Name: *Nyishi.*: Yarung

Ethnic Uses: fresh leaves are eaten, but sour in taste.

216. P. barbatum

Vern. Name: *Apatani*: Rerupi

Ethnic Uses: entire plant is crushed and made into paste; paste is mixed with water to catch fish. It acts as fish-poison.

217. P chinensis var. **ovalifolia**

Vern. Name: *Adi*: Amintaktabe; *Nyishi*: Tuthiku

Ethnic Uses: ripe fruits are eaten, sweet.

218. P. pubescens var. **acuminata**

Vern. Name: *Adi*: Tamu

Ethnic Uses: whole plant is crushed and made into paste; paste is thrown into stream. This stupefies the fish and makes them float up, helping an easy catch.

219. P. minus

Vern. Name: *Nyishi:* Paretam

Ethnic Uses: plant is used as fish poison. It is grinded and made into paste, and then mixed with the water in streams etc for stupefying fish.

220. P. molle

Vern. Name: *Nyishi:* Bonkung

Ethnic Uses: tender stem is eaten as raw. Ripe fruits are sweet and edible; also eaten by birds..

221. P. nepalense

Vern. Name: *Adi:* Ruri

Ethnic Uses: entire plant is crushed and eaten as *chutney*.

222. P.perfoliatum

Vern. Name: *Nyishi:* Posikung

Ethnic Uses: leaves are used in preparing *chutney*.

223. P. runcinatum

Vern. Name:Nyishi: Ruri

Ethnic Uses: tender leaves are eaten as *chutney*.

224. P. virginiana var. **filiformis**

Vern. Name: *Nyishi:* Pekammajam

Ethnic Uses: tender shoots are eaten..

225. Portulaca oleracea

Vern. Name: *Nyishi*: Pali echi; *Apatani*: Pathavi

Ethnic Uses: stem and leaves are used as vegetable to promote appetite by both the tribes.Pounded stem, leaves and flowers applied against skin allergy, rashes etc. by *Nyishi* tribe.

226. Pothos cathcartii

Vern. Name: *Nyishi:* Anoti

Ethnic Uses: leaves warmed above fire and bandgaged over in dislocation of bones by *Nyishi* people.

227. P. scandens

Vern. Name: *Nyishi:* Ridik

Ethnic Uses: boiled stems and leaves are used as vegetables for clear motion and in constipation by *Nyishi*.

228. Pouzolzia hirta

Vern. Names: *Adi:* Oike; *Nyishi*: Hosskhoyik

Ethnic Uses: stem and leaves are used as

vegetable. It is considered by *Adi* that the vegetable of this plant increases lactation in women.

229. P. viminea

Vern. Name: Phuti Bum

Ethnic Uses: paste of whole plant is applied locally on affected portion of itching.

230. Prunus cerasoides

Vern. Name: Apatani: Puta

Ethnic Uses: ripe fruits are edible, sweet.

231. P. persica

Vern. Name: *Nyishi:* Makan, Makum

Ethnic Uses: young leaves pounded and mixed with water and about ½ teaspoon is given twice daily after meal against dysentery; leaves warmed above fire and rubbed against insect bite and pain in eyes. Young leaves pounded and applied on wounds for killing of wound worms. This is more popularly used in case of animal wound such as cow, mithun etc; fruits are edible.

232. Prunus rufa

Vern. Name: *Apatani*: Gonde

Ethnic Use: fruits are edible.

233. Psidium guajava

Vern. Name: *Nyishi:* Madhuri

Ethnic Uses: leaves pounded, boiled in water and added 3-4 drops of mustard oil and little quantity of salt and filtered. About 2-4 teaspoonful of the extract is taken twice daily to cure dysentery. Fruits are edible.

234. Psychotria denticulata

Vern. Name: *Nyishi:* Reeme

Ethnic Use: leaves crushed and applied in cuts of iron and wound for immediate healing and relief.

235. Pteridium aquilinum

Vern. Name: *Adi:* Rukji

Ethnic Uses: whole plant is used by the local priest in religious ceremony.

236. Pterospermum acerifolium

Vern. Name: *Apatani:* Sippopasing; Dafla: Tanguru Changne

Ethnic Uses: paste of floral calyx is applied as plaster in swelling in the body.

237. Pueraria hirsuta

Ethnic Uses: seeds are boiled and kept in closed vessel for about seven days and then allowed to decompose. A drink is prepared from it and taken with rice.

238. P. peduncularis

Vern . Name: *Nyishi:* Fikpiring

Ethnic Uses: fruits are edible and taken either fresh or boiled.

239. Quercus dealbata

Vern. Name: *Adi*: Rajap; *Apatani*: Kra

Ethnic Uses: leaves and flowers are used in Apatani festivals; woods are used for preparing poles and wooden materials for house construction.

240. Rhaphidophora decursiva

Vern. Name: *Adi:* Tachitali

Ethnic Uses: plant is used in festivals to keep the evil spirits away.

241. R. glauca

Vern. Name: *Nyishi*: Chulu

Ethnic Uses: according to folk belief, the fruits of this plant are eaten by devil.

242. R. lancifolia

Vern. Name: *Adi*: Tachitale

Ethnic Uses: entire plant is used in religious ceremony to cure disease.

243. Rhus chinensis

Vern. Name: *Apatani:* Tamo

Ethnic Uses: fruits are edible, 10-15 fruits eaten twice daily in case of blood dysentery by *Apatani*. Fruits are used like that of tea leaves against body pain.

244. R. javanica

Vern. Name: *Nyishi:* Tamo

Ethnic Uses: people avoid burning plant as they are afraid of the sound produced by it.

245. Rhynchotechum calycinum

Vern. Names: *Adi*: Jaro;*Nishi:* Joako

Ethnic Uses: leaves are used in funeral ceremony. Leaves are cooked as vegetable.

246. Ricinus communis

Vern. Name: *Nyishi:* Rockrom

Ethnic Uses: seeds - oil massaged in joint pain, local application of young twigs in vagina causes abortion; leaf fomentation is given in muscular pain.

247. Roydsia suaveolens

Vern. Names: *Adi*: Titegille; *Apatani*: Rokputtutum

Ethnic Uses: fruits are edible, sweet.

248. Rubia manjith

Vern. Names: *Nyish & Apatani:* Tamin

Ethnic Uses: plant is used as a dye; stem is cut into pieces and boiled in water;extract thus obtained is used to dye the yarn (red); roots are also used as red dyes for colouring of local clothes and articles etc. 1-2 tea spoonful of powdered roots mixed with water is given to drink against cold & cough; often roots are chewed for the same purpose. Powder is also applied on forehead in case of headache.

249. Rubus alceifolius

Ethnic Uses: young stem twigs are chewed to cure cough by *Nyishi* people. Fruits are edible.

250. R. assamensis

Vern. Name: *Nyishi:* Fikteging

Ethnic Uses: fruits are edible.

251. Rubus ellipticus

Vern. Name: *Apatani*: Jilyung

Ethnic Uses: ripe fruits are eaten, sweet.

252. R. insignis

Vern. Names: *Adi*: *Taptere; Nyishi.:* Chechenimri

Ethnic Uses: leaves are eaten with bark of *Callicarpa arborea* var. *ovalifolia* as substitute of peper betel. Lip turns red. Ripe fruits are eaten, sweet.

253. R. niveus

Vern. Names: *Apatani*: *Nikhee*; *Hill-Miri*: Kiblupum

Ethnic Uses: fruits are edible but sour.

254. R. paniculata

Vern. Name: *Nyishi.; Chechenimri*; *Adi*: Taptara

Ethnic Uses: leaves are eaten by Adi children as substitute for peper betel. Ripe fruits are eaten, sweet.

255. R. rosaefolius

Vern. Names: *Apatani*: *Hitimbulum;* Adi: Kibo-lepum

Ethnic Uses: fruits are edible, sour.

256. Sambucus javanica

Vern. Name: *Nyishi:* Tago

Ethnic Uses: fruits are eaten by birds.

257. Sapium baccatum

Vern. Name: Adi: *Shigum*; *Apatani*: Samperai

Ethnic Uses: Fruits are edible, sweet.

258. Saurauia armata

Vern. Names: *Adi*: *Himpum; Nyishi:* Poprar

Ethnic Uses: Ripe fruits are edible, sweet. Crushed young twigs and leaves are applied on cuts and wounds to stop bleeding and for healing.

259. S. panduana

Vern. Name: *Hill-Miri*: Hinchi

Ethnic Uses: fruits are edible when ripe, sweet.

260. S. roxburghii

Vern. Names: *Apatani.: Tarsingahi*; *Adi*: *Hinche; Nyishi*: Ekeeprin

Ethnic Uses: leaves are used for preparing country liquor. Bamboo basket is wrapped with leaves and boiled with water and kept within the pot for few days. Leaves promote quick fermentation. Ripe fruits are eaten.

261. Schefflera venulosa

Vern. Name: *Nyishi:* Paleh

Ethnic Uses: warm leaves are applied to get relief from pain by the *Nyishi* people.

262. Schizostachyum capitatum

Ethnic Uses: 'Apatani' people use tender shoots or liquid inside bamboo in small quantity orally to get relief from diarrhoea, dysentery, stomach troubles. Young tender shoots are also considered as wormicides if added in water before bath.

263. Scoparia dulcis

Ethnic Uses: *Nyishi* people use 3 to 4 plants mixed with 2 gm of rhizome of *Curcuma longa* and pounded and a paste is made with water; this paste is taken twice daily for the treatment of Jaundice. It controls diabetes also.

264. Scurrula parasitica

Vern. Name: *Nyishi*: Tacha

Ethnic Uses: fruits are eaten by birds.

265. Selaginella wallichii

Vern. Name: *Adi*: Hojum

Ethnic Uses: tender leaves are cooked and served as vegetable.

266. Sesamum indicum

Vern. Name: *Nyishi*: Tanam

Ethnic Uses: seeds are ground and mixed with vegetable and taken as food.

267. Setaria italica

Vern. Name: *Nyishi*: Tayak

Ethnic Uses: seeds are used for preparing country liquor.

268. S. pallide-fusca

Vern. Name: *Nyishi*: Taya

Ethnic Uses: grains are used for preparing the local drink *Apong*.

269. Sida acuta

Vern. Name: *Adi*: Holap

Ethnic Uses: tender leaves are cooked and taken as vegetable.

270. Silene heterophylla

Vern. Names: *Apatani*: *Jajru*; *Hill-Miri*.: *Jajrar*; *Adi*: Kubumeku

Ethnic Uses: fruits are edible, sweet.

271. Skimmia anquetifolia

Vern. Name: *Apatani*: Dising

Ethnic Uses: plants are used by the *Apatani* people for the treatment of gastric pain.

272. Solanum indicum

Vern. Names: *Adi*: *Sotabayom*; *Nyishi*.: Beako

Ethnic Uses: fruits are taken as food after fry, bitter.

273. S. kurzii

Vern. Names: *Nyishi*: *Byakhe*; *Apatani*: Byakh, Byako

Ethnic Uses: Apatani peopleuse 10-15 fruits with small quantity of salt for the treatment of cough. Dried fruits are powdered and mixed with water (1:4) and boiled, all reduced to ¼ of the decoction. About 100 ml. of decoction is taken twice a day upto one week for complete relief from worms infestation. *Nyishi* people use 4-5 fresh fruits for the same purpose and also for the treatment of stomach pain.

274. S. myriacanthum

Vern. Names: *Nyishi & Apatani*: Byako, Thitbyako

Ethnic Uses: 1-3 teaspoonful of decoction of roots administered twice daily for the treatment of malarial fever by *Nyishi* people. Dried seeds pounded and mixed with water and mustered oil are kept on heated stone; liberating smoke is inhaled through mouth for removal of teeth worms by *Nyishi* people and sometimes by *Apatani* people.

275. S. nigrum

Vern. Names: *Nyishi*: Hora; *Apatani*: Harohamang; *Idu mishmi*: Akana

Ethnic Uses: stem and leaves are used as vegetable and considered digestive and liver tonic; also useful for clear motion by *Apatani*, *Nyishi*, *Idu* tribe men. Berries are eaten raw; leaves are eaten (raw/cooked).

276. S. torvum

Vern. Names: *Nyishi*: Byakta; *Apatani*: Bykh; *Adi*: Byako

Ethnic Uses: 10- 15 fruits are mixed with little salt and pounded and given thrice daily for the

treatment of cough by *Apatani;* fruit - juice applied in skin disorders. Seeds burnt and the smoke or fumes inhaled through mouth for killing teeth worms and also against toothache by *Nyishi* tribes. Fruits are used as *chatani* and also eaten raw. This is the substitute of *S.anguivii* and *S. kurzii*; fruits are cooked as vegetable.

277. S. verbascifolium

Vern. Name: *Hill-Miri*: Totnom

Ethnic Uses: leaves are used for ripening banana. Green banana is wrapped with the leaves and kept for four to five days.

278. S. viarum

Vern. Name: *Nyishi*: Siatobeale

Ethnic Uses: plant is used as cattle fodder.

279. Solena heterophylla

Vern. Name: *Adi:* Kubumiku

Ethnic Uses: both unripe and ripe fruits are eaten.

280. Sonchus brachyotus

Vern. Name: *Apatani:* Paku Hadu Hammang, Kochi hama

Ethnic Uses: decoction is made from stems and leaves after boiling in water. About 2-3 tea spoonful of the decoction is administered for the treatment of gastric, stomach pain, and waist pain. Boiled leaves are used as vegetable and said to be effective in stomach troubles.

281. S. oleraceus

Vern. Name: *Apatani:* Paku Hadu Hamang

Ethnic Uses: stem and leaves are used by the *Apatani* people as substitute for *S. brachyotus* .

282. Sonerila maculata

Vern. Name: *Nyishi*: Jakmalo

Ethnic Uses: leaves are cooked and taken as vegetable.

283. Sphenomeris chinensis

Vern. Name: *Adi:* Getepatey

Ethnic Uses: paste of the fronds is rubbed against swollen portion of body and sprains of feet.

284. Spilanthes paniculata

Vern. Names: *Nyishi:* Byadhi; *Apatani:* Yakho hama

Ethnic Uses: *Nyishi* people eat leaves and flowers as remedy for cough. Stem twigs with leaves mixed with *golmirch* (*Piper nigrum*) and is used as a condiment to kill intestinal worms. Apatani people use leaves as a condiment or eaten raw or boiled to remove constipation. Flowers made into paste and is applied or chewed in case of toothache by both the tribes. Flowers chewed to cure tooth-ache against the local name 'Marsang' by *Adi* tribe..

285. Spiradiclis bifida

Vern. Name: Adi: Sokho

Ethnic Uses: leaves are boiled and taken as vegetable.

286. Staurenthera grandiflora

Vern. Name: *Nyishi:* Beeh

Ethnic Uses: stem powder is used in rheumatic pain; bark of the plant is used in joint pain by *Nyishi* tribe against the local name *'Beeh'*.

287. Stephania glandulifera

Vern. Name: *Nyishi:* Teplar, Rabaka

Ethnic Uses: small fresh piece corms 10-20 gm or its powder is given thrice daily with water after child birth for removal of delivery pain. It is also given in case of abdominal pain and internal injuries. A few pieces of corm, 3-4 leaves are mixed with 3-4 leaves of *Dendrocnide sinulata*.*'Pudrangta'* (N.) and is boiled with water. The decoction is given 2-3 tea spoonful twice daily for the treatment of fever, malarial fever and also said to be a good cooling agent. Boiled leaves are eaten for the treatment dysentery.

288. Sterculia hamiltonii

Vern. Name: *Nyishi:* Takampalam

Ethnic Uses: ripe fruits are eaten as a substitute for groundnuts.

289. Stereopermum suaveolens

Vern. Name: *Nyishi:* Damium

Ethnic Uses: leaves after warming are used in fomentation, 2-3 times a day to relieve sprain etc.

290. Streptolirion volubile

Vern. Name: *Hill-Miri*: Tadaro

Ethnic Uses: whole plant is cooked and served as vegetable.

291. Styrax polysperma

Vern. Name: *Hill-Miri*: Tugu

Ethnic Uses: decoction of fruit is used as dye. Fruits are eaten by birds.

292. Symplocos racemosa

Vern. Name: *Adi*: Tumle

Ethnic Uses: plants are used in religious ceremony.

293. Tacca integrifolia

Vern. Names: *Nyishi*: Kanjok; *Adi:* Tagoon

Ethnic Uses: rhizome pounded and paste is applied in wounds and also applied in cracks of heels for healing.Berries pounded and mixed with water and taken 2 to 3 tea spoonful twice daily in dysentery. It is also said to be effective in stomach disorder and stomach pain; decoction of leaves along with normal salt are prescribed orally two teaspoonful twice a day for two to three days to the patient suffering from blood dysentery and acute diarrhoea. Overdose acts as poison; taste is bitter; stem is cut into pieces, made into bundles, wrapped with leaves and roasted in fire; juice thus extracted is used to poison arrow heads.

294. Terminalia bellerica

Vern. Name: *Nyishi:* Bahid

Ethnic Uses: fruits are eaten raw in constipation and also act as an appetizer.

295. T. chebula

Vern. Names: *Nyishi & Apatani*

Ethnic Uses: 1-2 fruits chewed 2-3 times daily for the treatment of cough. Fruits areconsidered ***stomachic*** by both thr tribes.

296. T. citrina

Vern. Name: Nyi*shi:* Hilika

Ethnic Uses: 1-2 fruits chewed twice daily for curing cough; bark is taken orally against colic.

297. T. myriocarpa

Vern. Name: Adi: Gilak

Ethnic Uses: plants yield timber.

298. Thelypteris gracilescens

Vern. Name: Nyishi: Nipiati

Ethnic Uses: bark of the stipe is used as thread for killing rats.

299. T. gracilescens var. **glandulysis**

Vern. Name: *Adi*: Rukdik

Ethnic Uses: entire plant is used for preparing country liquor. Leaves are used for giving hot fomentation to get relief from pain.

300. T. xylodes

Vern. Names: *Adi*: Rukdik; *Nishi:* Akalama

Ethnic Uses: powder of dried fronds are mixed with pounded rice, water and kept for at least for two days for fermentation to prepare local liquor *'Apong'*.

301. Themeda villosa

Vern. Name: *Nyishi:* Pkabar

Ethnic Uses: plants are used for thatching houses.

302. Thunbergia coccinea

Vern. Name: *Adi:* Pakrega

Ethnic Uses: flowers are used in festivals for decoration.

303. Tinospora cordifolia

Vern. Name: *Nyishi:* Nyam rak

Ethnic Uses: about 1 cm long stem is pounded and given with water twice daily in empty stomach. To get relief from gastric, dysentery and fevers; stem juice is applied against swollen muscles. Stem juice is considered as aphrodisiac.

304. Toddalia aculeata

Vern. Names: *Nyishi*: Tiktaksen; *Apatani:* Tanoai

Ethnic Uses: fruits are edible, fragrant.

305. Torenia asiatica

Vern. Name: *Nyishi:* Hankay

Ethnic Uses: fresh leaves about 5-10 or its powder eaten by *Nyishi* tribe with meal as a remedy for stomach troubles, gastric and enhance clear motion and appetite.

306. T. diffusa

Vern. Name: *Nyishi:* Ocheng

Ethnic Uses: whole plant is mixed with *Impatiens latiflora* ('Riong'- Nyishi) about equal proportion and pounded and is used as condiment in curry. But it is very effective if it is taken orally thrice daily as a remedy for fever, intermittent fever and headache. Plant juice is also applied over forehead to get relief from headache.

307. Trevesia palmata

Vern. Name: Adi: Tago

Ethnic Uses: fruits are used as fish-poison. The paste of pounded fruits is mixed in the water of stream or pond. This stupefies the fish, facilitating [illegible]

308. Trichosanthes bracteata

Vern. Name: *Apatani*: Bullungkoha

Ethnic Uses: fruit is considered poisonous.

309. T. tricuspidata

Vern. Names: *Nyishi*: Rikay; *Apatani:* Bhullung koha

Ethnic Uses: roots and stems are pounded, and is taken 1-2 tea spoonful with hot water twice daily for the treatment of dysentery by *Nyishi* tribe. Stem is kept for a long period after drying. The small pieces mixed with other vegetables are eaten as a remedy of stomach trouble. It is also used as appetizer if 10 -15 of almost dried stem is taken with hot water at bed time.Root of *Thunbergia coccinea* is also in use as substitute.

310. Trigonospora ciliata

Vern. Names: *Adi:* Taka; *Nyishi:* Akalami

Ethnic Uses: tender shoots are cooked as vegetable.

311. Urena lobata

Vern. Name: *Nyishi:* Borival, Sitoyorik

Ethnic Uses: 2-3 of roots are powdered and is taken with rice water or plain water thrice daily for the treatment of hyperacidity and dysentery. The stem is also used as tooth brush by Nyishi tribe.

312. Vernonia cinerea

Ethnic Uses: used in preparation of '*Tapyo*' which is known as '*Apatani black salt*'.

313. Viburnum coriaceum

Vern. Name: *Nyishi*: Nagam

Ethnic Uses: fruits are eaten by birds.

314. V. foetidum

Ethnic Uses: fruit juice is used as dye by *Nyishi* people.

315. Villebrunea frutescens

Vern. Name: *Adi*: Tappen

Ethnic Uses: dried leaves are pounded and applied as paste on skin diseases and the wounds due to burn. Fresh leaves are used as a poultice over cuts to relieve pain and to cure wounds.

316. V. integrifolia

Vern. Names: *Nyishi*: Boree; *Apatani*: Pattatan; *Adi*: Tane

Ethnic Uses: bark is used as rope. Sometimes it is used as a substitute of cotton thread for preparing fishing –net.

317. Viola betonicifolia

Vern. Name: Hill-Miri: Tadro

Ethnic Uses: leaves are cooked and taken as vegetable.

318. Vitis repens

Vern. Name: Apatani: Tarupakhu

Ethnic Uses: fruits are edible but sour.

319. Zanthoxylum acanthopodium

Vern. Name: *Apatani*: Yokhung

Ethnic Uses: tender shoots are cooked and taken as vegetable. Fruits are eaten. Pounded fruits are prescribed orally for dysentery and stomach-ache.

320. Z. armatum

Vern. Name: *Honyum*: Nyishi; *Yarkhung:* Apatani

Ethnic Uses: *Apatani* people use seed-powder with equal amount of salt against cold,cough and fever; also given to increase appetite.Seeds are also used as spice. Fruits are chewed and twigs are used as tooth brush in toothache. *Nyishi* people use decoction of dry fruits in stomach disorders (1- 2 teaspoonful twice daily).

321. Z. hamiltonianum

Vern. Name: *Honyor*: Nyishi

Ethnic Uses: tender leaves are used as condiment and also as a remedy for constipation and cold in *Nyishi* community.

322. Zingiber officinale

Vern. Name: Apatani: Sing Taki

Ethnic Uses: dried stem mixed with salt in hysteria. Fresh rhizome is eaten; juice is taken in cough by *Apatani* people.

Vegetation

Broadly the vegetation of Arunachal Pradesh can be described into following categoris :

I. **Tropical Vegetation** : This type of vegetation can be further divided into two subtypes viz. tropical evergreen and tropical deciduous types, based on the composition and structure:-

I.a. **Tropical Evergreen** (foothills up to 1000 m) : the areas receives maximum rainfall. Top canopy in these forestsy consists of tall trees like *Aglaia hiernii, Altingia excelsa, Artocarpus chama,Bischofia javannica, Bambax ceiba, Callicarpa arborea, Canarium bengalense, Castanopsis indica, Cinnamomum glaucescens, Chukrasia tabularis, Dillenia indica, Dipterocarpus gracils, D.retusus, Duabanga grandiflora, Dysoxylum gobara, Echinocarpus sp., Lagerstroemia flos reginae, Magnolia campbelli, M.caveana, Mesua assammica, M.ferrea, Pterospermum acerifolium, Quercus griffithii, Q.lamellosa, Shorea assamica, S.robusta, Terminalia chebula, T.myriocarpa , etc.* These tall trees with their close canopy cover stifle plants of the lower storeys of the forest and the dense, dark humid environ thus created provides excellent conditions for the profuse and luxuriant growth of the epiphytes.

The next canopy is represented by small trees and shrubs like *Actephila excelsa, Ardisia crispa, A.humilis, Baliospermum corymbiferum, Bauhinia purpurea, Boehmeria macrophylla, B.platyphylla, Buddleja asiatica, Capparis sacutifolia subsp. sabiaefolia, Clerodendrum bracteatum, C.colebrookianum, C.serratum, C.venosum, Coffea benghalensis, Dendrocnide sinuata, Ficus hispida, Friesodielsia fornicate, Goniothalamus sesquipedalis, Grewia disperma, Gynocardia odorata, Illicium manipurense, Leea robusta, Magnolia hodgsonii,Michelia doltsopa, Micromelum minutum, Mussaenda roxburghii, Oxyspora paniculata, Phlogacanthus spp., Pseudodissochaeta assamica, Rhus suceedanea, Sambucus hookeri, Saurauia punduana, Solanum torvum, Sterculia anisopetalum* and *Triumfetta rhomboidea. Canes like Calamus erectus* and *C.leptospadix* occur in swampy areas and form impenetrable thickets. Some palms are also found in these forests e.g. *Arenga pinnata, Caryota urens, Didymosperma nana, Licuala peltata, Livistona jenkinsiana, Pinanga gracilis and Phoenix rupicola, Salacca secunda, Wallichia densiflora, Pinanga gracilis* and *Phoenix rupicola. Salacca secunda, Wallichia densiflora and W.traindra* are found to grow scatteted on the drier hill slopes, whereas *Pandanus nepalensis, Cyathea spinulosa,* and *Angiopteris evecta grow at* moist places. Species of wild banana (*Musa spp.)* are abundant on hill slopes..

The trees are densely covered with numerous climbers like, species of *Acacia, Bauhinia, Derris, Entada, Gnetum, Hodgsonia, Mezoneurum, Mucuna, Piper, Rhaphidophora, Thunbergia, Taddalia, Unona, Vitis,* etc. Many species of *Calamus* are seen stretching from one tree to another.

Common epiphytic orchids found in these forests include the species of *Aerides, Coelogyne, Cymbidium, Dendrobium, Eria, Oberonia, Pholidota, Rhynchostylis, Saccolabium,* etc.Epiphytic species of ferns belong to *Asplenium, Nephrolepis, Drymoglossum, Colysis, etc.* Other climbers include *Aeschynanthus spp. Naravelia zeylanica, Piper spp., Pothos spp. Pueraria phaseoloides, Rhaphidophora spp. Tetrastigma bracteolatum, Trichosanthes cordata, Thunbergia coccinea, T.grandiflora* etc.

The ground flora is dominated by herbs like, *Asystasia neesiana, Begonia roxburghii, B.sikkimensis, Chirita oblongifolia, C.pumila, Commelina spp., Deeringia amarantoides, Exacum terragpnum, Floscopa scandens, Globba spp., Lindenbergia indica, Lobelia pyramidalis, Murdannia nudiflora, Oxalis corniculata, Polygonum spp.,Rhynchoglossum obliguum, etc. Arundina graminifolia (* bamboo orchid) with its beautiful lilac-red flowers is seen growing along with the tall grasses on open slopes of the hills . *Tacca spp.*with their showy floral bracts are also conspicuous in shady moist habitata at lower elevations. *Ichnanthus vicinus* grows on moist-wet rocks and boulders in open sunny places. *Gonatanthus pumilus* and *Selaginella sp.* are found on moist slopes along roadsides. Terrestrial orchid species of *Goodyera, Habenaria, Calanthe, Malaxis, Phaius,* etc.; ferns like *Angiopteris sp., Diplazium dilatatum, Pteris sp.* and fern allies, mainly species of *Equisetum, Lycopodium* and *Selanginella* are common

.Interesting root parasite, *Balanophora dioica* infesting the roots of many tree species ;the saprophytic species like *Epipogium roseum, Galeola falconeri(* giant orchid) and *Monotropastrum humile* occur in moist, shady, humus rich soils of these forests.

At lower elevations,the monocotyledons like, *Arisaema spp., Amischotolype mollissima, Colocasia spp., Costus speciosus, Curculigo capitulata, Curcuma spp., Curcumorpha longiflora, Gonatanthus spp., Hedychium spp., Homalomena aromatic, Musa rosacea, M.balbisiana, M.acuminata, Phrynium rheedei, Zingiber spp., etc.* with species of bamboos form a green belt. *Clerodendrum squamatum var. urticifolia* with beautiful red flowers in large terminal bunches is occasionally seen along the forest edges.

I.b. **Tropical Semievergreen** : The tropical semievergreen type of vegetation occurs along the foothills and river banks up to am elevation of 600 m. the top canopy in this type consists of generally deciduous trees whereas the remaining storeys are dominated by evergreen species and thick undergrowth of shrubs, climbers and lianas. This type may be further divided into two subtypes:

I.b. (1) **Low Hills and Plains Semievergreen** : The upper storey in this type is dominated by tall tree species like, *Aglaia heirnii, Ailanthus integrifolia ssp. calycina, Altingia excels, Anthoephalus chinensis, Artocarpus lacoocha, Bischofia javanica, Bombax ceiba, Canarium strictum, Castanopsis spp., Chukrasia tabularis; Cinnamomum glacescens, Dillenia indica, Duabanga grandiflora, Dysoxylum binectariferum, Elaeocarpus aristatus, Firmiana colorata, Gmelina arborea, Khasiaculnea oligocephala, Phoebe goalparensis, Pterospermum spp., Sterculia villosa, Stereospermum chelnoides, Terminalia myriocarpa, Tetrameles nudiflora, etc.*

The next storey is represented by small trees of *Crateva religiosa, Croton chlorocalyx, Ficus spp., Gynocardia odorata, Litsea panamonja, Meliosma simplicifolia, Turpinia nepalensis, etc.* Shrubs include shurb of *Ardisia, Boehmeria, Capparis, Clerodendrum, Phlogacanthus, Strobilanthes,* etc.

The ground flora is dominated by herbaceous species of *Ageratum, Amorphophalus, Arisaema, Colocasia, Costus, Impatiens, Phrynium, Strobilanthes, etc. Gouania tilaefolia, Stixis suaveolens* and *Thunbergia spp.* are common climbers and epiphytic species of *Dendrobium, Hoya, Papilionanthe, Eria* and several species of ferns.

I.b.(2). **Riverine Semievergreen** (Vegetation along river banks, riverine plains and swamps). Trees are generally deciduous, buttressed and lack dense canopy. The top canopy is dominated by species like, *Albizia spp., Artocarpus chama, Bischofia javanica, Bambax ceiba, Canarium strictum, Castanopsis spp., Dalbergia sissoo, Dillenia indica, Duabanga grandiflora, Lagerstroemia parviflora, L.flos reginae, Radermachera gigantea, Sterculia villosa, Terminalia bellirica,T. .myriocarpa, etc.*

The second storey (if present), generally consists of species of *Ficus, Litsea, Magnolia, Meliosma, Turpinia, Villebrunea, etc.* Species of *Calamus, Murraya,* and *Randia* often form dense covering at the ground level mixed with species of *Phragmites, Saccharum, Costus* and *Hedychium*. Climbers and epiphytes are not very common in this vegetation type.

II. **Subtropical Vegetation** : is basically of evergreen and dense. Forests of *Sessini* and its surrounding *Baha* and *Kalaktang* adjoining Bhutan border in Kameng district, Kherbari onwards to Ziro and beyond up to Amjee in Subansiri district, the entire region of Siang river valley, Upper Lohit Valley and South-Western part of Tirap district are some of the areas where the predominant vegetation is subtropical type. This vegetation can be broadly divided into two subtypes.

IIa. **Subtropical Broad Leaved Forests** : The dominant tree species of this vegetation are, *Acer oblongum, Actinodaphne obovata, Alnus nepalensis, Beilschmiedia roxburghiana, Byttneria grandifolia, Callicarpa arborea, Castanopsis armata, C.indica, C.purpurella, Dichroa febrifuga, Engelhardtia spicata, Euodia trichotoma, Ficus gasparriniana, Garcinia acuminata, Gynocardia odorata, Kydia calycina, Magnolia pterocarpa, Manglietia insignis, Michelia oblonga, Ostodes paniculata, Prunus napaulensis, Quercus acutissima,Q. griffithii, Q.lamellosa, Q.lanata, Q. semecarpifolia, Q. spicata, Saurauia armata, S. punduana, Schima wallichii var. khasiana, Stachyurus himalaicus, Sterculia hamiltonii, Ulmus lanceifolia, etc.* Small trees like *Capparis multiflora, Lepisanthes senegalensis; Photinia integrifolia,* etc.. are common alongwith *Ardisia spp., Artemisia indica, Berberis wallichiana* var. *latifolia, Camellia caudata, Cassia mimosoides, Dianella ensifolia, Drymaria diandra, Eurya acuminata, E.japonica, Lasianthus longicauda, Mahonia acanthifolia, M.napaulensis, Plectranthus griffithii, P.hispidus, Rosa indica, Solanum erianthum, Sophora acuminata, Stellaria uliginosa, Symplocos spp., Wendlandia spp., Tephrosia candida, Triumfetta pilosa, Urena lobata, Vernonia saligna, Viburnum foetidum,*

V.mullaha, Clematis acuminata, Holboellia latifolia and *Tinospora sinensis* are some of the common woody climbers. Other climbers and straggling shrubs met within forests are *Actinidia callosa, Argyreia wallichii, Boehmeria spp., Clematis gouriana, Clerodendrum spp., Clitora mariana, Combretum pilosum, Lygodium japonicum, Maesa spp., Phlogacanthus spp., Rubia cordifolia, Rubus moluccanus, Toddalia asiatica, Thunbergia spp.* and *Zanthoxylum oxyphylum.*

Common herbs include, *Anaphalis adnata, A.busua, A.contorta, Anemone vitifolia, Astilbe rivularis, Campanula khasiana, Cardamine hirsuta, Cynoglossum glochidiatum, Exacum tetragonum, Inula cappa, Justicia khasiana, Leucas ciliata, Osbeckia stellata, Plantago major, Polygonum spp., Potentilla spp., Valeriana hardwickii, Viola betonicifolia, V.diffusa, V. hamiltonniana* and *V. pilosa* alongwith several species of terrestrial orchids and ferns. Some herbaceous climbers like, *Clitoria mariana, Parabaena sagittata, Pericampylus glaucus, Stephania elegans,* etc. are also seen.

Epiphytes include *Asplenium ensiforme, Drynaria propinqua, Lepisorus spp., Pyrrosia spp., etc. Epiphytic* orchid species of *Bulbopyllum, Coelogyne, Dendrodium, Octochilus, Ritaia,* etc. are found in huge numbers Species of *Goodyera, Hebenaria, Malaxis* and *Phaius* constitute the ground cover. Common grasses include, *Arundo donax, Capillipedium assimile, Imperata cylindrica, Setaria palmifolia* and species *Panicum* and *Eriathum.*

IIb. **Subtropical Pine Forests** (1000-1800 m) : Seen in subtropical and semitemperate regions mainly in Dirang valley lower hill slopes around Apatani valley hill slopes around Walong and along inner Lohit river valley These forests are represented by 3 species of *Pinus viz., P.merkusii, P.roxburghii* and *P.wallichiana* in association with tree species like, *Alnus nepalensis, Betulu alnoides, Lyonia ovalifolia, Quercus spp., Rhus javanica, Tsuga dumosa* and species of *Ajuga, Coriaria, Desmodium, Elsholtzia, Indigofera, Luculia, Plectranthus, Pogostemon, Potentilla, Pteridium, Rubus, etc.*

Due to recurring annual fires in these forests during winter months, epiphytes and ground flora are scarce.

III. **Temperate Vegetation** : It is found around Chakoo, Peri La, Morsing, Bomdila, Dirang, Rapa and Shergaon in Kameng district; the forests beyond Amjee in Subansiri district; the upper slopes above the valley particularly from Garsing to Kapang La and along the track from Take Pokong to Sirang in Siang district, Lohit and Delei in Lohit district, Waka and along the border of Myanmar in Tirap district and other areas in this region within the range of altitude 1,800 - 3,500 m.

The characteristic appearance of this type of vegetation is open and apparent lax storeyed nature with dominance of oaks, members of Magnoliaceae and Ericaceae, *(Rhododendron).* But in several localities, a mixture of temperate with those of tropical and subtropical elements are also seen. The temperate vegetation can be broadly divided into two categories.

III.a. **Temperate Broad Leaved Forests** (1,800-2,800): The top canopy is o*f Acer hookeri, A. oblongum, A. pectinatum, Alnus nepalensis, Betula alnoides, Exbucklandia populnea, Castanopsis indica, Euonymus sp., Magnolia campbelli, M.obovata, Photinia sp., Populus ciliata, P. gamblei, Rhododendron spp., Symplocos racemosa,* etc. The middle storey is formed by the species of *Pyrus, Prunus, Spiraea, Acer, Symplocos* and *Rhododendron,* etc. Lower storeys are formed by small trees and shrubs of *Ardisia spp., Berberis wallichiana, Caryopteris odorata, Debregeasia longifolia, Illicium griffihii, Lyonia ovalifolia, Mahonia spp., Myrsine semiserrata, Rhododendron spp. Vaccinium sprengelii, etc.* Ground flora consists of species of *Arisaema, Begonia, Corydalis, Drymaria, Fragaria, Geranium, Ploygonum, Potentilla, Sedum, Thalictrum,* etc."

Climbers are rare, but epiphytic species of *Rhododendron, Agapetes and Vaccinium* are more common along with many orchids, ferns and lichens. Along the roadsides, forest edges and streams, a prominent herbaceous layer appears during rainy seasons which commonly includes, *Ambrosia artemisiaefolia, Cardamine hirsuta, Oenanthe javanica, Pilea umbosa, Rorippa indica, Stellaria uliginosa,* etc. Terrestrial ferns are few. Among the dimorphic ferns, *Plagiogyria scandens* is common on the forest floor.

III.b. **Temperate Coniferous Forests** (2,800-3,500 m): Dominated by species of *Abies, Cupressus, Pinus, Taxus, Tsuga,* etc. Pure stands of *Cupressus torulosa* are seen at Rupa-Shigao. Higher up, species of *Abies, Juniperus, Larix, Picea, Taxus,* etc., are found.

IV. **Subalpine** (3,500-4,000 m) and **Alpine Vegetation** (above 4,000 m): This zone is characterised by tree species like, *Abies spectabilis, Cupressus torulosa, Juniperus recurva, Larix griffithiana, Rhododendron spp., Taxus wallichiana* and *Tsuga dumosa,* and shrubs *like Berberis wallichiana, Eurya acuminata, Gaultheria*

fragrantissima, Photinia integrifolia and *Vaccinium venosum.*

The alpine zone is characterised by species of *Aconitum, Arenaria, Gentiana, Meconopsis, Polygonum, Primula, Rhodiola, Rhododendron, Saussurea, Saxifraga* and *Sedum.*

Secondary Forests

Primary forests are destroyed due to various biotic and abiotic factors like shifting cultivation (Jhumming), developmental activities and urbanization, land slides, fires, etc. These secondary forests my be categorised under 3 sub-categories:

1. **Degraded forests:** Generally dominated by shrubs and small trees. *Species of Bauhinia, Callicarpa, Glochidion, Mallotus, Capparis, Clerodendrum, Croton, Eurya, Randia, Rubus and Viburnum* are common shrubs alongwith weed species like, *Ageratum, Eupatorium, Mikania,* etc.

2. **Bamboo forests**: This type of secondary forests mostly occur in the areas which are abandoned after "Jhum" cultivation up to the elevation of 2,000 m. The common bamboo species are, *Arundina graminifolia, Bambusa pallida, B.tulda, Chimonobambusa callosa, Dendrocalamus hamiltonii, D. hookeri, D. strictus, Schizostachyum latifolium, S. polymorphum, etc.*

3. **Grasslands :** Developing after "Jhum" cultivation or due to fires or over-grazing have the grasses like, *Arundinella bengalensis, Chrysopogon aciculatus, Eragrostis tenella, E.unioloides, Imperata cylindrica, Mnesithea clarkei, Paspalum sp., Saccharum arundinaceum, Saccharum .spontaneum, Sacciolepis interrupta, Setaria palmifolia, Themeda caudata and Thysanolaena maxima* in association with sedges like, *Cyperus* spp., *Fimbristylis spp., Scirpus* spp., etc. and some scattered trees of *Bambax ceiba, Duabanga grandiflora, Macaranga denticulata,* etc. at lower altitude.

Floristic diversity

A perusal of the literature reveals that *ca* 24 % taxa of flowering plants found in India, grow in Arunachal Pradesh which has an area of about 2.54 % of the geographycal area of the country. Chowdhery *et al.* (1996) mentioned that 4117 species of Angiosperms belonging to 1295 genera and 192 families occur in Arunachal Pradesh. Out of these 2986 species under 970 genera and 165 families belong to Dicotyledonous group and 1131 species 325 genera and 27 families belong to Monocotyledonous group. These ratio between Dicots and Monocots is 2.6 : 1 and between genera to species is 1: 3.1. Forty-one families are monotypic. The families, genera and species recorded so far from Arunachal Pradesh are enlisted below :

Table I : Floristic Analysis of Flora of Arunachal Pradesh

Family	Genera	Species
A. **ANGIOSPERMS**		
I. **Dicotyledons**		
Rannunculaceae	13	48
Circiasteraceae	1	1
Dilleniaceae	2	5
Magnoliaceae	4	23
Illiciaceae	1	4
Schisandraceae	2	6
Tetracentraceae	1	1
Eupteleaceae	1	1
Annonaceae	11	30
Menispermaceae	14	30
Berberidaceae	3	11
Podophyllaceae	1	1
Lardizabalanceae	3	5
Nympheaceae	1	2
Papaveraceae	3	6
Fumariaceae	3	12
Brassicaceae	14	27
Capparaceae	4	11
Violaceae	2	17
Flacourtiaceae	1	2
Pittosporaceae	1	2
Polygalaceae	3	17
Xanthophyllaceae	1	3
Caryophyllaceae	9	21
Portulacaceae	1	1
Tamaricaceae	2	2
Hypericaceae	1	9
Clusiaceae	3	12
Theaceae	5	17
Actinidiaceae	2	9
Stachyuraceae	1	1
Dipterocarpaceae	4	7
Malvaceae	10	21
Bombacaceae	1	1
Sterculiaceae	10	21
Tiliaceae	4	13
Elaeocarpaceae	2	18
Linaceae	3	4
Malpighiaceae	2	5
Averrhoaceae	1	1
Geraniaceae	1	4
Balsaminaceae	1	33
Oxalidaceae	2	4
Rutaceae	15	36
Simaroubaceae	3	4

Ochnaceae	1	1
Burseraceae	2	4
Meliaceae	11	24
Dichapetalaceae	1	1
Olacaceae	3	6
Icacinaceae	4	5
Opiliaceae	1	1
Cardiopteridaceae	1	1
Aquifoliaceae	1	9
Celastraceae	7	24
Hippocrateaceae	1	3
Rhamnaceae	7	16
Vitaceae	5	25
Leeaceae	1	9
Hippocastanaceae	1	1
Sapindaceae	8	15
Aceraceae	1	15
Staphyleaceae	1	2
Sabiaceae	2	8
Anacardiaceae	12	17
Coriariaceae	1	1
Moringaceae	1	1
Connaraceae	2	2
Fabaceae	67	196
Rosaceae	18	102
Saxifragaceae	7	12
Grossulariaceae	2	4
Hydrangeaceae	4	8
Crassulaceae	4	9
Droseraceae	1	1
Hamamelidaceae	4	4
Haloragidaceae	1	1
Rhizophoraceae	1	1
Combretaceae	4	15
Hernandiaceae	1	2
Myrtaceae	7	22
Lecythidaceae	2	2
Melastomataceae	9	24
Crypteroniaceae	1	1
Lythraceae	4	8
Sonneratiaceae	1	1
Punicaceae	1	1
Onagraceae	1	11
Trapaceae	1	1
Passifloraceae	3	7
Caricaceae	1	1
Cucurbitaceae	18	30
Begoniaceae	1	11
Cactaceae	1	1
Molluginaceae	1	2
Apiaceae	17	23
Araliaceae	15	31
Cornaceae	4	5
Alangiaceae	1	2
Caprifoliaceae	6	24
Rubiaceae	52	158
Valerianaceae	2	3
Dipsacaceae	1	2
Asteraceae	68	186
Campanulaceae	8	15
Ericaceae	8	149
Pyrolaceae	1	2
Monotropaceae	1	1
Plumbaginaceae	1	1
Primulaceae	4	56
Myrsinaceae	8	45
Sapotaceae	7	9
Ebenaceae	1	8
Styraceae	5	6
Symplocaceae	1	13
Oleaceae	8	32
Apocynaceae	24	30
Asclepiadaceae	19	40
Loganiaceae	3	5
Buddlejaceae	1	8
Gentianaceae	9	27
Hydrophyllaceae	1	1
Boraginaceae	11	21
Convolvulaceae	6	24
Cuscutaceae	1	1
Solanaceae	10	32
Scrophulariaceae	23	65
Orobanchaceae	2	3
Lentibulariaceae	2	4
Gesneriaceae	15	56
Bignoniaceae	5	7
Pedaliaceae	1	1
Acanthaceae	24	85
Verbenaceae	14	55
Lamiaceae	11	16
Chenopodiaceae	1	2
Phytolaccaceae	1	1
Polygonaceae	7	30
Podostemaceae	1	1
Rafflesiaceae	1	1
Aristolochiaceae	2	6
Piperaceae	2	25
Saururaceae	1	1
Chloranthaceae	2	2
Myristicaceae	2	5
Lauraceae	11	62
Proteaceae	1	3
Thymelaeaceae	4	9
Elaeagnaceae	1	4
Loranthaceae	8	24
Santalaceae	2	2
Balanophoraceae	2	2
Euphorbiaceae	38	90
Urticaceae	18	61
Moraceae	4	58
Cannabaceae	1	1
Ulmaceae	3	7
Juglandaceae	2	3
Myricaceae	1	1
Fagaceae	3	27
Betulaceae	3	4

Salicaceae	2	10
Ceratophyllaceae	1	1
I.2. MONOCOTYLEDONS		
Hydrocharitaceae	3	3
Orchidaceae	123	552
Zingiberaceae	13	54
Costaceae	1	2
Marantaceae	1	2
Musaceae	2	10
Cannaceae	1	1
Iridaceae	2	2
Taccaceae	1	1
Dioscoreaceae	1	25
Stemonaceae	2	3
Liliaceae	25	64
Smilacaceae	2	21
Pontederiaceae	1	2
Commelinaceae	11	44
Juncaceae	2	9
Arecaceae	10	20
Pandanaceae	1	2
Araceae	18	58
Lemnaceae	1	1
Alismataceae	2	3
Butomaceae	1	1
Aponogetonaceae	1	1
Potamogetonaceae	1	2
Erioicaulaceae	1	5
Cyperaceae	22	95
Poaceae	71	145

B. GYMNOSPERMS

Species	**Occurence**
Cycas pectinata	Papumpare
C. revoluta	Papumpare, W.Kameng
Zamia furfuracea	Papumpare
Ginkgo biloba	Papumpare
Taxus wallichiana	W.Kameng
Amentotaxus assamica	Lohit
A. cathayensis	*s.l.*
Cephalotaxus griffithii	W.Kameng
Podocarpus brevifolius	Chimpu
P. macrophyllus	Chimpu
P. neriifolius	Papumpare
Araucaria columnaris	Papumpare
A. bidwillii	Papumpare
A. hetrophylla	Papumpare
Agathis robusta	Tirap
Pinus armandi	W.Kameng
P. bhutanica	W.Kameng
P. merkusii	Lohit
P. kesiya	Papumpare
P. patula	Lower Subansiri
P .elliotii	Chessa, Papumpare
P. carebea	Chessa, Papumpare
P. oocarpa	Chessa, Papumpare
P. roxburghii	W.Kameng
P. wallichiana	Lohit, W.Kameng
P. wallichiana var. parva	Lohit, W.Kameng
Tsuga dumosa	Tawang, Lohit
Picea spinulosa	Tawang, Lohit
P. brachytyla	Lohit
Abies densa	Tawang, W.Kameng
A. delavayi	W.Kameng
A. ernestii var. salouensis	Arunachal Pradesh *(s.l.)*
A. spectabilis	Lohit, Tawang
Cedrus deodara	W.Kameng, Lower Subansiri
Larix griffithiana	Lohit, Tawang
Taxodium distichum	Papumpare
T. mucronatum	
Cryptomeria japonica	Tawang
Juniperus indica	Tawang
J. recurva	Lohit, Tawang
J. squamata	Papumpare
Cupressus cashmeriana	W.Kameng
C. corneyana	W.Kameng
C. torulosa	
Thuja orientalis	Papumpare, W.Kameng
Gnetum gnemon	Tirap, Changlang
G. montanum	W.Kameng, E.Kameng, Lohit, Changlang, Papumpare
G. montanum f. megalocarpum	*s.l.*

Table II : Ten Dominant Families in Arunachal Pradesh Flora

Family	**Arunachal Pradesh**		**India**	
	Genera	**Species**	**Genera**	**Species**
Orchidaceae	123	552	184	1229
Leguminosae	67	196	167	1141
Asteraceae	68	186	167	803
Rubiaceae	52	158	113	616
Ericaceae	8	149	15	199
Poaceae	71	145	245	1194
Rosaceae	18	102	40	432
Cyperaceae	22	95	38	545
Euphorbiaceae	38	90	84	523
Acanthaceae	24	85	92	500

Table III : Ten Dominant Genera in Arunachal Pradesh Flora

Name of the Genus	No. of Species
Rhododendron	89
Bulbophyllum	62
Ficus	51
Dendrodium	47
Primula	40
Agapetes	34
Impatiens	33
Eria	31
Carex	30
Rubus	29

Curious Plants

Sapria himalayana is the pride of Arunachal. It is the largest root parasite, found in India. It was first reported by Griffith from Mishmi hills in Lohit district and subsequently by Bor (1938) from Aka hills in Kameng district; and later at Mahao and Miram loccalities (by author) *Ropalocnemis phalloides* occurs in Namadapha in Changlang district. *Balanophora dioica* is commonly found associated with the roots of several tree species in dense humid forests whereas, *Aeginitia indica* is a common root parasite on grasses. Similarly, *Boschniaekia himalaica*, a parasite on the roots of *Rhododendron* species, is found in the alpine meadows.

Among the common saprophytes, *Monotropa uniflora* and species of orchids like, *Epipogium* and *Galeola* are found in dense humid forests on organic matter and humus rich soil. Unusual plant forms of high altitude regions which from cushions, snowballs, etc like *Thylacospermum*, *Acantholemon* and *Sauccurea gosspihora* are quite common.

Primitive Angiosperms

Many primitive angiosperms are found wild in the state due to which this region has been called as 'Cradle of flowering plants'. These are:

Table IV : Primitive Angiosperms found in Arunachal Pradesh.

Botanical Name	Family
Magnolia griffithii	Magnoliaceae
M.gustavii	Magnoliaceae
M. hodgsonii	Magnoliaceae
M. hookeri	Magnoliaceae
M. insignis	Magnoliaceae
Tetracentron sinens	Tetracentraceae
Euptelea pleiosperma	Eupteleaceae
Decaisnea insignis	Lardizabalaceae
Holbellia latifolia	Lardizabalaceae
Parvatia brunoniana	Lardizabalaceae
P. elliptica	Lardizabalaceae
Altingia excelsa	Hamamelidaceae
Loropetalum chinensis	Hamamelidaceae
Exbuchlandia populnea	Hamamelidaceae
Corylopsis himalayana	Hamamelidaceae
Houttuynia cordata	Saururaceae
Chloranthus offinalis	Chloranthaceae
Ayrica esculenta	Myricaceae
Haematocarpus validus	Menispermaceae
Aspidocarya uvifera	Menispermaceae
Pycnarrhena pleniflora	Menispermaceae
Betula alnoides	Betulaceae
Alnus nepalensis	Betulaceae

Endemic plants

The high mountain ranges of Arunachal Pradesh ranging from 700 m at Kangto and the parallel deep Nalleys in between the mountains have created a number of ecological niches and isolated geographical islands. In addition, the presence of lofty mountain ranges and dry Tibetan plateau in the north, warm alluvial plains of Brahmaputra in the south act as natural barriers for plants to migrate.

The important microcentres of endemism in Arunachal are; Abor, Dafla and Mishmi hills; Tirap; Dibang; Namadapha; Tale Valley; Tawang Sela range; Dirang, etc. Some of the endemic species occuring in Arunachal Pradesh are:

Table V:Taxa endemic to N.E region found in Arunachal Pradesh

Botanical Name(s)	Family
Acanthus leucostachys	Acanthaceae
Acer oblongum var. microcarpum	Aceraceae
A. sikkimensis var. serrulatum	Aceraceae
Aconitum assamicum	Ranunculaceae
A. lethale	Ranunculaceae
Aconogonum pangianum	Polygonaceae
Aglaia edulis	Meliaceae
Agapetes aborensis	Ericaceae
A. disper	Ericaceae
A. refracta	Ericaceae
A.subansirica	Ericaceae
Albizia arunachalensis	Mimosoideae
Anemone howellii	Ranuunculaceae
A. trullifolia	Ranuunculaceae
Anoectochilus sikkimensis	Orchidaceae
Aeschynanthus parasiticus	Gesneriaceae
Aspidopterys glabriuscula var. lohitensis	Malpighiaceae
Baliospermum micranthum	Euphorbiaceae

Bauhinia khasiana	Caesalpinioideae
B.ovalifolia	Caesalpinioideae
Begonia aborensis	Begoniaceae
B.iridescens	Begoniaceae
B.scintillans	Begoniaceae
B.silhetensis	Begoniaceae
Beilschmiedia aborensis	Lauraceae
B.deomalica	Lauraceae
Berberis dasyclada	Berberidaceae
Blechnidium melanopus	Blechnaceae
Boehmeria tirapensis	Utricaceae
Boehmeria melanopus	Blechnaceae
Bulbophyllum ornatissimum	Orchidaceae
Belleyia yunnanensis	Orchidaceae
Calamus leptospadix	Arecaceae
Calanthe densiflora	Orchidaceae
Caltha palustris var. *purpurea*	Ranunculaceae
Camellia siangensis	Theaceae
Capparis acutifolia	Capparidaceae
C. pachyphylla	Capparidaceae
Cardamine scoriarum	Brassicaceae
Ceratostylis subulata	Orchidaceae
Cheirostylis munnacampensis	Orchidaceae
C. sessanica	Orchidaceae
Chirita macrophylla	Gesneriaceae
C. mishmiensis	Gesneriaceae
Cissus assamica	Vitaceae
Cleisostoma tricallosum	Orchidaceae
Clerodendrum lasiocephalum	Verbenaceae
Coelogyne arunachalensis	Orchidaceae
Coffia khasiana	Rubiaceae
Coptis teeta	Ranunculaceae
Corydalis oligacantha	Fumariaceae
Contoneaster assamensis	Rosaceae
Crculigo crassifolia	Hypoxidaceae
Cymbidium eburneum	Orchidaceae
Dalbergia oliveri	Fabaceae
Dendrodium cathcartii	Orchidaceae
D. nareshbahaduri	Orchidaceae
D. sulcatum	Orchidaceae
D. hookerianum	Orchidaceae
Desmodium dioicum	Fabaceae
D. likabalium	Fabaceae
Dicentra roylei	Fumariaceae
Didymosperma nana	Arecaceae
Dioscorea wattii	Dioscoreaceae
Dumasia villosa	Fabaceae
Diplomeris pulchella	Orchidaceae
Dysoxylum pallens	Meliaceae
D. reticulatum	Meliaceae
Echinocarpus tomentosus	Elaecarpaceae
Elaeocarpus dubius	Elaecarpaceae
Embelia subcoriacea	Myrsinaceae
Epipogium indicum	Orchidaceae
E. sessanum	Orchidaceae
Eranthemum leptanthus	Acanthaceae
Eria clausa	Orchidaceae
E. ferruginea	Orchidaceae
E. jengingensis	Orchidaceae
E. lohitensis	Orchidaceae
E. sharmae	Orchidaceae
Euonymus glaber	Celastraceae
E. fortunei	Celastraceae
Eurya arunachalensis	Theaceae
Galeola falconeri	Orchidaceae
Gastrodia arunachalensis	Orchidaceae
Garcinia acuminata	Clusiaceae
Gleditsia assamica	Caesalpinioideae
Globba multiflora	Zingiberaceae
Glycosmis boriana	Rutaceae
G. cymosa	Rutaceae
Glycopetalum griffithii	Celastraceae
Gomphogyne macrocaspa	Cucurbitaceae
Gomphostemma aborensis	Lamiaceae
Grewia denticulata	Tiliaceae
Haematocarpus validus	Menispermaceae
Hedychium longipedunculatum	Zingiberaceae
H. radiatum	Zingiberaceae
H. robustum	Zingiberaceae
H. wardii	Zingiberaceae
Hermimium longilobatum	Orchidaceae
Hopea shingkeng	Dipterocarpaceae
Hypericum griffithii	Hyepricaceae
H. wightianum	Hypericaceae
Illicium cambodianum	Illiciaceae
Impatiens assamica	Balsaminaceae
I. bracteolata	Balsaminaceae
I. citrina	Balsaminaceae
I. laetiflora	Balsaminaceae
I. mishmiensis	Balsaminaceae
I. porrecta	Balsaminaceae
I. racemulosa	Balsaminaceae
Indigofera nigressens	Fabaceae
Jasminum lanceolarium	Oleaceae
Lagenandra undulata	Araceae
Lasianthus sikkimensis	Rubiaceae
L. tubiflorus	Rubiaceae
Leycesteris dibangvalliensis	Caprifoliaceae
Lindera neesiana var. *griffithii*	Lauraceae
Liparis assamica	Orchidaceae
L. distans	Orchidaceae
L. plantaginea	Orchidaceae
Lithocarpus kamengensis	Fagaceae
Litsea membranifolia	Lauraceae
L. mishmiensis	Lauraceae
Livistona jenkinsiana	Arecaeae
Lobelia mishmica	Campanulaceae
Loxostigma griffithii	Gesneriaceae
Luculia pinceana	Rubiaceae
Lysimachia santapaui	Primulaceae
Maesa arunachalensis	Myrsinaceae
M. nayarii	Myrsinaceae
M. truncata	Myrsinaceae
Magnolia baillonii	Magnoliaceae

M. caveana	Magnoliaceae
Magnolia griffithii	Magnoliaceae
M. gustavi	Magnoliaceae
M. insignis	Magnoliaceae
Mapania arunachalensis	Cyperaceae
Michelia doltsopa	Magnoliaceae
M. wardii	Magnoliaceae
Miliusa dolicantha	Annonaceae
Musa velulina	Musaceae
Mycetia listeri	Rubiaceae
M. mukherjiana	Rubiaceae
M. radiciflora	Rubiaceae
Oberonia acaulis	Orchidaceae
O. sulcata	Orchidaceae
Ophiorrhiza calcarata	Rubiaceae
O. hispida	Rubiaceae
O. talevalliensis	Rubiaceae
Orthosiphon wattii	Lamiaceae
Paphiopedilum fairieanum	Orchidaceae
P. wardii	Orchidaceae
Paravatia elliptica	Lardizabalaceae
Pauia belladona	Solanaceae
Peliosanthes teta spp. *humilis*	Liliaceae
Petasites kamengicus	Asteraceae
Phanera khasiana	Leguminosae
Phlogacanthus gracilis	Acanthaceae
P. parviflorus	Acanthaceae
P. tubiflorus	Acanthaceae
Pholidoto convallariae	Orchidaceae
P. pygmea	Orchidaceae
Pholidota wattii	Orchidaceae
Pilea insolens	Urticaceae
Pileostegia subansiriana	Hydrangeaceae
Piper anisotis	Piperaceae
P. petiolatum	Piperaceae
Podochilus khasianus	Orchidaceae
Polyura geminata	Rubiaceae
Pratia longipedicellata	Campanulaceae
Premna milleflora	Verbenaceae
Prenanthes scandens	Asteraceae
Primula euosma	Primulaceae
P. mishmiensis	Primulaceae
P. subansirica	Primulaceae
Psychotria aborensis	Rubiaceae
P. burkillii	Rubiaceae
Pternopetalum senii	Apiaceae
Pueraria bella	Fabaceae
Pyrenaria barringtonifolia	Theaceae
Renanthera imschootiana	Orchidaceae
Rhaphidophora hookeri	Araceae
Rhododendron beanianum	Ericaceae
R. dalhousiae var. rhabdatum	Ericaceae
R. falconeri spp. eximium	Ericaceae
R. megacalyx	Ericaceae
R. nuttallii	Ericaceae
R. pemakoense	Ericaceae
R. pocophorum	Ericaceae
R. pruniflorum	Ericaceae
R. santapaui	Ericaceae
R. subansiriense	Ericaceae
R. tanastylum	Ericaceae
R. tawangensis	Ericaceae
R. tephropeplum	Ericaceae
R. walongensis	Ericaceae
Rhynochoglossum lazulinum	Gesneriaceae
R. calycinum	Gesneriaceae
Rubus burkillii	Rosaceae
R. ghanakantae	Rosaceae
Sadira erecta	Myrsinaceae
S. subbessilifolia	Myrsinaceae
S. boweri	Myrsinaceae
Sapria himalayana	Rafflesiaceae
Sarcoglyphis arunachalensis	Orchidaceae
Sauroupus stipulatus	Euphorbiaceae
Saxifraga assamensis	Saxifragaceae
Schisandra pleana	Schisandraceae
Schizopon wardii	Cucurbitaceae
Senecio mishmi	Asteraceae
Shorea assamica	Dipterocarpaceae
Silene chodatii	Caryphyllaceae
Skimmia aborescens	Rutaceae
Sonerila arunachalensis	Melastomataceae
Spiraea arunachalensis	Rosaceae
Strobilanthes aborensis	Acanthaceae
S. secundus	Acanthaceae
Strychnos quintuplinervis	Strychnaceae
Symplocos glauca	Symplocaceae
Synotis borii	Asteraceae
S. brevipappa	Asteraceae
S. saluensis	Asteraceae
Syzygium aborensis	Myrtaceae
S. mishmiense	Myrtaceae
Tetrastigma obovatum	Vitaceae
Tricarpelema glanduliferum	Commelinaceae
Trichodesma khasianum	Boraginaceae
Trichosanthes khasiana	Cucurbitaceae
Trollius farreri	Ranunculaceae
Tylostylis discolor	Orchidaceae
Viburnum corylifolium	Caprifoliaceae
Viola pogonantha	Violaceae
Vitis planicaulis	Vitaceae
Wallichia triandra	Arecaceae
Xanthophyllum burkillii	Xanthophyllaceae
Zalacca secunda	Araceae
Zanthoxylum burkillianum	Rutaceae
Z. pseudoxrphyllum	Rutaceae
Zeuxine lindleyana	Orchidaceae

RET Species

Extinction is an universal process where in a species disappears from the earth as a result of the evolutionary process of the Nature where "Survival of the fittest" is the rule. But premature extinction of different species of

Flora and Fauna is due to greed and lust of a single species- the *Homo sapiens*. The indiscriminate exploitation and the destruction of habitat by his various activities have led to the extinction of many species and a large number of them have become rare/ threatened/ vulnerable and await a similar fate. In Arunachal also many species have become rare or threatened. Fiftyone species of grasses and 361 species of Orchids,almost all species of 'Tree-Ferns', and several species of Gymnosperms are under severe threat. A few RET species are enlisted below:

Abies delavayi	*Aconitum lethale*
Alniphyllum fortunei	*Angiopteris evecta*
Aquillaria malaccensis	*Ardisia rhynchophylla*
Bergenia ciliata forma ligulata	
Boehmeria tirapensis	*Boschniakia himalaica*
Buddleja yunnanensis	*Bulbophyllum depressum*
Bulbophyllum mishmeense	*Bulbophyllum virens*
Bulleyia yunnanensis	*Cephalotaxus griffithii*
Coptis teeta	
Cyathea andersonii	*Cymbidium eburneum*
Cyathea hookeri	*Dioscorea laurifolia*
Diodcorea orbiculata	*Diplomeris hirsuta*
Diodcorea pulchella	*Dipteris wallichii*
Drosera burmanii.	*Eria discolor*
Eria ferruginea	*Galeola falconeri*
Gastrochilus inconspicous	*Hudendron biaristatum*
Ilex venulosa	*Leptodermis scabrida*
Luisia inconspicum	*Nertera sinensis*
Nomocharis synaptica	*Oberonia sulcata*
Paphiopedilum faireanum	*Paphiopedilum wardii*
Pauia belladona	*Podocarpus neriifolius*
Renanthera imshootiana	*Rheum nobile*
Rhododendron santapaui	*Rhopalocnemis phalloides*
Sapra himalayana	*Saurauia griffithii*
Saussurea obvallata	*Taxus wallichiana*
Tetracentron sinense	*Vanda coerulea*

Affinities of the Flora of Arunachal Pradesh

The flora of this state has close affinities with tropical South-East Asian-Malaysian, Temperate Himalayan-Chinese and Japanese floras and has some elements common with Peninsular India, Sri Lanka, Tibet and Euro-Siberian region as well.

South-East Asian-Malaysian affinities : Tropical South-East Asian (Myanmar, Thailand, Indo-China, Malaysia and Indonesia) elements include: *Actinidia callosa, Ampelocissus barbata, Antidesma accuminatum, Bauhinia purpurea,Bishofia javanica, Brassaiopsis glomerulata,Carallia brachiata,Cratava religiosa, Debregeasia longifolia,Dendrobium agreegatum, Duabanga grandiflora,Engelhardta spicata,Ertia paniculata, Exbucklandia populnea, Firmiana colorata,Hedychium coccineum,Hodgsonia macrocarpa, Lepisanthes senegalensis, Lithocarpus elegans,Mangifera indica,Meliosma simplicifolia, Michelia champaca, Mucuna nigricans,Musa balnisiana, Oroxylum indicum,Procris crenata,Spondias pinnata,Talauma hodgsonii,Tetrameles nudiflora,Toona sureni,Trevesia palmata,Vernonia volkameriaefolia,* etc. *Millettia cinerea,M. pachycarpa,Neillia rubiflora, Ostmanthus suavis,Panax pseudoginseng, Potentilla griffithii,Rhododendron [illegible],P. [illegible],Rubus fragarioides,Salix sikkimensis,Shuteria hirsuta, Smilax ferox, Tetracentron sinense, are common with China, etc.*

Himalayan-Chinese-Japanese species include : *Betula alnoides,Callicarpa rubella, Cardamine griffithii,Cinnamomum obtusifolium,Dalbergia mimosoidesHelwingia himalaica,Litsea cubeba, L . kingii,L. sericea,Lonicera adenophora,Magnolia campbellii,Meconopsis napaulensis, Michelia doltsopa* are common with China ; while, *Cornus controversa, Mucuna macrocarpa, Taxillus kaempferi, Stachurus, Helwingia* etc. extend upto Japan . *Anisadenia saxatilis, Arisaema intermedium, Dalbergia sericea, Eriobotrya dubia, Gardneria angustifolia, Lindera pulcherrima, Mohonia napaulensis, Michelia kisopa, Pinus roxburghii, P. wallichiana, Premna interrupta, Rhododendron anthopogon, R. barbatum, R. campanulatum, Rhus wallichii, Rosa macrophylla, Rubus nepalensis, Sorbus cuspidata, Spirarea canescens, Tsuga dumosa, etc* are the species that are of common occurence between North-Western Himalaya to China and even upto Japan. Apart from these common elements, there are many species which are restricted to Eastern Himalayas only. Some of these species which also occur in Arunachal Pradesh are : *Agapetes serpens, Capparis sikkimensis, Elatostema imbricans, Eriobotrya hookeriana, Ichnocarpus himalaicus, Impatients longipes, Primula whitei, Rhododendron camelliflorum, R. falconeri, R. glaucophyllum, R. grande, R. hodgsonii, R. keysii, R. lindleyi, R. pendulum, R. smithii, R. succothii, R. wallichii, R. wightii, Rubus fragariodes,* etc.

Elements common with Peninsular India, Sri Lanka, Tibet , Europe and Siberia: *Capparis*

olacifolia, Casearia zeylanica, Dendrophtoe falcata, Ficus benghalensis, F. drupacea, Leucas ciliata, Murraya koenigii, Palmbago zeylanica, Pterolobium hexapetalum, Tamarix indica, Thunbergia caccinea, Tylophora rotundifolia, Woodfordia fruticosa, etc. are typical 'Deccan' elements found in Arunachal Pradesh.

Euro-Siberia elements :*Goodyera repens, Hedera sp., Juncus inflexus, Lithosperum officinale,Polygala sibirica, Prunella vulgaris, Ranunculus scleratus, Stellaria uliginosa, Thlaspi arvense, Vernonia anagallis-aquatica, Viola biflora,* etc. found in Arunachal Pradesh.

USEFUL PLANTS

I. Crops : The state has rich crop plant diversity in barley, maize, buck- wheat, finger millet, fox tail millet, fmaranth, french bean, soyabean, cowpea, blackgram, pea, scarlet bean, pumkin, cucumber, Allium, ginger, chayote, tree tomato, brassica, pome and stone fruits.

I.1 **Cereals** : *Coix lacryma-jobi var. ma-yen* (used for preparing beverages), *Eleusine coracana, Hordeum vulgare, Oryza sativa, Pennisetum americanum, Setaria italica, Zea mays.*

I.2. **Vegetables** : *Abelmoschus esculentus, Benincasa hispida, Canavalis ensiformis, Capsicum annuum, Chenopodium album, Colocasia esculenta, Cucurbita pepo, Dioscorea spp.,Sechium edule,Glycine max, Ipomoea batatas, Lablab purpureus,agenaria ciceraria, Lycopersicum esculantum, Solanum melongena, S. tuberosum, Vigna umbellata, Clerodendrum colebrookianum, Zanthoxylum oxyphyllum, Z.armatum, Polygonum posumba, P. perfoliatum, Pogostemon benghalensis,Solanum torvum, S. nigrum, S. tuberosum, Colocasia affinis, C. esculenta, Atylosia goensis, Artemisia indica, Amaranthus caudatus,A. viridis, Diplazium esculentum, Sarchochlamys pulcherrima,Spondias pinnata, Eryngium foetidum etc.*

1.7.3. **Oil Seeds Crops** : *Brassica juncea, B. rugosa, Perilla frutescens* and *Sesamum orientale.*

1.7.4. **Fruits** : *Artocarpus heterophyllus, Artocarpus lakoocha, Syzgium cumini, Carica papaya, Citrus grandis, Citrus jambhiri, Citrus limon, Citrus medica, Citrus megalocarpa, Citrus sinensis, Citrus reticulata, Musa sapientum, Mangifera indica, Psidium guajaua, Pyrus malus, P. pashia, Prunus persica,* Pine apple*(Ananas comosus) Juglans regia, Litchi chinensis, Garcinia cowa,* Kiwi.*(Actinidia chinensis)*

1.7.5. **Spices** : *Amomum aromaticum, A. subulatum, Curcuma longa, Illicium griffithii, Cinnamomum tamala, Allium sativum, Houttuynia cordata, Mentha arvensis, Zingiber officinale, Ziziphus mauritiana, Z. rugosa.*

1.7.6. **Aromatic plants** : *Zanthoxylum armatum, Eryngium foetidum, etc.*

1.7.7. **Pulses** : *Cajanus cajan, cicer arietinum, Glycine max, Pueraria phaseoloides.*

1.8. **Thatching** : *Imperata cylindrica, Livistonea jenkinsiana, Saccharum spontaneum, Themeda villosa, Phyllostachys assamicus, etc.*

1.9. **Cultural materials** : *Calamus tenuis, C. flagellum, C. erectus, C. leptospadix,Daemonorops jenkinsiana, Bambusa tulda, B. pallida, Pinus wallichiana, P. roxburghii,* etc., and other timber species.

1.10. **Fuel** : *all dry trees* and *bamboos, tall grasses etc* and other timber species.

1.11. **Fodder** : Leaves of all bamboos, grasses, *Bauhinia purpurea, Eleusine coracana, Ficus dumosa, F. hispida, Themeda villosa,* all species of *Musa, Saccharum, Thysanolaena, Carex, Oryza, etc.*

1.12. **Rituals/ folklores/mythological** :*Calamus* spp, *Quercus rex, Q. lamellosa, Arundina graminifolia,Elaeocarpus sphaericus, Rhododendron* spp, *Pinus* spp, *Tsuga dumosa,Entada phasoloides.*

1.13. **Ornaments**: *Calamus erectus, C.tenuis,C.leptospadix, Daemonorops jenkinsiana, Bambusa tulda, B. pallida, Dendrocalamus hamiltonii, etc..*

1.14: **Detergents**:*Sapindus mukorossi, Gymnocladus assamicus, Entada purseatha.*

1.15. **Decoration**: Orchids, *Cryptomeria japonica, Polyalthia longifolia var pendula, Araucaria heterophylla,* Ferns and showy flowers

1.16. **Dye yielding**: *Rubia manjith, Acacia catechu, Viburnum foetidum, Eclipta alba, etc.*

1.17. **Broom**: *Thysanolaena maxima, Sida rhombifolia, Caryota urens, Saccharium spontaneum, Zalacca secunda* Bamboos, *Calamus sp. Wallichia densiflora., Imperata cylindrica, etc.*

1.18. **Beverages** : *Eleusine coracana, Oryza sativa, Saurauia roxburghii, Zea mays.*

I.19. **Important Timber yielding species:**

Botanical Name(s)	Local name	Family
Ailanthus grandis	Borpat	Simaroubaceae
Albizia lucida	Moz	Leguminosae
Adina oligocephala	Halud-Sopa	Rubiaceae
Alstonia scholaris	Satiana	Apocynaceae
Anthocephalus chinensis	Kadam	Rubiaceae
Artocarpus chaplasha	Sam, Cham	Moraceae
Altingia excelsa	Jutuli	Hamamelidaceae
Amoora wallichii	Amari	Meliaceae
Actinodaphne obovata	Pajihuta	Lauraceae
Artocarpus lakooha	Dewa-Chali	Moraceae
Bombax ceiba	Simul	Bambacaceae
Bischofia javanica	Urium	Euphorbiaceae
Beilschmiedia sp.	Bonjolokia	Lauraceae
Bauhinia variegata	Kanchon	Leguminosae
Betula alnoides	Birch	Betulaceae
Canarium bengalensis	Dhuna	Burseraceae
C. resiniferum	Dhuna	Burseraceae
Chukrasia tabularis	Bogipoma	Meliaceae
Cinnamomum cecicodaphne	Gonsoroi	Lauraceae
Castanopsis indica	Hingori	Fagaceae
Dipterocarpus macrocarpus	Hollong	Dipterocarpaceae
Dysoxylum gobara	Lali	Meliaceae
D. alliarium	Gondhaki-Poma	Meliaceae
D. binectariferum	Bandardima	Meliaceae
Dillenia indica	Outenga	Dilleniaceae
Duabanga grandiflora	Khokon	Lythraceae
Evodia frainifolia	Maiphak	Rutaceae
Eurya acuminata	Murmura	Theaceae
Gmelina arborea	Gomari	Verbenaceae
Garcinia sp.	Thekera	Clusiaceae
Gynocardia odorata	Bandapele, Chalmugra	Flacourtiaceae
		Kydia calycina
Pichola	Malvaceae	
Lannea coromandelica	Jia	Anacardiaceae
Lagerstroemia speciosa	Jarul, Ajaar	Lythraceae
Michelia baillonii	Tita-Sopa, Khorika-Sopa	Magnoliaceae
M. champaka	Champ	Magnoliaceae
Mesua ferrea	Nahar	Guttiferae
Morus laevigata	Bola	Moraceae
Magnolia pterocarpa		
Barampthuri-Sopa	Magnoliaceae	*M. hodgsonii*
Boromthuri,	Magnoliaceae	Dat-bhda
Pterospermum acerifolium	Hatipolia	Sterculiaceae
Phoebe paniculata	Mekahi	Sterculiaceae
Pinus roxburghii	Chir Pine	Pinaceae
P. wallichiana	Blue Pine	Pinaceae
Picea morinda	Spruce	Pinaceae
Quercus sp.	Oak	Fagaceae
Sloarea sterculiacea var. *assamica*	Joba-Hingori	Elaeocarpaceae
Syzygium cumini	Jamuk	Myrtaceae
Shorea assamica	Mekai	Dipterocarpaceae
Sterculia villosa	Udal	Sterculiaceae
S. indica	Pahari	Sterculiaceae

Schima wallichii	Gogra, Makrisal	Theaceae
Terminalia myriocarpa	Hollock	Combretaceae
T. bellirica	Bohera	Combretaceae
T. chebula	Hilika	Combretaceae
Tetrameles nudiflora	Bhelu	Combretaceae
Toona ciliata	Toon, Poma	Meliaceae
Talauma phellocarpa	Titasopa, Khorikasopa	Magnoliaceae
Trewia nudiflora	Bhelkar, Merua	Euphorbiaceae
Artocarpus chaplasha	Sam	Moraceae
Castanopsis hystrix	Hingori	Fagaceae
Dillenia indica	Outenga	Dilleniaceae
Stereospermum chelonoides	Paroli	Bignoniaceae

I.19. **Rattans/ Canes**

Following species of Canes/ Rattans are found in different localities of Arunachal Pradesh (*cf*.Thomes & Haridasan *in Arunachal Forest News 17: 26-28. 1999). Name in* bracket are the local names.

1. *Calamus leptospadix* (Lejai)
2. *C. tenuis* (Jati)
3. *C. floribundus* (Lejai)
4. *C. flagellum* (Raidang)
5. *C. erectus* (Jenk)
6. *C. acanthospathus* (Jati)
7. *C. gracilis* (Chuli)
8. *C. inermis* (Takat)
9. *C. nambariensis* (Hooka)
10. *C. latifolius* (Takat/ Hooka)
11. *C. khasianus* (Takat)
12. *Daemonorops jenkinsianus* (Raidang)
13. *Plectocomia himalayana* (Dorrey)
14. *P. bractealis* (Panibet)
15. *P. assamica* (Hati bet)
16. *Zatacca secunda* (Jenk).

Government of Arunachal Pradesh has established cane garden (Canetum) at Karsingsa and Chessa wherein 14 species have been grown.

I.20. **Bamboos**

Botanical Names	**Locality of occurence**
Arundinaria gracilis	West Kameng
A. maling	West Kameng, Tawang
A. racemosa	West Kameng, Tawang
Bambusa balcooa	Tirap, Changlang, Lohit, D. Valley, East Siang, West Siang, Lower, Upper Subansiri, Papum Pare, West Kameng, East Kameng.
B. cacbarensis	West Siang
B. bambos	Papum Pare
B. glauascens	Papumpare
B. longispiculata	West Siang
B. mastersii	Lower Subansiri
B. multiplex	East Siang
B. nana	Papumpare
B. nutans	Tirap, Lohit, D.Valley, East Siang, Lower and Upper Subansiri, Papum Pare, West Kameng, East Kameng.
B. pallida	Tirap, Lohit, D.Valley, East Siang, Lower and Upper Subansiri, Papum Pare, West Kameng, East Kameng.
B. polymorpha	Lower Subansiri
B. pseudupallida	Lower part of Arunachal Pradesh
B. tulda	Tirap,Changlang, Lohit, D.Valley, East Siang, Lower and Upper Subansiri, Papum Pare, West Kameng, East Kameng.
B. vulgaris	Papum Pare
B. ventricosa (B.wamin)	Papum Pare
Chimonobambusa callosa	Lohit, D.Valley,Upper Subansiri, West Kameng, Tawang, PapumPare.

Dendrocalamus asper	Papumpare
D. giganteus	Lohit, Upper Subansiri, Papum Pare, East Siang.
D. hamiltonii	Tirap, Changlang, Lohit, D.Valley, Upper Siang, East Siang, West Siang, Lower and Upper Subansiri, Papum Pare, West Kameng, East Kameng.
D. hookeri	Papum Pare
D. membranaceus	Papumpare
D. patellaris	Papum Pare
D. sahnii	Lower Subansiri
D. sikkimensis	West Kameng
D. strictus	Papumpare
Gigantochloa albociliata	Lohit, Papum Pare
Meloconna baccifera	Tirap, Papum Pare
M. bambusoides	Papumpare
Phyllostachys bambusoides	Lohit, D.Valley, Lower Subansiri, Papum Pare,West Kameng.
P. assamica	Upper Subansiri
P. manii	Upper Subansiri
P. pubescens	Lower Subansiri
Pleioblastus simonii	Lower Subansiri
Pseudostachyum polymorphum	Papum Pare, W.Kameng, E.Kameng, Lower Subansiri, Upper Subansiri
Schizostachyum arunachalensis	West Siang
S. fuchsianum	Lohit, Dibang Valley, West Siang, Upper Subansiri
S. helferii	
S. latifolium	Lohit, West Kameng
S. pallidum	West Kameng
S. pergracile	Lohit, Papum Pare
S. polymorphum	Lohit, Papum Pare
Sinarundinaria elegans	West Kameng
S. griffithiana	Tawang
S. hirsuta	Lohit, West Kameng, Tawang
S. bookeriana	West Kameng
S. intermedia	West Kameng, Tawang
S. pantlingii	Lohit, West Kameng
S. suberecta	Tawang
Teinostachyum dulooa	
Thamnocalamus aristatus	Lohit, Tawang, East Kameng
Thyrostachys oliverii	Tirap, Papum Pare
T. regia	Papum Pare

I.21. **Medicinal Plants**

Arunachal Pradesh is the abode of medicinal plants. A large number of reports have been published from time to time, but a detailed work on medicinal flora of this state is yet to be published. Some medicinal plants with their common name(s) and uses are given below :

S.N.	Botanical Name(s)	Common Name(s)	Uses
1.	*Abroma augusta*	Ulatkamal	Root, unterine tonic and emanagogue; stem bark for checking rectocele, leaves for uterine disorders diabetes; rheumatic pain and sonusitis; seed oil for lowering cholectrol level in blood.
2.	*Aconitum ferox*	Aconite, Bish	An extremely poisonous plant used for nasal caterrh, tonsilitis, sore throat, gastric disorders, debility and fever of inflammatory origin; also used as sedative

			and daiphoretic, applied for relieving pain and rheumatism. Paste used for poisoning arrows in hunting.
3.	*A. heterophyllum*	Atis root	Highly medicinal as febrifuge and tonic. Roots for hysteria, throat infection, dyspepsia and vomiting. Also for abdominal pain and diabetes.
4.	*Aloe vera*	Ghrit-kumari	Leaf cut and the mucilage applied to cuts and burns also for dermatitis.
5.	*Alpinia galanga*	Kulanjan	For rheumatism bronchial catarrh, stimulant and carminating.
6.	*Andrographis paniculata*	Chiraita teeta	Anthelmintic (for worms in Kalmegh kids), fever, jaundice, liver tonic, blood purifier, diabetes, stomach ailments.
7.	*Aquilaria agallocha*	Agar	Oil from transformed hard wood known as *agar wood* on distillation for perfumery and is stimulant, tonic and carminative.
8.	*Asparagus racemosus*	Satamul	Tuber coolant and demulcent and also for fever.
9.	*Azadirachta indica*	Neem	Leaves for skin diseases, fever, insecticidal also as tonic, twigs as tooth brush, seeds yield oil for antiseptic soaps and creams, bark boiled in water for pain relief.
10.	*Abrus precatarius*	Leturmani	Climbers with shinning red and black Ghumchi marked seeds, used in swelling nervous disorders, fever and as contraceptive.
11.	*Achyranthus aspera*	Apamarg,	Herbs with deflex spiny fruits on spikes; leaves and seeds Latjeera used in skin diseases, wounds, piles, etc.
12.	*Aegle marmelos*	Bel	Thorny trees with trifoliate leave and ball like fruits. Root one of the Dasamoola, fruit for diarrhoea and constipation, coolant.
13.	*Ammi majus*	-	Herbs with beautiful white umbels used in leucoderma.
14.	*Artemisia annua*	-	Annual herbs, aromatic, used as a source of malarial drug.
15.	*A. nilagirica*	-	Aromatic herbs, used as inscence, anthemintic, antiseptic and antispasmodic.
16.	*Berberis aristatus*	Indian	Bitter tonic for intermittant berberis fever, bark for eye lotion, yields alkaloid berberin and is a dye.
17.	*Bacopa monnieri*	Brahmi	Aquatic or amphibian herbs, used in insanity, mental weakness, epilepsy, etc. Also in fever, oedema, anaemia, etc.
18.	*Boerhaavia diffusa*	Punarnava	Prostrate herbs with reddish stems and small pink flowers. Roots used in anaemia, asthma, internal inflammation, food poisoning, oedima, etc.
19.	*Caesalpinia crista*	Karanju	Nuts and bark considered to be tonic, and bark emmenag ogue and anthelmintic.
20.	*Centella asiatica*	Thankuni	A general tonic, improves physical strength, digestive power, intellectual faculties and memory power. Also

			used in leprosy.
21.	*Coptis teeta*	Mishmi teeta	Tonic and stomachic used for debility, locally used in dysen tery, diarrhoea and fever.
22.	*Costus speciosus*	Keu	Bitter, astringent, purgative, anthelmintic. An alternative source of diosgenin, locally used in case of diabetes.
23.	*Caesalpinia bonduc*		Prickly shrubs with densely prickly pods, leaves for curing liver problems, oil from seeds for stoping ear discharges and nervous complaints.
24.	*Cardiospermum helicacabum*	Baloon-vine	Plant used in rhematism, ear ache and nervous disorders.
25.	*Catheranthus roseus*	Sadabahar	An anticancer drug yielding plant, till recently with a wide market. The leaves are used against diabetes.
26.	*Cissus quadrangularis*	Harjora	Stems used in case of fracture also for ulcers, epileptic fits, scurvy etc.
27.	*Dioscorea floribunda*		The plant is a source of the steroidal alkalloid Diosgenin which is widely used by pharmaceutical industry.
28.	*Embelia ribes*		Fruits used in the treatment of fever, bronchitis and diseases and chest and skin, roots for cough and diarrhoea.
29.	*Eclipta prostrata*	Bringhraj	Herbs for marshy and wet areas with white head. Used as hair tonic.
30.	*Fritillaria cirrhosa*	Yathu	For diseases like tuberculosis, Asthma, Bronchitis, etc.
31.	*Gaultheria fragrantissima*	-	Fruits edible, leaves yield winter green oil, used for rheumatism, muscular pain and as antispetic. Also said to be stimulant ans carminative.
32.	*Gymnadaenia orchidis*	Panch Hath	Supposed to be an adaptogen; the tubers helps in improving general health, also in diarrhoea, dysentary, fever, etc; locally used to reduce abdominal swellings.
33.	*Gmelina arborea*	Gamari	Flowers are eaten as a vegetable. Flowers and fruits are colling, diuretic and astringent. Root is one of the ingredients of the Aurvedic preparation Dasamoola. It helps gain appetite. Also used in fever and urinary discharges.
34.	*Garcinia pedunculata*	Thekra	The fruit is used to cure diarrhoea and dysentery; fruits are dried and stored.; aqueous extract is used in the treatment.
35.	*Gynocardia odorata*	Chalmugra	The oil extracted from seeds used to cure skin diseases, leprosy etc.
36.	*Gloriosa superba*	Glory lily	Climbers with leaftendrils and beautiful orange yellow flowers. Used in colic and skin diseases.
37.	*Holarrhaena*	*antidysentrica*	Dhudhi Bark and fruits for diarrhoea and dysentary. Seeds are also used for bleeding piles.
38.	*Hypericum spp.*		Astringent; plants also show some anti HIV/cancer activity.

39.	*Hemidesmus indicus*	-	Linear leaves and aromatic roots are used in skin diseases and fever.
40.	*Helinia elliptica*	-	As a substitude and adulterant in place of *Swertia chiraita*
41.	*Illicium griffithii*	Lissi	Carminative; improves appetite.
42.	*Jatropha glandulifera*	-	Bark used for gastric problems and abdominal swellings.
43.	*Leucas lavandulaefolia*	Dron	Decoction of leaves is used as vermifuge, stomachic; leaf - paste is used for skin disease. The whole plant is used in fever.
44.	*Mucuna pruriens*	-	Shinning red and black marked seeds used in swelling nervous disorders, fever and as contraceptive.
45.	*Ocimum sanctum*	Tulsi	Stimulant; expectorant, and used in bronchitis, ringworm and other skin diseases; decoction of roots for fever.
46.	*Oroxylum indicum*	Bhat ghila	Bark is purgative and stomachic also used against rhematism fruit is expectorant and increases appetite, also used in the treatment of leucoderma. Roots are used in preparation of "Dasamoola.." Root bark is used as tonic and against diar rhoea.
47.	*Panax pseudo-*	Ginsengs	An adaptogen, aqueous extract an alround tonic, used against *-gingeng.* depression and fatigue. Promotes mental alertness and well being.
48.	*Phyllanthus amarus*	Bhui Amla	Plant is astrigent, coolant; roots leaves or whole plant is used in fresh forms for jaundice, also for urino-genital infections powdered leaves for ulcers and swellings, leaf paste for sores.
49.	*Phyllanthus emblica*	Amlaki	An ingradient of Triphala, Chyvanapras and other Ayurvedic preparations. It is a rich source of vitamin C. fruits are used in a variety of diseases like vomiting, urinary problems, leprosy, constipation, anemia, fever, cold etc. Bark a stringent. A general tonic.
50.	*Plumbago zeylanica*	-	Roots used in skin diseases, leucoderma, dyspepsia and influenza.
51.	*Podophyllum*	*hexandrum*	Papra Rhizomes purgative, vermi fuge and yields an alkaloid for treating some form of cancer, fruits edible.
52.	*Piper nigrum*	Golmirch	Fruits pungent used as condiment and in case of cough, weakness,fever, arthritis, etc.
53.	*Rauvolfia serpentina*	Sarpagandha	Yields alkaloid capable of reducing blood pressure. A remedy for anxiety and mental troubles. It is a sedative and tranquilizer. Also promotes uterine contraction during difficult delivery.
54.	*R..tetraphylla*		Though slightly lower in alkaloid content it is used as a sub stitute of *R.serpentina* and as an adulterant. Stem, bark and leaves also yield some alkaloids and fruits yield a dye.

55.	*Rheum emodi*	Indian Rhubarb	Purgative, astringent, stimulant; used in dyspepsia.
56.	*Rubia manjith*	Manjista	Used in various Ayurvedic preparations; also for colouring medicinal oils.Tonic,. astringent, antidysenteric and antiseptic. Also used for ulcers, skin rashes and inflammations, ingredient in septillin.
57.	*Solanum khasianum*	Bonbaigan	A rich source of the steroidal alkaloid solasodine.
58.	*Swertia chirata.*	Chiraita	Tonic and febrifuge.
59.	*Santalum album*	Chandan	Trees with fragrant roots yielding *(planted) sandal oil, paste of wood in headach and skin* diseases.
60.	*Scoparia dulcis*	-	Herbs, older stems sweet; leaves said to be useful in jaundice; root for mental troubles.
61.	*Sida cordifolia*	-	Roots leaves and seeds are used in *spermatarrhoea fever, paralysis, dysentery etc; also* said to be aphordisiac.
62.	*Smilax* spp.	-	Root as substitute for *Hemidismus indicus.*
63.	*Spilanthus paniculatus*	Akalkara, Marsang	Herbs produce tingling effect when chewed; good for tooth-ache.
64.	*Taxus wallichiana*	Himalayan yew	Leaves contain *Taxol* used as an anticancer drug.
65.	*Terminalia bellirica*	Bahera	Fruits are one of the ingredient of *Triphala*, used in liver diseases, bronchitis, asthma, heart problems,diabetes dropsy, diarrhoea ,etc.; also as tonic, laxative and antipyretic.
66.	*Terminalia chebula*	Harra	Another ingredient of the Ayurvedic preparation *Triphala.* A tonic, particularly for liver. It is an astringent, laxative, carminative and expectorant; also used in leucoderma, piles and anaemia.
67.	*Tinospora cordifolia*	Guruchi	Used against general debility, dyspepsia, fever and urinary diseases; also used against urinogenital infections. Fruits used in rheumatism ;young leaves for curing boils and swellings; said to be an alterative and aphrodisiac.
68.	*Valeriana wallichii*	Taggar	Used in hysteria, nervous unrest, emotional troubles as sedative and tranquilizers.
69.	*Vetiveria zizanoids*	Khus-khus	Tall grasses with aromatic roots, infusion of roots as refrigerant, febrifuge stimulant and stomachic.
70.	*Withania somnifera*	Ashwagandha	Root for sexual vigour and vitality also hiccup, dropsy and rheumatism; leaves as febrifuge and applied to lesions and painful swellings.

I.22. **Pipers**

Gajurel & Rethy (1998) have recorded the occurence of 20 species of *genus Piper* L. viz. *Piper betle, P. nigrum, P. longum, P. attenuatum, P. aurantiacum, P. boehmeriaefolium, P. hamiltonii, P. hymenophyllum, P. lonchites, P. mullesua, P. pedicellatum, P. peepuloides, P. rytidocarpum, P. sylvaticum, P. schmidtii, and P. thomsoni,* in Arunachal Pradesh.

I.23. **Wild Edible Plants**

Botanical Name(s)	Parts used
RANUNCULACEAE	
Caltha palustris L.	Roots & leaves (after boiling only)
Ranunculus scleratus L.	Whole plant (after boiling only)
ACTINIDIACEAE	
Actinidia strigosa Hook. f. & Thoms.	Fruits
A. callosa Lindl.	Ripe fruits
DILLENIACEAE	
Dillenia indica L.	Ripe fruits
D. pentagya Roxb.	Ripe fruits
SAURAUIACEAE	
Saurauia napaulensis DC.	Ripe fruits
MAGNOLIACEAE	
Kadsura heteroclita (Roxb.) Craib	Fruits
SCHISANDRACEAE	
Schisandra grandiflora Hook. f. & Thoms.	*Fruits*
MENISPERMACEAE	
Aspidocarya uvifera Hook. f. & Thoms.	Fruits
BERBERIDACEAE	
Berberis aristata DC.	Ripe fruits
B. aristana Roxb. ex DC	Fruits
Mahonia nepalensis DC.	Fruits
LARDIZABALACEAE	
Decaisnea insignis Hook. f. & Thoms.	Ripe fruits
Holboellia latifolia Wall.	Ripe fruits
BRASSICACEAE	
Capsella bursa-pastoris (L.) Medikuz	Whole plant
Cardamine hirsuta var. *sylvatica* (Link) Hook. f. & T. Anders	Leaves & flowers
C. loxostemonoides O.E. Schultz.	Whole plant
Rorippa islandica (Oeder) Borbass.	Leaves
PAPAVERACEAE	
Meconopsis napaulensis DC.	Seeds
M. paniculata (D.Don) Prain	Stalks as salad
CAPPARACEAE	
Crataeva magna (Lour.) DC.	Young leaves & fruits
Stixis suaveolens (Roxb.) Pierre	Ripe fruits
FLACOURTIACEAE	
Casearia glomerata Roxb.	Tender shoots & young leaves as vegetable or with rice
Gynocordia odorata R. Br.	Fruit-pulp after boiling
POLYGALACEAE	
Polygala arillata Buch.-Ham. ex D.Don	Fruits
CARYOPHYLLACEAE	
Drymaria cordata (L.) Willd. ex Roem. & Schult	Leaves
PORTULACACEAE	
Portulaca oleracea L.	Young shoots
CLUCIACEAE	
Garcinia stipulata T. Anders	Fruits
G. xanthochymous Hook. f.	Fruits
THEACEAE	

Camellia kissi Wall.	Leaves as tea
DIPTEROCARPACEAE	
Shorea robusta Gaertn. f.	Seeds
MALVACEAE	
Malva verticillata L.	Leaves and tender shoots cooked
BOMBACACEAE	
Bombax ceiba L.	Calyces, tender fruits & seeds after roasting
STERCULIACEAE	
Abroma augusta L. f.	Seeds
Firmiana fulgens (Wall. ex Masters)Corner.	Tuberous roots
Melochia corehorifolia L	Young leaves
Pterigota alata (Roxb.) R. Br.	Seeds after roasting
Sterculia indica Merr.	Tender fruits cooked & seeds after roasting
S. lanceaefolia Roxb.	Roasted/ Baked seeds
TILIACEAE	
Grewia asiatica L.	Ripe fruits
G. elastica Royle	Ripe fruits
G. sapida Roxb.	Fruit pulp
G. sclerophylla Roxb. ex G. Don	Fruits
ELAEOCARPACEAE	
Elaeocarpus lanceaefolius Roxb.	Fruits
E. sikkimensis Mast.	Fruits
OXALIDACEAE	
Oxalis acetosella L.	Leaves
O. corniculata L.	Leaves
BALSAMINACEAE	
Impatiens racemosa DC.	Seeds
I. sulcata Wall.	Seeds
I. roylei Walp.	Seeds
I. glandulifera Royle	Seeds
I. helferi	Leaves
RUTACEAE	
Clausena dentata (Wild.) M. Roem.	Fruits
Evodia fraxinifolia (D.Don) Hook. f.	Fruits
Fagara hamiltoniana (Wall. ex Hook. f.) Engl.	Fruits
F. oxyphylla (Edgew.) Reader & Cheo	Tender shoots are cooked
Glycosmis pentaphylla (Retz) Corr.	Ripe fruits
Toddalia asiatica (L.) Lamk.	Fruits & leaves
SIMAROUBACEAE	
Picrasma quassiodes (D.Don) Benn.	Fruits
BURSERACEAE	
Canarium benghalense Roxb.	Fruits
Garuga pinnata Roxb.	Fruits
MELIACEAE	
Aglaia edulis (Roxb.) A Gray	Fleshy part of fruit
Melia composita Willd.	Fruits
ICACINACEAE	
Natsiatum herpeticum Buch. -Ham.	Leaves and slender shoots are cooked
CELASTRACEAE	
Celastrus paniculatus Willd.	Boiled unripe fruits as vegetable
RHAMNACEAE	
Gouania napalensis Wall.	Young leaves
Hovenia acerba Lindl.	Inflorescence stalk
Ziziphus apetala Hook. f. ex Lawson	Ripe fruits
Z. rugosa Lamk.	Ripe fruits

VITACEAE	
Ampelocissus barbata (Wall.)Planch	Fruits
Cayratia trifolia (L.) Domin	Young leaves & stem boiled.
Cissus adnata Roxb.	Leaves cooked
C. repens Lamk.	Leaves & tender shoots
Parthnocissus himalayana(Royle) Planch.	Fruits
Tetrastigma bracteolatum (Wall.) Planch	Fruits
T. dubium (Lawson) Planch	Fruits
T. planicaulata (Hook. f.) Gagnep	Water from stem
T. rumicispermum (Laws.) Planch	Fruits
LEEACEAE	
Leea macrophylla Roxb. *ex* Hornem.	Ripe fruits and young leaves
SAPINDACEAE	
Aphania rubra (Roxb.) Radlk.	Ripe-fruits
Erioglossum rubiginosum (Roxb.) Bl.	Ripe fruits eaten; leaves & shoots as veg. etible
Acer caudatum Wall.	Sweet-sap obtained by making holes in trunk
STAPHYLEACEAE	
Turpinia pomifera (Roxb.) DC.	Fruits
SABIACEAE	
Meliosma pinnata (Roxb.) Maxim.	Tender leaves
ANACARDIACEAE	
Mangifera sylvatia Roxb.	Fruits
Pegia nitida Colebr.	Tender leaves
Poupartia axillaris (Roxb.)King & Prain	Ripe fruits eaten; inner bark chewed as areca nut
Rhus griffithii Hook. f.	Tender leaves as vegetable
R. javanica L.	Ripe fruits
Spondias pinnata (L.f.) Kurz	Flower buds in curry; fruits (young) pickled, ripe fruits eaten.
FABACEAE	
Indigofera atropurpurea Buch. -Ham.ex Hornem	Flowers as vegetable
Abrus precatorius L.	Leaves chewed with pan
Desmodium microphyllun (Thunb.) DC.	Young leaves as vegetable
Eriosema himalaicum Ohashi	Tuberous rootstock edible
Moghania macrophylla (Willd.) O. Ktze	Pods
Pueraria tuberosa	Tubers & new shoots
(Roxb. *ex* Willd.) DC.	Tubers & new shoots
Smithia sensitiva Ait.	Young leaves
CAESALPINACEAE	
Bauhinia purpurea L.	Flower buds & ripe seeds
B. vahlii Wt. & Am.	Tender pods cooked, seeds eaten after roasting
B. variegata L.	Flower buds & young leaves as vegetable
Cassia fistula L.	Young leaves & flower buds
C. occidentalis L.	Young leaves & flower buds; seeds as Coffee
C. sophera L.	Young leaves cooked
ROSACEAE	
Docynia indica (Wall.) Decne	Fruits
Fragaria nilgerrensis Schlectt. *ex* f. Gay	Fruits
F. nubicola Lindl. *ex* Lacaita	Fruits and rootstock as tea
Mallus baccata (L.) Borkh.	Fruits
Prinsepia utilis Royle	Seed-oil edible
Prunus undulata Buch.-Ham. ex D.Don	Fruits
P. cerasoides D.Don	Fruits, also used for making brom
P. cornuta (Wall. ex Royle) Stand.	Fruits
Rosa macrophylla Lindl.	Ripe fruits
R. sericea Lindl.	Fruits
Rubus biflorus Buch. -Ham. *ex*	Fruits
R. calycinus Wall.	Fruits
R. ellipticus Sm.	Fruits
R. fruticosus var. *discolor Hook. f.*	Fruits

R. lineatus Reinw.	Fruits
R. macilentus Camb.	Fruits
R. rugosus	Fruits
R. niveus Thunb.	Ripe fruits
R. paniculatus Sm.	Fruits
R. rosifolius Sm.	Fruits
Sorbus cuspidata (Spach.) Hedl.	Fruits
CRASSULACEAE	
Rhodiola discolor (Franch.) Fu	Leaves as salad or cooked as vegetable
COMBRETACEAE	
Terminalia bellirica (Gaertn.)Roxb. *ex* Flaming	Seed kernel
T. chebula Retz.	Seed kernel
MYRTACEAE	
Syzgium claviflorum (Roxb.) Wall *ex.* Cowan & Cowan	Fruits
S. cumini (L.) Skeels	Fruits
S. formosa Wall.	Fruits
S. kurzii Duthie	Fruits
S. wallichii (Wt.) Walp.	Fruits
S. tetragonum Wall. *ex* Walp.	Fruits
LECYTHIDACEAE	
Careya arborea Roxb.	Root-bark pounded & ground to make bread
MELASTOMATACEAE	
Medinilla erythrophylla Lindl.	Leaves, cooked fruits edible
Melastoma malabathricum L.	Fleshy placenta & seed
LYTHRACEAE	
Woodfordia fruticosa (L.) Kurz	Flowers
CUCURBITACEAE	
Coccinia grandis (L.) Voigt.	Unripe fruits and tender shoots as vegetable
Diplocyclos pabmatus (L.) C. Jeffrey	Young leaves as vegetables
Hodgsonia heteroclita (Roxb.) Hook. f. & Thoms.	Seed - kernel
Momordica dioica Roxb. *ex* Willd.	Leaves, fruits & roots
Mukia maderaspatana (L.) Roem.	Unripe & ripe fruits
Solena heterophylla Lour.	Whole plants
BEGONIACEAE	
Begonia roxburghii (Miq.) DC.	Leaves as pot herb
B. hatacoa Buch.-Ham. *ex* D.Don	Leaf-stalks
APIACEAE	
Bupleurum falcatum L. var. *marginata* Clarke	Roots
Oenanthe thomsonii Clarke	Leaves
ARALIACEAE	
Trevesia palmata (Roxb.) Vis.	Flower-buds cooked; fruits eaten
Panax pseudoginseng Wall.	Roots
CORNACEAE	
Swida macrophylla (Wall.) Sojak.	Fruits
CAPRIFOLIACEAE	
Lonicera angustifolia Wall. *ex* DC	Fruits
SAMBUCACEAE	
Sambucus hookeri Rehder	Leaves
Viburnum nervosum D. Don	Fruits
V. cordifolium Wall. *ex* DC.	Ripe fruits
RUBIACEAE	
Chassalia curviflora (Wall.) Thw.	Leaves
Galium aparine L.	Seeds as substitute of coffee
Gardenia campanulata Roxb.	Leaves cooked

Mussaenda roxburghii Hook. f.	Leaves as vegetable
Oldenlandia auricularia (L.) K.Schum.	Leaves
Hedyotis scandens Roxb.	Leaves
Pavetta indica L.	Fruits
Randia longispina (Roxb.) DC.	Ripe fruits roasted or cooked
DIPSACACEAE	
Dipsacus inermis Wall.	Tender shoots & young leaves are cooked
ASTERACEAE	
Sonchus asper Hill.	Tender shoots (as salad)
Spilanthes calva DC.	Leaves (as pot herb); seeds are chewed
Vernonia cinerea (L.) Less	Young leaves
CAMPANULACEAE	
Codonopsis parviflora Wall. *ex* DC.	Young leaves cooked
ERICACEAE	
Gaultheria fragrantissima Wall.	Fleshy blue calyx around fruit
VACCINACEAE	
Agapetes serpens (Wt.) Sleumer	Fruits
Vaccinum vacciniaceum (Roxb.) Sl.	Flowers
MYRSINACEAE	
Ardisia thyrsiflora D. Don	Ripe fruits
A. macrocarpa Wall.	Fruits
Embelia gamblei Kurz *ex* Cl.	Leaves
E. undulata (DC.) Mez.	Leaves cooked with fish, fruits eaten
Maesa argentea Wall.	Fruits
M. chisia D. Don	Young shorts & fruits
SAPOTACEAE	
Aesandra butryacea (Roxb.) Bachmi	Seeds
OLEACEAE	
Olea gamblei Clarke	Fruits
APOCYNACEAE	
Melodinus monogynus Roxb.	Fruit - pulp
Wrightia arborea (Dennst) Schluss.	Leaves as vegetable
ASCLEPIADACEAE	
Holostemma adakodien J. A. Schultes	Leaves and flowers as vegetable
Marsdenia roylei Wt.	Roots
LOGANIACEAE	
Buddleja asiatica Lour.	Flowers cooked; roots powder used in preparation of a liquor
CORDIACEAE	
Cordia dichotoma Forst. f.	Ripe fruits & flowers
Ehretia acuminata var. *serrata*	Fruits
E. laevis Roxb.	Fruits & innerbark
SOLANACEAE	
Solanum surattense Burn. f.	Fruits
S. crassipetalum Wall.	Leaves cooked
S. anguivi Lour.	Fruits as vegetable
S. indicum L.	Fruits
S. erianthum D. Don	Fruits
S. verbascifolium L.	Fruits cooked
S. nigrum L.	Young shoots, leaves & ripe fruits
S. viarum Dunal	Fruits
GESNERIACEAE	
Rhynchotechum ellipticum A. DC.	Leaves as vegetable
BIGNONIACEAE	
Oroxylum indicum (L.) Vent	Flowers & seeds
ACANTHACEAE	
Phlogacanthus thyrsiflorus (Roxb.) Nees	Flowers as vegetable
Thunbergia grandiflora	Leaves as vegetable

VERBENACEAE	
Clerodendrum colebrookianum Walp.	Young leaves
C. indicum (L.) O. Ktze	Leaves as vegetable
Gmelina arborea Roxb.	Fruits
Premna mucronata Roxb.	Bark
Pygmaeopremna herbacea (Roxb.) Moldenke	Ripe fruits
LAMIACEAE	
Leucas cephalotes Spr.	Young leaves as pot herb
L. lanata Benth.	Tender shoot
Mentha longifolia (L.) Hudson	Leaves
Origanum vulgare L.	Tender shoots as vegetable
Perilla frutescens (L.) Britton	Leaves as vegetable; seed yield oil
NYCTAGINACEAE	
Boerhavia diffusa L.	Young leaves
AMARANTHACEAE	
Alternanthera sessilis (L.) DC.	Tender shoots and leaves are eaten at pot herb or soup
Amaranthus spinosus L.	Tender shoots and leaves the year
CHENOPODIACEAE	
Chenopodium album L.	Stem & leaves as salad or vegetable
C. murale L.	Leaves
PHYTOLACCACEAE	
Phytolacca acinosa Roxb.	Leaves cooked
POLYGONACEAE	
Aconogonum molle (D.Don) Hara	Leaves
Bistorta vivipara (L.) S.F. Gray	Young leaves
Oxyria digyna (L.) Hill.	Young leaves as salad
Persicaria glabra (Willd.) Gomes	Leaves
P. polystachyum H. Gross	Young leaves & shoots
Rheum nobile Hook. f. & Thoms.	Acidulous stem is eaten, dried leaves used as tobacco
Rumex hastatus D.Don	Young leaves & shoots
Rheum spiciformae Royle	Leaves cooked
SAURURACEAE(Piperaceae)	
Houttuynia cordata Thunb.	Rootstocks as vegetable; leaves eaten
LAURACEA	
Litsea cubeba (L.) Pers	Fruits
Machilus edulis King *ex* Hook. f.	Fruits eaten
PROTEACEAE	
Helicia nilagirica Bedd.	Fruits edible
ELAEAGNACEAE	
Elaeagnus infundibularis Momiyama	Ripe fruits
SANTALACEAE	
Pyrularia edulis (Wall.) DC.	Fruits eaten
EUPHORBIACEAE	
Antidesma acidum Retz	Fruits
A. acuminatum Wall.	Fruits edible
A. bunius (L.) Spr.	Leaves & juicy fruits eaten
A. diandrum (Roxb.) Roth.	Leaves as chutney, fruits pickled or eaten raw
Antidesma dioica (Roxb.) Muell.-Arg.	Fruits
A. ghaesembilla Gaertn.	Fruits are eaten; leaves as chutney
Aporasa octandra (Buch.-Ham. *ex* D.Don) A. R. Vickery	Fruits
Baccaurea ramniflora Lour.	Aril around seed coat
Bridelia retusa (L.) Spreng	Ripe fruits
B. stipularis (L.) Bl.	Fruits
Phyllanthus emblica L.	Fruits
Euphorbia hirta L.	Tender shoots & leaves
Pterococcus corniculatus (Sm.)	Leaves as vegetable.

Pax. & Hoffm.	
Sapium baccatum Roxb.	Fruits
Securinega virosa (Roxb. *ex* Wild) Pax & Hoffm.	Fruits
CANNABACEAE	
Cannabis sativa L.	Roasted seeds
URTICACEAE	
Debregeasia longifolia (Burm. f.) Wedd.	*Ripe fruits*
D. wallichiana Wedd.	Fruits
Girardinia diversifolia (Link) Friis	Leaves & young shoots
Laportea terminalis Wt.	Boiled tender shoots
Pouzolzia sanguinea (Bl.) Merr.	Leaves as veg.; barkpowder during scarcity
Urtica ardens Link	Young leaves and apical portion of branches after boiling
U. dioica L.	Young shoot-tops as pot herb & seeds
U. hyperborea Jacq.	Young leaves cooked as pot herb
Urtica mairei H. Lev.	Young leaves
ULMACEAE	
Gironniera cuspidata (Blume) Kurz.	*Fruits*
MORACEAE	
Artocarpus lakoocha Roxb.	Fruits
Ficus auriculata Lour.	Fruits as vegetable
F. geniculata Kurz	Young leaves are cooked
F. hirta Vahl	Young leaves
F. hispida L.f.	Unripe fruits as vegetable
F. nerifolia Sm.	Ripe fruits
F. nemoralis (Wall. *ex* Miq.) Corner	
F. oligodon Miq.	Ripe fruits
F. racemosa L.	Ripe fruits
F. racemosa var. elongata (King) Barrett	*Ripe unpire fruits*
F. semicordata Buch. Ham. *ex* Sm.	Ripe fruits
F. virens Aif	Young shoots
Morus australis Poir	Ripe fruits
Macura cochinchinensis (Lour.) Corner	Ripe fruits
JUGLANDACEAE	
Juglans regia L.	Seeds & sap from trunk
MYRICACEAE	
Myrica esculenta Buch. -Ham. *ex* D.Don	Fruits
BETULACEAE	
Betula alnoides Buch. - Ham.	Inner portion of soft bark
CORYLACEAE	
Corylus ferox Wall.	Kernel of fruits
FAGACEAE	
Castanopsis hystrix Miq.	Nuts
C. indica (Roxb.) DC.	Fruits
C. tribuloides (Sm.) A. DC.	Fruits
Quercus glauca Thunb.	Nuts
Gymnosperms	
EPHEDRACEAE	
Ephedra gerardiana Wall. *ex* Royle	Fruits
GNETACEAE	
Gnetum montanum Markf.	Fruits
TAXACEAE	
Taxus wallichiana	Fruit edible; bark as tea
CYCADACEAE	
Cycas pectinata Griff.	Tender leaves used as vegetable; seeds are edible. Coarse sago is obtained from pith.

Angiosperms (Monocots)

ORCHIDACEAE	
Satyrium ciliatum Lindl.	Tubers
MUSACEAE	
Musa sikkimensis Kurz.	Inflorescence
M. balbisiana Colla	Inflorescence
M. rosacea Jacq.	Core of scape is taken as vegetable or is dried and made into flour
ZINGIBERACEAE	
Costus angustifolia Roxb.	Tubers
Curcuma zerumber Roxb.	Tubers yield 'Shoti' starch
HYPOXIDACEAE	
Curculigo capitulata (Lour.) Kuntz.	Fruits
C. orchiodes Gaertn.	Roots (boiled)
DIOSCOREACEAE	
Dioscorea belophylla Voigt ex Prain & Burk	Tubers
D. glabra Hook. f.	
D. bulbifera L.	Tubers Bulbils after boiling
D. hamlitonii Hook. f.	Tubers
D. hispida Dennst.	
D. daemona Roxb.	Tuber eaten after thorough processing
D. melanophylla Prain & Burk.	Tubers
D. pentaphylla L.	Leaves, flowers & tubers
D. puber Bl.	Tubers & Bulbs
AMARYLLIDACEAE	
Allium prattii C.H. Wright	Leaves for seasoning curries
apud forbes & Hemsl.	
A. wallichii Kunth.	Leaves
LILIACEAE	
Asparagus filicinus Buch. -Ham.	Tender shoots as vegetable
A. racemosus Willd.	Tuberous roots & tender shoots
Asphodelus tenufolius Cav.	Plants & seeds edible
Chlorophytum arundinaceum Baker	Flowers
Smilax zeylanica L.	Young leaves & ripened berries
Tulipa clusiana DC. f. *stellata* (Hook.) Das Gupta & Deb.	Bulbs
Drimia indica (Roxb.) Jessop	Leaves
Urginea indica Kunth.	Leaves
PONTEDERIACEAE	
Monochoria vaginalis (Burm. f.) K.B. Presl.	Young leaves
COMMELINACEAE	
Commelina benghalensis L.	Tender shoots and young leaves with flour as "pakodas"
C. maculata Edgew.	Tender shoots
ARECACEAE	
Phoenix rupicola T. Anders	Pith (raw) & ripe fruits
Wallichia disticha T. Anders	Pith of trees of the upper portion
ARACEAE	
Colocasia esculenta (L.) Schott	Young leaves, petioles
Lasia spinosa (L.) Thw.	Roots, petioles and young leaves as vegetable
Scindapsus officinalis Schott	Young leaves as vegetable
Arisaema concinnum Schott	Corns after boiling
A. speciosum (Wall.) Mart.	Corns after boiling
A. tortuosum (Wall.) Schott	Corns used in making bread
CYPERACEAE	
Cyperus rotundus L.	Young tubers
POACEAE	
Schizostachyum capitatum (Munro)	Grains (as rice)

R. Majumdar *S. fuchsianum* (Gamble) R. Majumdar	Grains (as rice)
Chimonobambusa hookeriana (Munro) Makai	Grains (as rice)
Dendrocalamus hamiltonii Neest Arn. *ex* Munro	Grains as rice & boiled tender shoots e eaten as vegetable
Thamnocalamus aristatus (Gamble) E.G. Camus	Grains
Himalayacaiamus falconeri (Hook. f. *ex* Munro) Keng. f.	Grains
	Pteridophytes
CYATHEACEAE *Cyathea spinulosa* Wall. ex Hook.	Soft tender inner part
ATHYRIACEAE *Diplazium esculentum* (Retz.) Sw.	Young fronds
DICRANOPTERIDACEAE *Dicranopteris linearis* (Burm. f.) Underw	Rhizomes yield starch
ANGIOPTERIDACEAE *Angiopteris evecta* (Forst) Hoffm.	*Flour is prepared from the rhizome*
BOTRYCHIACEAE *Botrychium virginianum* (L.) Sw.	Whole plant (boiled)
OPHIOGLOSSACEAE *Ophioglossum vulgatum* L.	Leaves
EQUISETACEAE *Equisetum debile* Roxb. *ex* Vauch.	Boiled strobili
NEPHROLEPIDACEAE *Nephrolepis tuberosa* Presl.	Tubers

1.24. **OIL-YIELDING TREES**

Botanical Name(s)	Local name(s)	Locality	Part Used
Adenanthera pavonina	Red chandan	Chessa	Seeds
Albizia arunachalensis	Siris	Sessa	Seeds
A. chinensis	Siris	Drupong	Seeds
A. falcataria	Siris	Chessa	Seeds
Albizia lucida	Moj	Chessa	Seeds
Alnus nepalensis	Alnus	Dirang	Seeds
Alangium chinense	Bogamrulia	Tarajuli	Seeds
Amblyanthus glandulosus	Alnus	Namsai	Kernel
Amoora wallichii	Amari	Sonajuli	Kernels
Antidesma acuminatum	Pani Helash	Chessa	Seeds
Aphanamixis polystachya	Pani Helash	Chessa	Kernels
Artocarpus chaplasha	Sam	Namsai	Kernels
A. heterophyllus	Kathal	Namsai	Kernels
A. lakoocha	Dewa-sali	Chessa	Kernels
Ailanthus grandis	Borpat	Chessa	Kernels
Aphonamixis polystachya	Bogamari	Bihpuria	Kernels
Baccaurea sapida	Leteku	Chessa	Kernels
Bauhinia variegata	Boga katra	Chessa	Kernels
B. purpurea	Kamchan	Chessa	Seeds
Bischofia javanica	Urium	Drupong	Seeds
Bombax ceiba	Semul	Chessa	Seeds
Brassaiopsis speciosa	Pani Helash	Pasighat	Seeds
Bridelia retusa	Kuhir	Seijusa	Seeds
Canarium strictum	Dhuna	Chessa	Kernels
Casearia vareca	Bhagini	Chessa	Seed
Cedrus deodara	Deodar	Dirang	Seeds

Chisocheton paniculatus	Baderdima	Chessa	Seeds
Cinnamomum glaucescens	Gonsorai	Bihpuria	Kernels
Claxylon khasianum	Deodaru	Chessa	Seeds
Cordia grandis	Lasora	Hayuling	Seeds
Cratava nurvala	Barun	Chessa	Kernels
Croton caudatus	Ghahe-lewa	Drupong	Kernels
C. oblongifolius	Mahunda	Chessa	Kernels
C. tiglium	Jamalgota	Namsai	Kernals
Dysoxylum procerum	Lali	Chessa	Seeds
Endospermum chinense	Phulgamari	Gangalake	Seeds
Ehretia acuminata	Jarigath	Tarajuli	Seeds
Elaeocarpus aristatus	Gahorisopa	Seijusa	Kernels
E. floribundus	Jalpai	Bihpuria	Kernels
Garcinia stipulata	Phulgamari	Sessa	Kernels
Gironniera cuspidata	Lali	Chessa	Kernals
Gnetum montanum	Mamelilet	Chessa	Kernel
Gmelina arborea	Gamari	Khorubanda	Kernels
Grevillea robusta	Silver Oak	Chessa	Seeds
Gynocardia odorata	Chaulmugra	Chessa	Kernels
Hevea brasiliensis	Rubber	Chessa	Kernels
Holigrna longifolia	Silver Oak	Sessa	Kernals
Hovenia acerba	Chetla bola	Chessa	Seeds
Jatropha curcas	Bengali	Chessa	Kernels
Kayea assamica	Sianahor	Pathalipam	Seeds
Knema angustifolia	Tezranga	Chessa	Kernals
K. linifolia	Amool	Chessa	Kernels
Kydia glabrescens	Pichola	Chessa	Seeds
Leucaena leucocephala	Subabul	Chessa	Seeds
Magnolia griffithii	Chaharisopa	Chessa	Kernels
Mallotus phillippensis	Losan	Chessa	Seeds
M. albus	Morali	Chessa	Seeds
Melia azedarach	Choraneem	Sonajuli	Kernels
M. dubia	Choraneem	Chessa	Kernels
Mesua ferrea	Nahor	Harmuty	Kernels
Michelia champaca	Titasopa	Seijusa	Seeds
Micromelum integenimum	Bonjamin	Khorubanda	Kernels
Neolitsea cuipala	Subabul	Chessa	Kernals
Olea dioica	Poreng (A)	Chessa	Seeds
Ostodes paniculata	Tasichagne	Nampong	Kernels
Pinus wallichiana	Bluepine	Dirang	Seeds
Polyalthia jenkinsii	Koliori	Chessa	Seeds
Premna latifolia	Gondari	Chessa	Seeds
Prunus jenkinsii	Tereju	Bhogpur	Kernels
Pterygota alata	Karibadam	Chessa	Kernals
Putranjiva roxburghii	Putranjiva	Chessa	Kernels
Quercus griffthii	Oak	Dirang	Kernals
Sapium baccatum	Saleng	Tarajuli	Seeds
Sapindus mukorossi	Ritha	Bihpuria	Kernels
Sterculia villosa	Udassl	Chessa	Kernels
Styrax serrulatum	Phulkat	Chessa	Kernels
Symplocos cochinchinensis	Oak	Chessa	Kernals
Syzygium kurzii	Bogajamun	Chessa	Kernals
Syzygium cuminii	Jamun	Chessa	Seeds
Talauma phellocarpa	Karikasopa	Tarajuli	Seeds
T. hodgsonii	Boranthuri	Chessa	Seeds
Terminalia bellirica	Bohera	Chessa	Kernels

Thuja orientalis	Thuza	Dirang	Seeds
Turpinia pomifera	Panil ateku	Chessa	Seeds
Vangueria spinosa	Ketkora	Drupong	Kernels
Vatica lancaefolia	Morhal	Ganga	Kernels
Zanthoxylum armatum	Panilateku	Hayuliang	Seeds

I.25. WILD ORNAMENTAL PLANTS

Name of the species	Family
Alocasia fallax Schott.	Araceae
Arenga pinnata (O.Ktze) Merr.	Arecaceae
Asparagus racemosus Willd.	Liliaceae
Aster sikkimensis Hook f.	Asteraceae
Begonia griffithiana (DC.) Warb.	Begoniaceae
B. nepalensis (DC.) Warb.	Begoniaceae
B. palmata D. Don	Begoniaceae
B. roxbirghii (Miq.) DC.	Begoniaceae
Calamus erectus Roxb.	Arecaceae
Caryota urens L.	Arecaceae
Cleome speciosa Raf.	Capparaceae
Clerodendrum colebrookianum Walp.	Verbenaceae
C. kaenpferi (Jacq.)	Verbenaceae
Hedychium coronarium Koenig	Zingiberaceae
H. gardnerianum Sheppard *ex* Ker.-Gawl	Zingiberaceae
H.spicatum Buch. Ham. *ex* Smith	Zingiberaceae
Hypericum choisianum Wallich *ex* Robson	Hypericaceae
Impatiens acuminata Benth.	Balsaminaceae
I.bicornuta Wallich	Balsaminaceae
I. brachycentra Kar. & Kir	Balsaminaceae
Ixora acuminata Roxb.	Rubiaceae
I. cuneifolia Roxb. *ex* Hook f.	Rubiaceae
Livistona jenkinsiana Griffith	Arecaceae
Lobelia pyramidalis Wallich	Lobeliaceae
Melastoma malabathricum L.	Melastomataceae
M. normale D.Don	Melastomataceae
Musa velutina Wendl. & Drude	Musaceae
Mussaenda roxburghii Hook. f.	Rubiaceae
Osbeckia nutans Wallich *ex* Clarke	Melastomataceae
O. stellata Buch.-Ham. *ex*Ker.-Gawl.	Melastomataceae
Oxyspora paniculata (D.Don) DC.	Melastomataceae
O. vagans (Roxb.) Wall.	Melastomataceae
Phoenix rupicola T.Anders	Arecaceae
Pinanga gracilis (Roxb.) Bl.	Arecaceae
Pothos scandens L.	Araceae
Rhaphidophora decursiva (Roxb.) Schott	Araceae
Scindapsus officinalis (Roxb.) Schott	Araceae
Stixis suaveolens Pierre	Capparaceae

I.26. ORNAMENTAL CLIMBERS

Antigonon leptopus	Polygonaceae
Aristolochia tagala	Arisolochiaceae
Artabotrys caudatus	Annonaceae
Asperagus racemosus	Liliaceae
Bignonia venusta	Bigoniaceae
Bougainvillea glabra	Nyctaginaceae
Calamus tenuis	Arecaceae
Cissus quadrangularis	Vitaceae
Clematis laureriana	Ranunculaceae

Clerodendrum spendens	Verbenaceae
Combretum roxburghi	Combretaceae
Crawfordia speciosa	Gentianaceae
Crytostegia grandiflora	Asclepiadaceae
Dischidia nummularia	Asclepiadaceae
Elaeagnus conferta	Elaeagnaceae
Entada purseatha	Mimosaceae
Ficus pumila	Moraceae
Fissistigma biclor	Annonaceae
Galium asperifolium	Rubiaceae
Hedera helix	Araliaceae
Holboelia latifolia	Araliaceae
Holmskioldia sanguinea	Verbenaceae
Hoya lanceolata	Asclepiadaceae
Ipomoea quamoclit	Convolvulaceae
Jasminum grandiflorum	Oleaceae
Lonicera macrantha	Caprifoliaceae
Merremia umbrella	Convolvulaceae
Mussaenda glabra	Rubiaceae
Passiflora edulis	Passifloraceae
Periploca calophylla	Periplocaceae
Piper boehmerifolia	Piperaceae
Pothos scandens	Araceae
Quisqualis indica	Combretaceae
Rivea ornata	Convolvulaceae
Raphidophora decursiva	Araceae
Rosa macrophylla	Rosaceae
Schefflera venulosa	Araliaceae
Senecio scandens	Asteraceae
Solanum jasminoides	Solanaceae
Stephania hernandifolia	Menispermaceae
Thunbergia coccinia	Thunbergiaceae
T. grandiflora	Thunbergiaceae
Uvaria hamiltonii	Annonaceae
Wisteria sinensis	Fabaceae

Conservation Strategies

About 81.9% area of Arunachal Pradesh is under forest cover and as per Hon'ble Supreme Courts order, tree felling is fully banned in the state. But due to lack of awareness the damage to the forests is going on. Government of India as well as State Government have made appreciable attempts to protect the biodiversity of the state. There are 11 wildlife Sanctuatries, 2 National Parks and 1 Biosphere reserve. Another BR is proposed. About 9815.37 sq km area is under Reserve Forest; *ca* 175.20 sq. km under village Reserve Forest; *ca* 256.08 sq. km under Anchal Reserve Forest; *ca* 7.79 under protected forest and *ca* 32039 sq. km under unclassified state forest.

Sanctuaries & National Parks in Arunachal Pradesh

	WLS/ National Park	District	Area (sq. km)
I.	**Wildlife Sanctuaries**		
1.	Dibang Wildlife Sanctuary	Dibang Valley	4149.00
2.	Eagle Nest Wildlife Sanctuary	East Kameng	217.00
3.	Itanagar Wildlife Sanctuary	Papum Pare	140.80
4.	Kamlang Wildlife Sanctuary	Lohit	783.00
5.	Kane Wildlife Sanctuary	West Siang	55.00
6.	Lali 'D' Ering WLS	East Siang	190.00

7.	Mehao Wildlife Sanctuary & Tiger Res.	Dibang	Valley, Lohit 281.50
8.	Pakhui Wildlife Sanctuary	East Kameng	861.95
9.	Sessa Orchid Sanctuary	West Kameng	100.00
10.	Tale WLS	-	337.00
11.	Yardi Rabe Supsa WLS	-	491.62
II.	**National Parks**		
1.	Mouling National Park	East Siang	483.00
2.	Namdapha N.P & Tiger Res.	Tirap	1807.23
III.	**Biosphere Reserve**		
1.	Dihang-Dibang BR	D. Valley dt.	8200 sq.km
		E.Siang dt.	
		W.Siang dt.	
2.	Tawang (BR)	Tawang dt.	(proposed)

Sacred Groves

Sacred-groves (Sacred-forests) are the natural habitats governed by socio-cultural sanction that harbour biodiversity in its pristine form. Dr. Arunachalam of NEERIST, Nirjuli near Itanagar (Arunachal Pradesh) has been able to enlist over 105 sacred groves under a DST ptoject. Gupta (2005) reported interesting information about 10 sacred forests viz. *Ropiyasinelak, Deigo Sinelak, Yalee Sinelak, Yalse Sinelak, Yappye Sadang, Adi Langme, Dangdoo Ropo, Puli-pu, Pata-pu and Mebua* from East Kameng District. Srivastava (2006) mentioned about 'Murhate' sacred grove in Kurung Kumey District.

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A view of the vegetation

Armosia robusta

Parkia roxburghii

Mesua ferrea

Pb. Univ. Res. J (Sci.), Vol. 58, 2008, pp. 185-205

SCHIRMACHER ECOSYSTEM : NATURE AND FABRICS

Surjit S. Dhillon

Punjab State Council for Science & Technology, Chandigarh.

Abstract

The following general account of the Schirmacher ecosystem is the result of an integration of ideas which took shape during field studies and laboratory analysis of sediment-traps and water-samples, and of those organisms which were exposed to Schirmacher locale for about two months. Data given in this account is restricted to five observations made during the period that extended between December, 1987 and February, 1988.

Key words : Antarctica, oasis, schirmacher ecosystem

INTRODUCTION

Antarctica is often viewed as an extremely cold continent which is almost entirely covered over by a thick ice cap. It is hard to believe in its association with fresh water lakes and pools or ice-less valleys. Yet such features comprise parts of the continent and such features are referable as 'oases'. One such oasis is Schirmacher, placed in a peripheral corner of the continent, close to the cross-section point of 71°S and 12°E.

This oasis is a tiny segment of land which is sandwiched between the continental ice-cap in the south and by the ice-shelf in the north. Schirmacher oasis fringes the continent in a kidney shaped sweep, being about 20 km in length with variable width, which mostly remains within the range of a kilometer or so. Viewed from an aircraft, this oasis appears like a brownish quilt with irregular folds and studded all over with deep blue melt water lakes. The lakes are numerous and are of various shapes and are scattered all over. The land is profusely marked by undulating curves and curvatures.

Two terms, "nunatak" and "oasis" are employed to indicate ice-free areas of Antarctica which comprise meagre 2% of the entire continent. Such areas are either mountaineous or are in the form of continental parapets. The former are devoid of snow, while the latter occasionally get some snow in summer. Schirmacher is an oasis of this latter type which sprawls along the continental boundary, between the over-reaching glacial tongues of the continental ice-cap and the proximal alignment of the ice-shelf.

NATURE

I) Macroclimate

Slightly milder climate, relative to that prevailing on main antarctic continent, has shaped the schirmacher environment. Generally, during peak summer, from December to February, air temperature remains around 1°C. In 1987 and 1988, for the same period, however, it ranged between 8°C and -10°C, but most of the time remaining close to – 10°C. The wind blowing from east or south east attained average velocity, during this period, of 15m/sec, which at times, reached the maximum value of 40 m/sec. The average precipitation during this period was about 300 mm, while the relative humidity hovered around 40%. Extreme limits of relative humidity remained between 10% and 80%. Snowfall occurred twice in the month of February (1988), which was mild by even ordinary standards while the last week of January and most of February had remained cloudy and windy.

The summer on the oasis is the period when water is in abundance. There are melt-water streams, there are pools and there are lakes, and some of these are inter-connected. As water flows liberally into the lakes and pools due to melting of ice, which also overflows from one lake into another that is at a lower level, and ultimately on to the ice-shelf. Whatever quantity of organic material the outflowing water carries is a real and permanent trophic loss of the schirmacher ecosystem. This is a constant decrement on its biomass supporting capacity.

ii) Biotic Environment

There are distinct phases round the year when water is available, and during these phases life on Schirmacher is thrown into active cycle of growth and proliferation. Otherwise, living activities remain in spasmic state of dormancy. During summer, the water bodies pass through short phases of freezing and thawing. This situation is of unique importance for the flora and fauna that subsist on it. The alternate freezing and thawing impart changes in the physical form of available water

**Corresponding Author: ksbath@yahoo.com*
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as well as in its chemical characteristics. Such transformations greatly affect the potentials of the habitat by limiting or dilating its adaptive range. The growth and reproduction among living forms are totally dependent on water and on its properties such as osmolarity, pH value and temperature. These properties sharply fluctuate during freezing and thawing of water, which simultaneously also affect its salinity and gas contents.

Such fluctuations mostly occur along the peripheral limits of water bodies, during spring and autumn in schirmacher oasis. The observations made in the month of February (1988), at marked sites, revealed this fact. The situation changes in winter and in summer, when conditions are stable and when the water remains in either frozen or melted state for far longer durations. Thus the life sustaining capacity of schirmacher ecosystem varies widely during the year. This generalization is also supported by the differences occurring in the population density of protozoa and rotifers along the fringes of melt-water streams and in the interior of water bodies. The freezing and thawing of water favours growth and reproduction among animals, which is indicated by the increase in their population density during such periods.

As a biotic environment or even otherwise, Schirmacher offers a mixed fare. There are lakes and pools, there are melt-water streams and there are moist fringes of the streams and pools, and then there is dry soil. All these independently present contrasting habitats. In combination, these offer to life a habitat which is highly complex yet adequate for subsistence. This kind of habitat is peculiar to Schirmacher. Life here is peculiarly endowed with resilience and it possesses the capacity to survive in different conditions of any specified habitat. During bright and sunny periods of summer, spring or autumn, when it is calm also, Schirmacher provides the most comfortable conditions for lower forms of life to exist along the moist marginal fringes of streams or pools. But on cloudy and windy days, the living creatures shift to the interiorly placed niches within the pools or deep down into the moss-beds, which by themselves, comprise an ecosystems of their own kind.

The slow melting of ice allows the water to flow with idle speed along its leeward course, which is also constantly checked by accumulated moraine debris. This also makes the water to spread, beyond its course of flow, as a thin layer. Due to this, the moisture seeps into the areas lying away from the actual course of the stream. This helps the meandering water to gather processed or unprocessed organic material to feed the trophic cycle, leading to the cultivation of moss community, which is a fundamental ingredient of schirmacher ecosystem. The occurrence of the moss-carpets provides micro-climatic niches where the temperature is higher than the surroundings and the incidence of moisture much more prolific.

Most of the pools around Maitree Station remain unfrozen during the period of intense summer. The largest among them is given the name of Pryadarshni lake, which freezes partly and sometimes entirely during winter. Local wind patterns are also variable. During summer strong winds blow, which shake the water considerably. It is, therefore, assumed that the planktons do not remain confined to specified territory. Their distribution and density in a water-body is determined by the direction and velocity of winds. The physical shaking of water by high velocity winds creates a situation which is akin to circumstances caused by extreme fluctuations of temperatures. However, this also provides for uniform distribution of nutrients.

The melt-water streams deposit silt-loads into the pools, which are not without nutrients. The nutrients in the raw form impregnate the soil because of the activities of the decomposers. The lichens erode the rocky substratum, thus creating circumstances suitable for the activities of decomposers. The sediment load, which is regarded an impediment for dispersal of aquatic life, here contributes to up-keep the living activity. The melt water, on its way and before reaching the water body, thus gets enriched by dissolved and particulate organic matter released from the soil in notable quantities. Moreover, the lichens and mosses growing close to the streams, during thaw and freeze cycles, release from their body cells polyols (sugar alcohols) and other carbohydrates which mingle with water and enter the pools as nutrition, ready for use by the living organisms. The observation in this regard made by Wynn Williams (1985) is quite relevant. The thaw and freeze cycles release organic material into the pools in pulses, during spring. In summer, however, thaw and freeze cycles are almost non-existent.

In summer, Schirmacher is warmer than the areas covered with ice-sheet because of reduced albedo and the net positive radiation balance. In winter, it is just the opposite, because the heat loss by the bare rocks and uncovered moraine is quicker. Hence, the fall of temperature here is sudden and so is the freezing of water bodies. Before it happens, all non-migratory forms of life encyst themselves and then their developmental

strages cease to proceed and their activities stop till the return of spring. The spring sparks spurt in photosynthesis while the ice begins to melt. It is then that Schirmacher becomes an oasis in the desert of ice.

Another feature that influences life in Schirmacher is seasonal availability of sunlight. There are prolonged days and prolonged nights. However, the absence of sunlight is more pronounced than its availability, because extended cloudy periods occur during summer. Cutting down sunlight means cutting down photosynthesis and cutting down photosynthesis means reducing the life sustaining capacity of the ecosystem.

iii) Microclimates

Ordinarily the schirmacher oasis is not fit for habitation by any kind of animal life. Yet, animals exist there, though in an extremely modest variety. Their subsistence is made possible by the microclimatic niches which are tiny in expanse and narrow in limits. Such niches occur in moss-beds or within the wet substratum lying close to the pools.

Observations revealed that the moss beds support variety of animal life. These posses higher temperature than the surroundings and remain almost saturated with moisture. Observations made at several sites gave the same results. For measuring temperature within the moss-beds mercury thermometers were used, while for assessing the moisture contents sensors were employed. Microclimatic niches within these moss-beds provide shelters to creatures in otherwise extremely hostile environment, which can be classified as sunny, cold, still and humid on a clear day, and as cloudy cold, windy & humid on a cloudy day.

It is not that these niches totally insulate life from outside influences. Life in them is certainly affected by winds. On windy days, collection made from the usual sites showed extremely poor results. High winds in Schirmacher negatively affect the biological activities of organisms and these do so in two ways : one, by sapping away the humidity and second, by further lowering the already low temperature. Both these processes occur almost simultaneously, one being the cause of the other. Besides, wind-chill effect is more pronounced on the animals than on the plants, such as algae and lichens. The snow storms invariably occur whenever wind velocity is high, which do affect the mosses in physical terms. The drifting ice-crystals, which are needle sharp, cause surface abrasions of moss-beds. By virtue of such lesions, carbohydrates from mosses bleed into the stream. After this initial injury the subsequent affect of the ice on a moss-bed is always beneficial, which gets covered with ice, and the insulating affect of this ice-cover temporarily stops evaporation of moisture and therefore further cooling. The animal life within the moss-bed thus escapes desiccation due to high velocity winds.

Main features of this moss-bed microclimatic zone for animal life is shelter from the wind and comforts of higher temperature and moisture. The relationship of humidity with the temperature gets reversed in a moss-bed. Away from the moss-bed the co-relation between the two is negative: higher the temperature, lower the moisture contents. But within a moss-bed, higher the temperature and higher are the moisture contents. Such conditions prevail when yet it is spring or summer. On the approach of autumn, in February, the green hue of the moss-bed turns black. The observations made then with respect to temperature and humidity indicate that while the temperature within the moss-bed varied from the outside temperature, but the differences in the moisture contents of the two places were not quite evident. It was also observed that moss-bed's moisture holding capacity gradually diminished during autumn. Or, in other words, while the streams froze, the moss-beds also turned towards dormancy. The air immediately above the moss-bed, when it was green, held more moisture than later on, when it had turned black. Moreover, at this stage, the moisture ingredient also reversed within the moss-bed. When the moss is green the maximum moisture is held at the base of the bed and when the moss surface withers and turns black, the moisture contents are maximum at the top.

The moss-beds, in Schirmacher, thus comprise a micro--ecosystem of their own. The foundation of this micro-system is due to the property of the moss-bed that it imbibes more solar radiation than the surroundings. This initiates chain of events which subsequently provide for conditions that result in higher temperature and higher moisture contents. The moisture gradients within such niches are maintained within the ranges comfortable for life. These niches are often insulated against wind, desiccation and cold by the very factor which creates them i.e. ice-cover.

iv) Geological Background

For properly understanding the nature of schirmacher ecosystem, it is desirable to understand its

geological background. Paleontological evidences indicate that Antarctica was in its near polar position already during the late cretaceous period (close to 65 million years B.P.), after having broken loose from Gondwana land, and after having drifted apart from other continents. The process of breaking and then drifting must have taken 150 million years. The near polar position alone was not sufficient for the development of ice--cap, which only later on covered it almost entirely with an average of 2 km thickness. Till about 40 million years before the present Antarctica, for most of the part, experienced temperate climate. Major climatic cooling and continental glaciation became precipitated between 40 million years and 20 million years before the present. Oxygen isotope data clearly indicate this (Shackleton and Kennet, 1975). These evidences also indicate that no major ice-cap had developed till about 10 million years before the present.

The present ice-cap came to be formed after this and it gradually grew into full form, with minor modifications. After formation, its dimensions went on changing with time. The cap went on extending further and further covering the entire continent, and its limits went even beyond the continental boundaries so as to cover the oceanic surroundings of Antarctica as ice-shelf. This was happening because of cooling; and cooling being followed by more cooling. Because of glaciation under the growing impact of excessive cooling, life, in general, became sparse. Accumulation of so much of ice on the continent lowered also the sea-level in general (Bergren and Hag, 1976).

Under these conditions, all eukaryotic life vanished from the continent. It could not persist even in pockets, for there did not remain dry valleys or wet-oases anywhere on the continent. Mounding of the ice-cap continued till about 5 million years before the present. Even after the full growth of the ice-cap, earlier conditions continued unchanged for another couple of million years. Then antarctic glaciation began to recede, but this recession was only minor. The removal of ice from pint-sized patches on Antarctica can be traced back to as recent as about 12,000 years before the present. Till then, Schirmacher must have remained covered with ice and must have remained without eukaryotic life.

The contention that Schirmacher shrugged away the ice-cover to expose its certain minor land segments only recently is supported by the findings which are both abiotic and biotic in nature. The presence of the type of moraine and the presence of the type of micro-fauna help to confirm this view. This type of life cannot be considered an extension of the life that belonged to temperate Antarctica. Mesozoic life was represented by genera and species of much more generalized nature. If that life had persisted, then in Schirmacher, where isolation has been total and perfect, it would have evolved along quite different lines. The rotifers, the tardigrades, the nematodes, the collembolans and mites which now comprise schirmacher fauna; and the mosses, algae and lichens which comprise schirmacher flora could not have been of the types as these are today. All these organisms are closely related to fauna and flora of the sub-antarctic islands.

If there is close relationship between schirmacher flora and fauna and those belonging to sub--antarctic islands, then the means of dispersal of these life-forms from the neighbouring areas to Schirmacher becomes the major point of discussion. However, the fact still remains that whatever life existed on Schirmacher during the late mesozoic and early cenozoic eras, if it did exist, had vanished with the extension of ice-cap. It, thereafter, remained barren for millions of years. Only subsequently, after its fractional exposure from underneath the ice--mantle, conditions appeared on Schirmacher which were favour-able for existence and continuance of life. Such conditions materialized because of gradual lowering of albedo and positive radiation balance; and due to which ice continued melting and thus making availability of water a possibility, at least during the part of the year. Only then migration of some life, that was worthy of dispersal through winds and birds, occurred. This also happens to prove the dictum that "no available niche in the world will ever remain unoccupied by life."

There is yet another point that needs explaining and it is that till now, no fossil of any category of animal or plant has been discovered from Schirmacher. It may be on account of inadequate studies made so far; but till such discovery is made, it is better to assume that 10,000 years to millions of years before the present, Schirmacher had no life worthy of being fossilized. If at a later stage, we do discover fossils on this land, then these would, possibly, belong to animals or plants which existed earlier during the mesozoic era. If the missing of fossils from Schirmacher is read along with the type of life that

persists here now, then it is not possible to avoid the contention that whatever life in whichever form it once existed on Antarctica, had perished due to over-glaciation, extremely low temperature and non-availability of water. Only subsequently, at a later date, probably couple of thousands of years before the present, its more modern forms returned to inhabit the niches which became available on Antarctica and on Schirmacher.

The fact is that the present day fauna of Schirmacher holds no relationship with the mesozoic life that once existed on Antarctica, at a time when the latter was the central bowl of Gondwana land and from where the life had radiated out on to the other Gondwana land continents including India. This contention happens to base on the validity of another hypothesis falling in the realm of geology, which explains that once there existed the super-continent Gondwana land that was not polar in position. This super--continent originally was positioned closer to the equator, and possessed milder and temperate climate, and therefore fully nursed the life of those times, which ran backward and forward from 200 million years before the present.

It is also interesting to note that the fossils, which have been discovered on antarctic continent, are only of amphibians and reptiles. No mammalian fossil has been reported thus far. If subsequently no such discovery is made, then it will be safe to assume that at the time of origin of mammals, during the late mesozoic era, Antarctica was already widely separated from the other continents of Gondwana land. As Australia had no native mammals, Antarctica also remained devoid of them. During the earlier part of the drift, such conditions must have prevailed on Antarctica, which could have appropriately allowed the survival of warm-blooded mammals. This can be taken as another evidence for corroborating the time of drift and arrival of Antarctica at the south pole, as was established on the basis of geological evidences.

v) Characteristics of Schirmacher Ecosystem

If the objective is to discover that how an ecosystem functions, then it has to be viewed in totality and its dynamics analysed in entirety. The schirmacher oasis is an extra-ordinary ecosystem. It is far too simple. It is insulated by unsurmountable barriers which are both physical as well as climatic in nature. It is quite limited in dimensions and is comprised of few widely spaced strands. Yet, it is untouched by human impact. Indeed it is a unique natural laboratory, where it is possible to test hypotheses related to environment. Also the living creatures here comprise a closely knit community of limited interactivity.

As elsewhere, here on Schirmacher too, the ecosystem rolls along decomposition, primary and secondary cycling of the nutrients; and the participants in these processes are yeast, bacteria, fungi, lichens, algae, mosses and invertebrate fauna. The birds do affect the ecosystem, but only as casual visitors. They are peripheral to the schirmacher ecosystem. Because of extreme isolation, there has not been any in or out migration; and because of climatic intensity, the specific diversification of organisms has remained largely restricted. The niches available to life are narrow and are quite varied. Differing from place to place, these support peculiar flora and fauna.

On Schirmacher pools and streams exist for short duration, and thus in overall terms, it is akin to an arid or semi-desert land. Moisture is available but only for part of the year and that too on the ground only. Swiftly blowing air is almost always devoid of moisture. Most of the native life, therefore, is mainly confined to the pools and streams, or along their fringes. Thus life exists here in two dimensional space only. Besides moisture, the organic material is also available at places, skirting the water bodies. It does not mean that the nutrients are available in abundance. On the contrary, these are scarce and for their procurement the animals adopt strategic devices.

On the basis of algal population during spring and summer, it is possible to deduce that primary productively in Schirmacher varies from place to place, pool to pool and stream to stream. Even within the space of couple of meters this variation stands out. Productivity is particularly richer along the peripheral borders of melt--water streams. On the other hand, it is relatively lesser in pools, and still less in isolated pools which are not inter-connected with others. There are certain pools which are formed but dry up soon, and then are re-formed. In such pools primary productivity is almost negligible.

vi) Raw Material for Primary Productivity

The main role in primary productivity though is played by diatoms and algae, but the raw material for initial utilization is provided by lichens. Those lichens which form crusts over the rocks play extremely important role. They make available organic material for primary production through enzymatic activity and induct this material into the protoplasm via photosynthesis. The

importance of lichens to the schirmacher ecosystem is indeed unique. The algal activities cease when sunlight is unavailable during the polar night and also for prolonged spells during polar day, when blizzards prevail. However, lichen activity continues when there is diffused light or even if these are partially covered with snow. Production of soft soil on account of the erosion of rock surface is another by-product of lichen activity. Lichens, therefore, form the solid base of schirmacher ecosystem and their importance can never be over-emphasized.

While lichens release organic material, the decomposers, which include bacteria, fungi and yeasts, assist them by releasing carbohydrates and amino acids, thereby enriching the general pool of nutrients. To do so, the decomposers act on dead organic material which could be dead mosses or bird droppings. However, decomposing activity much depends on the temperature. It is negligible during entire winter and below optimal rate for most of the time during spring and summer. Since decomposers cannot fully exploit all the available dead organic matter, it is on that account that the moss-peat goes on accumulating. On the basis of its thickness, the age of the peat can be determined. In same cases on sub-antarctic islands a few peats are more than 5,000 years old. But if only the thickness is the criterion of age, then schirmacher peat should be considered much younger in age. However, the relative thinness of schirmacher peat is also attributable to relatively reduced metabolism because of lower temperature and shortened photosynthesizing period.

The productivity, then, in the terrestrial environment is limited to the availability of fresh-water and basic nutrients. The basic nutrients are made available as mentioned above, but their transmission to the site of productivity entirely depends on water. When the ice melts and streams become alive, the water spreads at many places where earlier decomposers and lichens were active. The water then gathers the organic material which flows along with the water into the pools, if it does not get utilized on the way. Even otherwise, running melt-water contributes to the general nutrient input of the system by leaching the un-processed rock surfaces. Moreover, the melt-water streams, on their way, pass over the moss-beds and lichen covered stones, and this way also contri-bute to the general nutrient input.

The biomass in schirmacher ecosystem is never prolific. Its extent is determined by several factors. Deficiency of any one of the basic nutrients could be one stalling factor and deficiency of phosphate, nitrogen or calcium could occur more often. Their deficiency, however, cannot be equated with deficient sunlight and low temperatures, which affect the biomass productivity in a big way. Yet these elements are basic ingredients of protoplasm and their induction into the schirmacher ecosystem is governed by their availability through quick succession of thaw and freeze, to which the living or dead cells get exposed. On exposure, the cell walls and plasma membranes of the cells rupture and the cell contents flow out into the stream of water that carries them away for distribution.

But, by far the major contribution to the pool of basic nutrients comes from the sea birds, which do not pay deliberate visit to Schirmacher and only inadvertently stray here during blizzards. But there is one bird that pays deliberate visits to this land and that is skua and his contribution to the schirmacher ecosystem is considerable.

vii) Transfer of Nutrients through Birds

Some of the sea birds are associated with schirmacher oasis, either remotely or intimately. These are penguins, skuas, arctic or snow petrels. These birds normally die at sea, mostly at the hands of predators, where they mainly live and feed, and it is as part of marine ecosystem that their remains are recycled. However, these do visit the land during breeding season, and during their stay a few of them die on land also. But the main contribution to the land ecosystem is provided by their droppings, as well as by those eggs which fail to hatch, and by those chicks which fail to develop. The number of eggs of birds is considerable that perish before hatching. And numerous chicks also die before these mature into adults. Additionally, at both these stages, penguins and petrels are vulnerable to predation by skuas. This is then the way by virtue of which a fractional part of the marine biomass is retained on the land for recycling along pathways belonging to the terrestrial ecosystem of Schirmacher.

The above mentioned four kinds of marine birds contribute to the schirmacher ecosystem, however, their contri-bution is differential. To reach schirmacher oasis from sea, these birds have to traverse across a distance of about 100 km. Schirmacher oasis, indeed, could be an ideal place for breeding by Penguins. But covering 100 km distance is too much for these flightless birds. Moreover, their visit to the sea has to be frequent for the purpose of feeding. Thus, penguins do not favour the oasis as their breeding place. They could only stray

to this place after loosing their way during blizzards. Having separated from the companions, the straying birds become disoriented and such birds often die, and thereby contribute to the energy budget of the terrestrial ecosystem of Schirmacher, but only marginally.

In the last week of December (1987), while roaming through the oasis, the author discovered one adelie penguin swimming all alone in an agitated state in one of the pools of Schirmacher. This bird had strayed here during blizzard. This bird too could have died on the oasis, had it not been transported back to the sea-coast by human agency.

Skuas live in pairs and they nest in rocks for breed-ing. Since these are good fliers, hence they prefer nesting far away from the sea-coast. Skuas nest in Schirmacher. These birds predate on penguin eggs and chicks, which they also carry to their nests for feeding their chicks. This way they carry considerable amount of nutrients from the penguin rookeries, lying close to sea-coast, back to schirmacher oasis. They feed on the fleshy portion, but bones are mostly discarded which is a contribution to the ecosystem budget.

Skuas have been observed walking into the kitchen to pick up dressed chicken and flying off to the nest while holding the chicken in the claws. This behaviour betrays two facts: one, that skuas do not recognize man as a hunting predator thus do not fear him; and two, the means skuas adopt to carry chicks or dead birds across long stretches to their nesting areas.

The skuas also contribute to the ecosystem budget through their droppings, which are in the form of liquefied white nitrogenous emulsion. From this it can also be deduced that skuas do not feed on penguin chicks alone. They seem to feed on fish and krill and other sea creatures as well with considerable amount of liquid in their tissues. There is hardly any rain, and because of this the bird droppings remain where these are dropped and dry up quickly as a thin paste on the rock surface. What invariably follows after a couple of weeks at the exact spot where dropping was deposited that it becomes inhabited by lichens. Three such examples of this kind came to the notice of the author, indicating that skua droppings are recycled rather quickly than one could have considered possible in Antarctica. While nitrogenous droppings could hardly be considered as contribution to the ecosystem elsewhere in the world, but in Antarctica, even this is regarded as a factor worth considering for sustaining the micro-flora and fauna of the region. Skuas pass considerable time in Schirmacher where they often die also.

The major contribution, however, for sustaining the oasis ecosystem is made by snow petrels. These die in large numbers, perhaps during blizzards. These often fly from the sea to reach their breeding grounds in the antarctic mountains, across a distance that could be as much as 200 km. The petrels often nest in the crevices of mountains, which are more than 5,000 ft high. These fly in flocks and in good numbers and if these get caught on the way in a blizzard, these die also in good numbers. Their bodies are often swept back, along with outward moving ice or by strong winds, to places where normally these are not found. Schirmacher oasis, being at a lower level, receive these dead birds in substantial numbers. This is sufficiently evident from the collections of their bones and feathers made in Schirmacher. The skeletons were without soft tissues which either were picked away or else were quickly recycled through decomposers. However, the keratinous feathers and calcified bones were not as quickly affected by decomposers. They do, ultimately, bring about recycling of bones, though this process may take long time. It was not difficult to make distinct-ion between the bones which were recently deposited and those which were deposited several decades earlier. The latter were brittle and fragile, and were collected from the sides of pools. Such bones mostly were found entangled with moss-beds, with a very thin layer of soil binding both together. It would be interesting to discover if the enzymatic activity of lichens and mosses, which grow in Schirmacher, directly brings about the release of phosphates from within the calcified tissues of bones, or else, for this purpose, they depend on the decomposers within the soil. However, it was quite evident that the moss-beds with entangled bones showed better growth. Should it be considered incidental or consequential?

All the material of biological origin, such as dead soft tissues, bones, feathers, droppings, contribute phosphates and nitrates, which otherwise may only be marginally available for utilization by the living creatures of Schirmacher. This material also contributes calcium and carbonates which, however, are not as scarce. The presence of rotifers in dense populations in schirmacher pools and streams is an indication of this fact. On the sub-antarctic islands, the sea-birds contribute to the energy budget in a big way through excretion of the waste products, loss of eggs and chick and molting of feathers. But in Schirmacher their contribution is mostly in the form of bones of dead birds, which happened to be swept back here either by blizzards or by moving ice. Their recycling provides phosphates and also nitrates for promoting the growth of primary producers.

This input has been quantified with respect to sub--antarctic islands, and it has been estimated that about 90% of nitrogen, that is being cycled through the food web interactions, is a contribution of the sea-birds. The schirmacher food-web, however, is built up along different lines. Here the bulk of nitrogen is being provided by decomposers through their activity involving the dead organic material, which besides dead birds, includes the native flora and fauna, in addition to whatever is contributed through the processing of rocks by lichens. And this ecosystem also differs from the sub-antarctic island ecosystem, because from here nearly nothing flows back into the sea. Schirmacher topography is saucer--shaped with elevated edges, thus not allowing the escape of most of the melt-water accumulated in the pools, thereby not releasing to the sea whatever is washed into them. Indeed fraction of melted water does trickle over on to the ice-shelf, when melting is substantial during peak summer. Schirmacher ecosystem, thus, does loose, but only marginally to the marine ecosystem.

viii) Phenomenal Impact of Wind

The link between terrestrial and freshwater habitats on Schirmacher is not as clear and distinct as elsewhere. To the extent that all-organisms do need micro and macro nutrients which are a joint contribution of the two habitats, the connection between the two is obvious. However, the nutritional exchanges between the two habitats are extremely slow and it is a long and drawn-out process. It is so because of the absence of rain. Here, the function of rain is performed by wind, though in a minor and obviously in somewhat crude manner. These sweep into the pools widely strewn organic matter, while from the dried pools algae and other dead aquatic organisms are swept back on to the land. Most of the pools in fact do dry up, when the ice stops melting on the approach of autumn. The author collected algal discs strewn far and wide away from the pools, that had dried up, because of absence of melt-water source.

Wind and wind driven snow is a specified phenomenon on Antarctica and on Schirmacher as well, the magnitude of which greatly influences the pattern of life : Wind directly affects the distribution of nutrients from land to water and from water to land. Wind, in other words, is one of the major grids of schirmacher ecosystem.

ix) Temperature, A Cornerstone

Extremely low temperature which even in summer mostly fluctuates around 0°C in Schirmacher (the maximum being 8°C and minimum -10°C during the months of December,1987 and January and February,1988) is a real elbow bend for life to traverse. Merely low temperature is only one affliction for life to combat against, while more Catastrophic is temperature's quick fluctuations occurring constantly and at short intervals. The life has to stretch great deal to adjust to quick and sharp rise and fall in temperature. The temperature fluctuations during summer are quite marked and are brought about by alternations of sunny and cloudy spells. The temperature fluctuations are peculiar to Schirmacher because oasis rocks imbibe and discharge radiation quickly, depending on sun shining or is behind the clouds. The Schirmacher pools may not be registering as much temperature fluctuations for obvious reasons. Still the temperature fluctuation in these water bodies is appreciably more than what it is in the sea, since the pools are not deep enough.

The biggest pool of Schirmacher, christened as Pryadarshni lake, is only about 6 meters deep in its middle. The living creatures in Schirmnacher adopt double ended strategy for survival: one to cope with the low temperature and the other to cope with the temperature variations materializing in quick succession. The latter drastically tax the adaptive potential of organisms, who are able to weather the tidal affects of temperature by occupying micro-climatically protected niches. Such niches are located inside the moss-beds sufficiently insulated to maintain a fairly uniform temperatur, in spite of outside fluctuations. On a cloudy day (January 19, 1988) the surface temperature in the oasis, close to Pryadarshni lake, was recorded to be -8°C, while the moss-bed interior registered -3°C. Subsequent observations indicated it to be even higher, when the outside temperature was -4°C. As long as melt-water is available, and it is humifying the moss-bed, the question of freezing of organisms inhabiting the bed does not arise. However, with the fall of temperature, either that of melt-water or that of the surrounding habitat, a certain fall in the metabolic rate of animals do occur, which results in mitigating the animal activities related to nutrit-ion and reproduction. But still living activities continue though on a dull note. But the real crunch comes when the temperature falls to the point that the organisms are likely to freeze. It is then the mosses begin to wither away. They loose their green sheen and turn black, while the animals living among them resort to cyst formation and become dormant. If the animal eggs have not thus far initiated development,

they also remain dormant throughout the winter and hatch only during subsequent spring. In fact, the strategy common to rotifers and nematodes (perhaps collembolans as well) is to lay eggs close to autumn only. Eggs of these animals have not been collected, but the females had not yet laid eggs at the time of their collection, which was prior to the approach of autumn. These animals were collected from amongst the moss-beds.

The need to avoid freezing during winter is greater in animals than in plants. How it is achieved is a question that seeks an explanation. There cannot be any one way which all the animals of Schirmacher adopt to avoid freezing. The methods adopted differ from group to group. It is common knowledge that protozoans winter as spores, which are highly resistant to water entering the cells or allowing the escape of material from within. This seems simple enough. However, the problem is not of the frozen water that is outside, but of that water which is within the cell as component of cellular fluids and which may freeze. If that occurs then it is an impediment for survival. One strategy adopted to side step this eventuality is to expel as much of water from the cellular fluids as possibly could be tolerated before encystment.

The dehydration of tissues is certainly manipulated by nematodes, tardigrades and rotifers as is evident from the shriveled forms of those which were collected close to autumn. These animals do not form cysts, yet they do survive. It is quite appropriate to assume that after partial dehydration the body fluids of these animals must come to possess a lower freezing threshold, which may have become further lowered due to the presence in them of polyols or chemicals possessing similar property.

It is an accepted contention that an organism's tolerance to freezing is directly related to water contents by its tissues. Low temperature, by itself, is not fatal. What leads to fatality is freezing of the fluids within the body. If the tissues are devoid of free water, or else their freezing point is lowered through some kind of chemical improvisation then exchange of gases in them continues and thus these remain capable of metabolism and hence alive.

The animals who are capable of surviving during the polar winter are ordinarily classified into two groups on the basis of their reaction to freezing temperatures. Those belonging to Schirmacher also are similarly grouped in to 'freezing susceptible' and 'freezing tolerant'. The 'freezing susceptible' are normally those animals who possess body - spaces filled with fluids and these on Schirmacher include collembolans and mites. Rest of the Schirmacher micro-fauna is considered 'freezing tolerant', in which the body tissues are directly exposed to the low temperature. This group includes protozoans, nematodes, and rotifers.

In the 'freezing susceptible' insects and mites, the fluid filled haemocoelic columns surround the vital internal organs of the body and this fluid does not freeze because of the presence of anti-freeze compounds. These organisms manage to retain the internal body vitality even when the outside temperature is extremely low. In the 'freezing tolerants,' the body tissues manage to withstand freezing by themselves. It is certain that all these animals, both "freezing susceptible" and "freezing tolerant", do not possess any independent system to combat low temperature. These mostly exploit their pre-adaptability for generating polyhydric alcohols (polyols) and sugars (glycerol) for insulating the tissues against cold. The animals surviving in Schirmacher generate these chemicals in relatively higher concentrations and because of them the freezing temperature of the body fluids gets lowered. That is how a mite *(Mandheimia wilsoni)* is able to survive at -30°C, and a collembolan *(Isotoma klovstadi)* at -50°C (Pryor, 1962). Not all mites and collembolans can withstand such low temperature. Most of them become inactive and die if the temperature falls beyond -20°C, and that is the main reason that Schirmacher possesses a thin population of collembolans and mites.

Synthesis of anti-freeze compounds, thus, is strategic for survival in Schirmacher, and their synthesis cannot be a normal feature among the animals whose energy budget is already scarce. Metabolically the production of anti-freeze compounds could be quite costly, since their production has to be at the expanse of the energy sources within the body, and the availability of which in Schirmacher cannot be unlimited. This puts limit on the production of anti-freeze compounds, and hence, on the population of surviving communities of animals in Schirmacher.

During our visit in December, 1987 to Antarctica, pupae of *Athalia* (a hymenopterous insect that lives in plains, but is considered a descendent of the group that mostly dwells among the high reaches of mountains) were exposed to antarctic conditions to find out their impact on the post-embryonic development of this insect. The insects were brought back after 8-weeks exposure and processed in the laboratory for studies. It has been discovered that the pupae remained in different stages

of development, which had ceased much short of formation of the adult. The most affected tissues were malpighian tubules and alimentary canal. The cells of both of these systems were cracked open and their contents along with the nuclei had drained out. It seems that the cell membranes had ruptured because of freezing of inner fluids. This was expected also. Most of the other tissues such as salivary glands and muscles were also affected but comparatively to minor extent. These observations clearly tell as how the low temperature affects that living tissue which is not adapted for the purpose.

x) Sun, The Prime Mover

On Schirmacher, as on Antarctica and its neighbourhood, the availability of sunlight is seasonal, and therefore seasonal is also the primary productivity of the ecosystem. Thus, there is only seasonal availability of food to the consumers, which also grow and reproduce seasonally. This fact is made obvious by the population densities as well as the body sizes of rotifers, nematodes, and tardigrades which were observed first in December and then in February. The observed differences among these animals were well marked. The hue and colour of moss-beds also betrayed the same. The green of the moss-bed surface turns black by mid-February, indicat-ing the cessation of their photosynthetic activities. Not only this, lichens settle down on them, which at this stage appear as white dusty specs against the dark background of the moss-bed. Such sights become the general pattern of schirmacher topography by mid--February. By then the ice stops melting and the melt-water streams dry up completely and consequently, the moss-beds begin to dessicate generally. Even those moss-beds, which lie close to the pools that have not yet dried completely, also begin to turn black. But in them, the dessicating process is delayed by about a week.

Normally lichens continue their partial activity even in the absence of sun light. However, foliose lichens wither away by the time it is mid-February, as these bloom in water; thus these wither away when the water in ponds vanishes. It is the melt-water rather than the sun light which should be considered primary for the active life of foliose lichens.

Still the point is that with the return of a full day in about November, the sun returns and with the return of sun, life returns to Schirmacher and it begins to pulsate. Contrarily, when the day slowly begins yielding to prolonged polar night, the life here also begins to prepare for a prolonged slumber.

FABRICS

i) Introduction

The flora and fauna of Schirmacher comprising the fabrics of its ecosystem is poor in variety as well as in biomass. Though 100 Kms away, in contrast, the marine ecosystem is one of the richest biomass site in the world. The reason for this biomass poverty and richness occuring side by side is not uncertain. Though the temperature is equally low at both the places, however, its fluctuations are not. Besides, the change in the temperature during the past millions of years had been a gradual process in the sea; while In Schirmacher the fall in temperature, during the same period, was drastic and sudden. As a consequence, in Schirmacher life, instead of evolving, had perished and today here only the casual drifters survive. The life in the antarctic sea never perished. Instead, it went on evolving along with slowly changing conditions. Since the beginning of tertiary period of cenozoic era, about 60 million years ago, when Antarctica was already close to its present-day position, the fall in the temperature in the ocean surrounding it has been only of the magnitude of 11°C. This has been determined through the study of oxygen isotopes of foraminifera. On the other hand, in Schirmacher, the fall of temperature has been much more, which was sufficient to wipe out all native life. Even at present, because of albedo, the difference in temperatures in summer and winter is wide, and it is not possible for life in general adjust to it through adaptations of normal type. Thus the situations differ drastically in the antarctic ocean and on the antarctic continent.

The ecosystem dynamics pertaining to Schirmacher oasis operates at low temperatures, and therefore the phytoplankton bloom (primary producers) is scarce, and also it only lasts for about two months. Nutrient depletion of the system, though not significant, but is constant during summer, when water overflows on to the ice-shelf from several pools. The rate of growth of populations, without exception, is extraordinarily slow with rather slower rate of dispersal. The physical circulation of life, thus, is almost nil. However, skua is the real exception, whose identity has become integrated with the local ecosystem.

The food-webs are built up for appropriate oxygen, carbon and nitrogen flux. However, the other food-web elements such as phosphorus and calcium lack this disposition. Since the living community of Schirmacher migrated here only during the post-glaciation period, this has not provided the community with sufficient time

for achieving stability and a well knit status. When Schirmacher became habitable, first to invade this place should have been lichens, which were then immediately followed by mosses and algae. Their settlement must have brought change in the micro--topography of the land, and created conditions far accommodating micro-fauna, which must have followed the plants.

The migration of micro-flora and fauna to Schirmacher could have been brought about by those birds who normally migrate, during winter, from Antarctica to sub--antarctic islands. Besides high velocity winds may have also assisted the process. Both these agencies provide good means of spore-dispersal. The spores entangled into the feather-warbs of birds could be carried over long distances by the birds. The study of Adelie penguin feathers did reveal that several unidentified small rounded objects were sticking to them, and these could be disentangled with effort only. This effort was certainly of the magnitude with which wind blows in Schirmacher. In the initial transfer of life from sub-antarctic lands on to Schirmacher, the skuas must have played an effective role. Taylor (1954) actually found the presence of plant bits adhering to the feet of black-browed albatrosses. The earlier settlement of mosses was conducive for the subsequent settlement of micro-fauna. The mosses must have continued creating humic soil, which when moist, leads to the formation of interspersed web of tiny spaces. This is a device of induction of nitrogen for further growth of mosses. After moss-beds were created, these then provided micro-climatic niches for micro-fauna.

The input to Schirmacher ecosystem is also contributed by birds, their chicks and eggs which perish either due to wind-chill effect or due to snow-storms. To some extent, the primary productivity is supported through leaching of soil by lichens. To this also gets added the by – products turned out on account of weathering of the surroundings.

Briefly, it can be stated that Schirmacher presents an ideal situation for devising models involving colonization, succession, community development and cyclic changes.

ii) Flora

Schirmacher flora is disharmoniously distributed, surviving in certain marked environmental pockets only. There is no horizontal or vertical continuity and the floristic components are structurally simple and scarce. Hence, the interactions between them remain restricted to the trophic level alone.

Mosses comprise a major component of plant community of Schirmacher. They occupy wind swept arid habitat and these occur in the form of moss-cushions, which coalesce to form moss-beds with smooth but convoluted surface. Moss-beds occur on wet soil close to pools or melt-water streams. When their photosynthesising activity ceases on the approach of autumn, then these often become encrusted with lichens. The moss-beds are favourable abode of animal life that prevails in Schirmacher. The thickness of moss-bed sometimes is taken as a scale of its age: thicker the bed, more aged it is. But this measurement is not absolute. Factors governing thickness of a moss-bed differ from place to place and from region to region.

Mosses in spring and summer are of dark-green shinny colour which enhances their capacity for imbibing solar radiation. According to one study, mosses possess rich concentrations of sugar and sugar phosphates and on which account they are able to withstand low temperatures better. Sugars are also a good source of energy which the grazers living among the moss-beds consume. Indeed this is one good reason that micro-fauna of Schirmacher is mostly confined to the moss-beds.

The lichens in Schirmacher comprise another major component of plant community. Lichens probably are the hardiest of all living creatures and that is why they are most suitably entrenched in schirmacher oasis. About them, a lurking thought remains that if there were any continuity of life from preglaciation to post-glaciation on Schirmacher, then lichens could be the only survivers. Even otherwise they are considered as the first to occupy Schirmacher and then initiating succession. The foliose lichen collected from one of the pools in Schirmacher appeared to be of good age, perhaps older than all other kinds of life around.

In fact, lichens are able to fill all the types of available niches. These are variable in form, in shape, in size in colour and occupy quite variable kinds of habitats. Most fascinating among this community are the lichens with large lobed and umblicate foliose, which are confined to pools, where they remain submerged in water. The author discovered two tiny pools which were occupying higher stratum and which were filled to the brim by foliose lichens. These pools had no outlet. These were fed with the melt-water and when the ice ceased melting, these pools naturally dried up quickly. With this happen-ing, the lichen-foliage also withered away. Such pools do not seem to support any other kind of life which in itself is a unique feature. It could be because

the lichens are nitrophobus and also because the lichens possess acids and glycosides. The latter act as anti-freeze, but otherwise keep all other life away.

It has been suggested that the age of foliose lichens can be ascertained by measuring the width of their foliage. These are long perpetuating plants and the rate of their growth is extremely slow under antarctic conditions. Dating through lichenometry cannot be considered very precise, but it can give vague estimation about their age and of the life that the ecosystem supports.

Algae comprise the third component of the Schirmacher plant community. The blue-green algae occur in the form of circular discs and the assembly of their strands form loose convoluted sheets mainly on the wet soil or within the pool. On drying of the pool, these remain temporarily sticking to the substratum. However, subsequently these get disengaged from the soil because of wind and are dispersed over long distances. The algal communities otherwise are not widespread. These possess a metabolic system which can capture, store and utilize energy at low temperatures and for short periods. Algae i.e. green and blue-green along with diatoms are the primary producers of schirmacher ecosystem. The diatoms remain confined to pools, and are of several types. They differ in their forms and chlorophyll contents and their distribution is widespread, which is densest in a pools.

iii) Impact of Flora on Schirmacher Ecosystem

Mosses and lichens seem to wield more influence on the mechanics of nutrient cycling of the oasis ecosystem than algae. The latter are the prime movers of the cycle, while it is kept in a state of flux by the other two. Both, algae and mosses enhance the retention of nutrients by the ecosystem. Besides retaining the nutritional elements, mosses also retain water within the intervening extra--cellular spaces of their beds, thus saving it from evaporating while high velocity winds blow. Instead, this water percolates further down into the beds carrying the nutrients, and keeping the interior moist. This moisture is vital for metabolic activities.

Dead organic matter along with loose soil comprise the lowermost strata of a moss-bed. The dead organic matter is the result of the withering of moss tissues. This portion of the moss-bed retains most of the nutrients and prevents their leaching. This retention of nutrients within the moss-bed is made certain by their association with the dead organic matter, and also the water carrying the nutrients is not allowed to escape because of the network of capillaries which are automatically formed within the moss-bed. There is also yet another possibility for locking away the nutrients, and it is through the formation of permafrost which is greatly aided by the withering tissues of mosses. The fact remains that mosses and lichens also lock away the nutrients in themselves, the scarcity of which in Schirmacher can never be over-emphasised. This way these immobilize bulk of nutrients and reduce their availability to other organisms. But taking a long view of the events, the locked up nutrients should be considered sort of a fixed deposit of energy, from which the organisms can withdraw subsequently, after the withering of such tissues. The nutrients are retained within the cellulose laden cell walls or as material which, without enzymatic activity, is not soluble in water.

The mosses and lichens do increase total nutrient pool of the ecosystem by restraining its excessive or immediate use. The evidences for this being the case are several, which lead to the conclusion that mosses and lichens play an efficient role in the nutrient retention by the ecosystem. The ability of mosses to remove elements from percolating water has been experimentally established by Allen, Grimshaw and Holdgate (1967). It has also been demonstrated by Sendstod (1981) that removal of lichen cover leads to decrease of organic matter in the soil.

Lichens appear to stimulate chemical weathering. On their own, neither lichens nor mosses play any role in the fixation of nitrogen, though it is established that both play an indirect role in this process by becoming associated with cyano-bacteria, either individually or in combination. The mosses or lichens, all alone, at antarctic low temperatures, are unable to convert nitrogen into nitrate in a free living state, as blue-green algae can. Lichens also do not seem to interact with other organisms in the manner as mosses do, who provide favourable habitats to invertebrates.

iv) Fauna

The dominant features of schirmacher fauna are micro--arthropods, protozoans, rotifers, tardigrades and nematodes. The micro-arthropoda possess two components, which are springtails or collembolan insects and mites. These live in the inbuilt shelters, at the base of moss-cushions as these tiny creatures cannot withstand the strong wind currents. Rest of the schirmacher micro-fauna, unlike insects and mites, live in total aquatic surroundings. Protozoans, rotifers and tardigrades are both vertically and horizontally

distributed among the pools, while nematodes are mostly only horizontally settled. However, the general distribution of these animals is random and wherever the bits of plant material float, close by gather the animals. For that reason, the moss-cushions on the banks of melt-water streams support the maximum density of micro-faunal distribution.

Protozoa

Protozoans were mostly collected from Priyadarshni lake and from the adjoining pools. These included amoebae, ciliates and flagellates. Four kinds of amoebae were found to be distributed on the substratum horizontally, while the ciliates were found all over the place. The flagellates came along with the collection of surface water.

Rotifers

Schirmacher rotifers were collected from pools as well as moss-beds. Their community, which comprised of several identifiable species, seems to tolerate, with ease, adverse conditions. They are capable of surviving the freezing conditions for months without undergoing encystment. They can live at a temperature as low as -40°C. *Philodina gregaria* has been observed surviving even at -78°C for a couple of hours (Aoki & Konno, 1961). Rotifers can also survive desiccation through ablation. All rotifers, to live, require a water film. Evan those rotifers which have been collected from moss-beds are really aquatic and these dwell in water that permeates through the moss-beds. The collected specimens possessed body--lengths that were under 0.5 mm, and thus in body-size they are akin to single-celled ciliates, amongst which these live. All possess ciliated corona; and in some this corona is double. Their population in Schirmacher is the densest as has been established by sample study. They occur in thousands in a square meter space. Of their two sub-groups represented in Schirmacher, delloids are more abundant, comprising more than 70% of the total population of identifiable rotifers. Monogonont rotifers are comparatively fewer.

Tardigrades

Tardigrades are relatively less dense in Schirmacher than the rotifers. However, these too cover a space of square meter in thousands, and these mostly inhabit moss-beds. However, their population-density varies appreciably from one moss--bed to the other. In body size, these are almost of the size of rotifers. These are aquatic in habit and live in water films within the moss-beds. From the dessicating moss-beds certain rounded shriveled objects have been collected, which seem to be the cysted forms of tarigrades, which they acquire for over-weathering the winter. These cysted forms are highly resistant to chemical corrosion. Even a touch of formaldehyde did not affect them. But if put in water, the cyst wall acquired placidity. Even long periods of preservation in the laboratory failed to distort their placidity. Their hardy ways are suited to withstand antarctic low temperature as well as extended periods of drought. Thus their dispersal through some living agency, such as birds, can not pose any problem.

Nematodes

Nematodes are also bracketed with rotifers and tardigrades for their universal distribution, and Antarctica is no exception. These occur in Schirmacher and are quite densely distributed among the moss-beds and along the substratum of pools. Their distribution within moss-beds is somewhat stratified; it is thin in the upper strata, but dense closer to the base. With the fall of temperature, nematodes tend to migrate vertically down-wards. The dessicating portions of moss-beds are equally densely populated by nematodes. However, their general population, which is horizontally placed along the soil, are in hundreds per square meter. Nematodes break-down dead organic matter, hence, these be regarded as decomposers. This way they aid in the circulation of material in the food chain.

Springtails (Collembola)

Lipper (1971) reported the occurrence of Collembola only among mosses. Collembolans, in Schirmacher, were discovered from among the samples of only one specific moss-bed, that was generous in dimensions and rich in moisture. This collection site occurred right on the bank of the main melt-water stream. Discovering springtails from this bed made it a unique site which, in ecological terms, has to be different than others. The couple of individuals belong to single species with elongated multi-jointed antennae and distinct abdominal segments. The abdominal appendages are present and so are the ventral-tube and the jumping organ. These insects are of extremely small size, whitish in colour and inconspicuous to the naked eye. Their distribution seems to be extremely scanty in Schirmacher. Though terrestrial in habits, yet they prefer moisture rich shelters, and this tendency may be an impediment in their wider distribution in the moisture starved surroundings.

Among the insects, the springtails live furthest in the south, and these have been found inhabiting as far south

in Antarctica as 83°50'S by Jyndale-Biscoe (1960), and Schirmacher is over 10° shorter in latitude. They feed on dead and decaying plant tissues and on living algae as well.

Mites (Acarina)

The top of the food chain of schirmacher ecosystem is occupied by mites, which feed on the micro-fauna, but mostly on nematodes. This is being stressed, because nematodes were discovered entangled with the mite appendages. This entanglement does not seem to be only by chance. If it is viewed in the background of the generally recognized habit of mites, then the event is interpreted differently.

Acari is a large group and is widely distributed. Wise and Gressitt (1965) discovered their one form existing as far as as 85°32'S. This means that their distribution is closer to the South pole than the distribution of even springtails by about 2^0. Schirmacher mite is free living and is not entirely carnivorous. It does supplement its food with living or dead plant materials. Mites have been collected from the same moss-bed where were also present springtails. These are able to live under polar conditions due to their elevated rate of metabolism and are able to survive in water. The mites from Schirmacher belong to the group of cryptastigmatids, which are obligate polar species, living ideally around 0°C.

Migratory and *non-migratory birds*

There are birds, in fact sea-birds which are directly or indirectly associated with schirmacher ecosystem. Among these are penguins, petrels and skuas: penguins are of Adelie kind; petrels are snow-petrels; and skuas are brown polar skuas. Out of these, skua is a regular summer visitor, and nests in schirmacher oasis. On the other hand, non-migratory Emperor penguin, though a native of Antaretica, never ventures into this land, as often migratory Adelie penguin does. Schirmacher is never the destination of snow-petrels. However, their fragmentary remains flood this land after being mechanically transported by either wind or moving ice from the mountains, in the crevices of which they nest and lay eggs. Association of Emperor penguin with schirmacher ecosystem, however, is indirect and it is forged through skua, which picks up their eggs or chick, and bring them down to the nesting site for feeding its own chick. This way, the organic material gets transferred from the ice-shelf to Schirmacher via skuas. It is not the predation alone by skuas which cause mortality during the earlier stages of growth among penguin and petrel chicks. The major cause of their mortality is the wind-chill effect during snow-storms; and mortality due to this may be as high as 80% (Jouventin, 1975) among penguins. This rate of mortality is not as high among petrels, since their chicks occupy the mountain burrows or crevices.

v) Aquatic Life of Schirmacher

Lakes and pools in Schirmacher oasis, by and large, comprise an integral part of its composite ecosystem, while maintaining their identifiable status. Most of the pools are closed systems, but a few of them are not. Among these few is also Priyadarshni lake, the most dominating feature of Schirmacher and close to which now lies India's permanent station. During summer it overflows into another pool occupying the next lower terrace towards the north, which in turn, on getting flooded, overflows further into yet another pool lying next towards the ice--shelf. Thus unlike other Schirmacher pools, Priyadarshni lake and a few other pools are affected both by inputs and outputs.

These pools provide habitat for protozoans, rotifers, tardigrades, nematodes along with bacteria and phytoplanktons, both green and blue-green algae and variety of diatomos. Though Ingole, Verlencare and Parulekar (1987) found turbellarians, in Priyadarshni lake, which the present author was not able to collect. In the pools, the distribution of nematodes is horizontal along the substratum, while those of rotifers and tardigrades it is vertical. The protozoans are distributed along three dimensional grid. All these animals mostly feed on diatoms and bits of algal strands, but in no way their association with algae is as intimate as with the moss-beds, outside the pools. Their distribution in the pools is determined by the conditions which differ great deal from one water body to the other in terms of water volume, inputs and intrinsic habitat, the quality of which is determined by vegetative density and salinity. Therefore, the fauna of pools differ from one water body to the other as to diversity and population density.

The conditions in pools and lakes, which all are oligotrophic, vary. Inspite of their common origin, catchment geology and climate they vary, under the prevailing circumstances. The variations are caused by several environmental factors such as glaciation or deglaciation and durations between thawing and freezing, and also the diverse brand of surrounding terrestrial habitats comprising the immediate catchment areas. The pools, by and large, are shallow. Even the most eminent among them is around 6 meters at the deepest. On this account, most of the Schirmacher

pools freeze entirely in winter and those which are comparatively shallower dry up completely, when in autumn the water stops meting. This situation does make a difference for the life that inhabits such pools with the water being unavailable, even underneath the ice-cover for major part of the year.

There is also another factor which greatly influences aquatic life in Schirmacher, and it is turbulence caused by high velocity winds. Whenever turbulence is induced by a snow-storm, the entire water in a pool gets churned up. This prevents stratification of any kind. The snow-storms continue for 100 or more hours, and churning for such a long period is certainly consequential for any kind of aquatic life. The prolonged periods of turmoil affect algae and diatoms individually, as well as the primary productivity of the pool generally. The disturbance may not unsettle the benthic life, yet in some way, availability of nutrition to them gets affected. Benthic decomposers, mainly bacteria, do contribute, though only marginally, to the primary productivity in a pool.

The primary productivity is initiated in spring (late October and early November), when the ice-cover begins to melt. Inspite of the fact that during this period the sun is constantly out, yet the primary productivity is never vigorous. This is because the sunny diurnal scale is interspersed with long spells of cloudy periods. Besides, the high velocity winds during such periods do not allow the productivity of the pool to reach closer to its peak.

Algal and phytoplankton bloom occurs earlier than blooming of the moss-beds. The spring, more than the summer, is the period of maximum phytoplankton growth, and it is attributed to the accumulation of nutrients in the pools as a result of bacterial activity, which continues during the best part of the winter as well. It was observed that the diatome population went on progressively dwindling during the later part of summer.

On the other hand, the moss-beds receive nutrients only after the ice has melted and the water begins to flow. As a consequence the pools get loaded up to their brim and the moisture begins to seep all around. Under these conditions, the moss-beds bloom and their blooming continues throughout the summer.

vi) Food-Chain (Pyramid)

As far as pattern of life and its inter-activity is concerned, Schirmacher presents an entirely simplified set up; and for this reason it could be considered a natural laboratory for testing ecological generalizations.

All food-chains begin with the induction of organic material. Its source on Schirmacher is quite enigmatic. Nothing, which is obvious, seems to be its source. But in depth investigation and introspection will reveal its sources which though are not abundant, yet are sufficient to sustain whatever life exists at present.

The input, in stark terms, is provided by rocks, which are processed by two agencies. One agency acts purely in mechanical terms. This is detonation of rocks due to glaciation which then begin yielding material to the flowing melt-water. The water imbibes from them whatever is soluble. The other agency is biological in nature. The lichens settle on the rocks, and their enzymatic activity leach out the organic material that ultimately finds its way into the streams and pools.

The other kinds of inputs, inducted into the system in indefinite quantity, are provided by bird-droppings and by those birds who died in Schirmacher, or after having died elsewhere got transferred to the oasis, or else same thing happening to their chicks and eggs. Skuas, the renowned predators, provide one of the means of transportation of dead matter to this part of Antarctica, besides winds and moving ice. All these agencies pour nutrients into the system which is then processed in phases and at a very slow pace, because of the absence of specified decomposers. The decomposition is brought about by enzy-matie activity, the source of which could be lichens as well as mosses. Both have been found to be intimately associated with the remains of birds. Soft tissue is the first to be processed, and. the processing of feathers and bones takes a great deal longer.

These inputs are outside contributions. Intrinsically contributed inputs are the dead bits of plants and animals belonging to the region. This only amounts to the recycling of the material that is already a part of the regional ecosystem.

The source of distribution of all the organic material is the flowing melt-water leading to the pools. Appropriately the growing plants pick up this material along with the moisture out of the running streams or from within the pools, after it is rendered usable by basic decomposers, the bacteria, or else after being leached out of rocks by lichens. This is precisely the reason that all life in Schirmacher is confined either close to or within the streams and pools.

Diatoms and other algae, both green and blue-green, are the primary producers in the lakes and pools. Out of the water, mosses and lichens act similarly. Most of the invertebrates are herbivores, which are the primary consumers. Only a fraction of primary productivity is consumed by the mosses themselves, while most of it trickles into peat. The rate of accumulation of this peat, in the sub-antarctic islands, is 1mm per year. It may not be that much in Schirmacher, as here decomposition is slower and the primary productivity per year far too low.

Basic edifice of schirmacher ecosystem though is structured by primary producers and primary consumers alone, yet one or two animal groups could be assigned the status of 'secondary consumers'. These are mites, nematodes and tardigrades. These mainly live on plants as browsers, and as such fall in the same category as protozoans, rotifers and collembola. But mites have also been observed mouthing nematodes; while nematodes and tardigrades depend on protozoa for the same reason. On that account, these animals may be regarded as occupying the top of the schirmacher trophic pyramid. Nematodes are real omnivores of the region. These feed on plants and these feed on other animals and besides, these also act as decomposers. Nematodes have been reported to break-down the dead organic material. Thus, these are extremely important agents that initiate and help in the circulation of material along the food-chain paths. In schirmacher too, it cannot be assumed that nematodes are capable of playing any different role far removed from this, where the ecosystem is devoid of even moderate competition.

Animals which live in such lakes, where primary productivity is marked by seasonality and is carried out only for short intervals, cannot be but opportunistic feeders. Here, even bacteria depend on algae for their nutrition. This is an example of short circuiting within the food cycle.

All the animals living in pools are browsers of algae. The observations of Priddle and Dartwall (1970) confirm the view that the animals from the pools often migrate to the moss-beds, where these then feed on mosses and, in turn, themselves become occasional food of the mites. The mites and springtails remain mostly confined to the moss--beds.

Vegetation crop of schirmacher ecosystem is meager only. This is quite expected under the prevailing conditions which can be summed up as those of a 'middle grade desert'. The ratio between total biomass and primary productivity also confirms that.

Among the primary consumers protozoans, rotifers and tardigrades comprise an impressive component of the total biomass. All of these groups individually show biomass value which is greater than that shown by the rest. Co_2 is a valueable asset and its major source once was respiration alone in Schirmacher, besides the atmosphere. Recent arrival of man here has changed the setting. Man has become the major Co_2 contributing factor, because he does not merely exhale Co_2 but also produces it in bulk, through his style of living. Helicopters, diesel generators and cooking agents produce so much of it, that its magnitude is quite capable of tilting the delicately balanced system too far in one direction, to topple it altogether, thereby breaking Shelford law of tolerance.

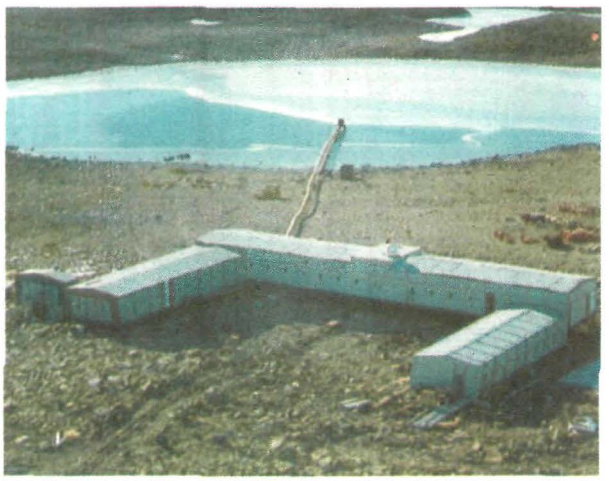
To sum up, at present, the ecological efficiency of the food-chain within the schirmacher ecosystem is within the normal range and is sustainable under the given conditions of light, space and moisture, where mosses, lichens and algae are primary producers, producing for protozoa, rotifers, tardigrades, nematodes, mites and spring-tails, out of which tardigrades, nematodes and mites also turn round to feed on their compatriates, and thereby becoming secondary consumers. Bacteria are partially dependent on algae, and these also function, as nematodes do, to act as decomposers. Spring-tails besides browsing the mosses, also feed on dead organic matter. It is logical to state that feeding habits of most of the animals that live in schirmacher oasis are 'opportunistic' as a rule, rather than as an exception.

The above mentioned trophic associations are presented in fig. 1.

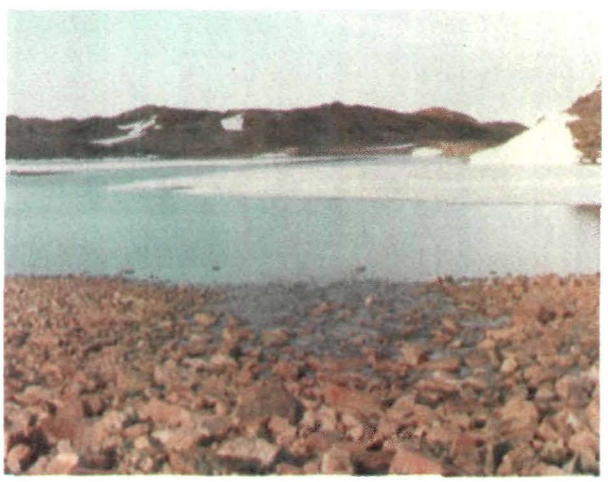
An Overview of Schirmacher's Trophic Situation:

1. The total absence of herbivores from Schirmacher has put its ecosystem at a different level of subsistence than those prevailing elsewhere in the world.
2. For this reason, the energy flux of the system is based on micro-organisms, which act as decomposers.
3. Microbivores, saprovores and micropredators comprise the next successive stage in the schirmacher food chain.
4. It is bacteria, algae and protozoa which are mainly responsible for biological transfer of materials and energy.

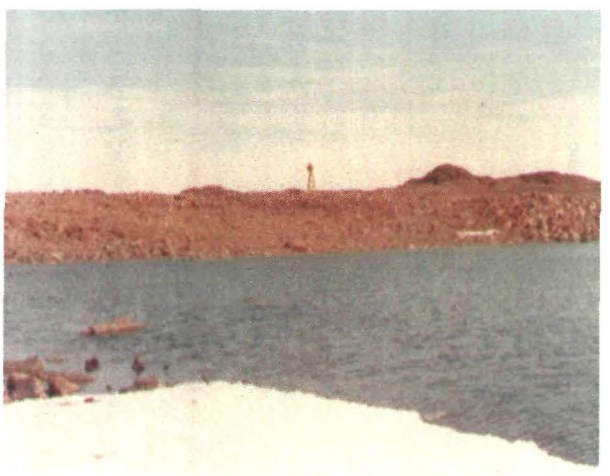
Antarctica Landscape



Maitri- Indian Research Station



Open stream



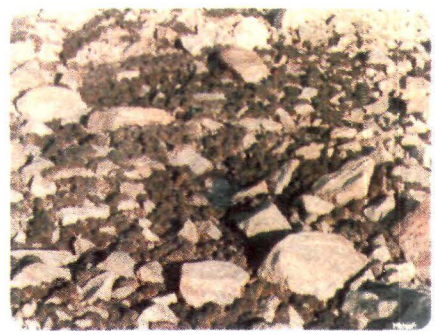
Open stream

Moss

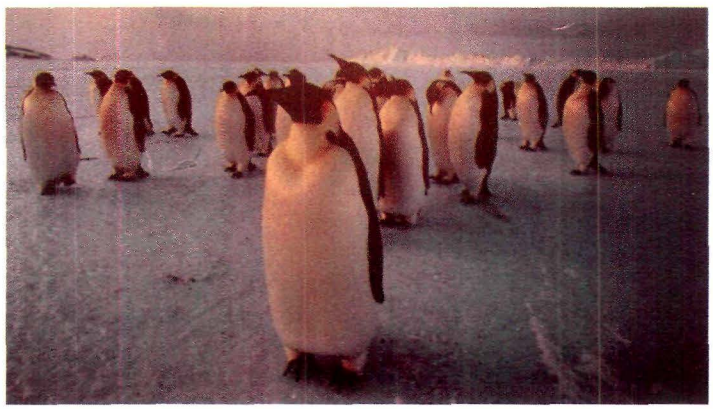
Moss

Moss

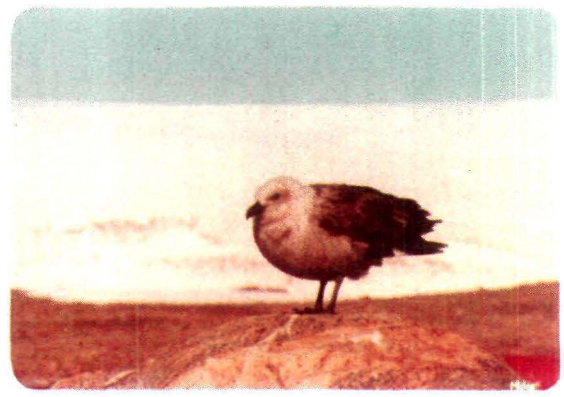
Lichen



Moss and Lichen



Penguins



Skua

5. The ecosystem, inspite of being poor in diversity is yet in a state of balance.

6. Soil invertebrate and microbial interactivity is the cornerstone of this ecosystem, which is moss dominated in the sense that to most of the animal communities these provide microclimatically established niches, while these release as well the dissolved, organic carbon from their tissues during freeze-thaw cycles, resulting from cellulose decomposition.

7. In the absence of tertiary consumers or predatory birds, the invertebrate fauna occupies the top of the trophic pyramid.

8. Springtails and mites do not numerically dominate the ecosystem, yet their presence in Schirmacher indicates their tolerance to cold and to physiological stresses, resulting from erratic availability of nutrition.

PROPOSED EXPLORATIONS

The terrestrial ecosystem of schirmacher oasis is devoid of herbivores or predators and their task is performed by decomposers alone. This ecosystem is thus a kind of minor inversion of that which is normally viewed as full blooded ecosystem. This indeed is a stable system and that is why it is perpetuating. But still it is a fragile system possessing low capacities of repair and rehabilitation. Though the world-wide pollution has not crippled the system, yet its dynamics is ecologically of poor resilience.

It is not possible, at this stage, to suggest a satisfactory model of the system. There is lack of knowledge about specificities and magnitudes of various parameters involved. With further gain in the knowledge, it would be possible and also worthwhile to construct a meaningful model representing the inherent processes, which are expected to be simple and straight, and it may be possible to initiate them in a laboratory.

Schirmacher indeed is unique place for testing concepts related to 'genetic drift' and role of isolation in the process of speciation. But it will need time and patience. Besides, the springtails and mites, which live here, show an extreme tolerance for cold. These two arthropods can be used as experimental animals for discovering elements of physiological adaptations to cold. Biochemical analysis of the tissues of these animals could also reveal the basics of the interplay between the body physiology and environmental components such as temperature, light and moisture, which manifest themselves, in Schirmacher, with variable intensities.

Detailed studies of the Schirmacher ecosystem is extremely important from another angle also. Now in Schirmacher, there is a permanent Indian station with all the improvisations wich cause the induction of more and more carbon into the sphere and more of sulphur, more of phosphates and more of nitrates into the ecosystem. This is bound to make a difference. The study of the ecosystem, thus, acquires a significance of different kind. Can we manage to keep it in a state of dynamic stability, even with human factor added to it ?

It is interesting to note that man has been visiting the oasis for only couple of years. Since then it has been depositing excreta without discrimination, and in the vicinity of the site of the Indian station., and this deposit had remained without any visible affect of decomposers even till the time, when in January, 1988, VII expedition paid a visit to the oasis. Decomposers failed to act on the human excreta either because the local decomposers lacked the specific enzymatic capacity to act on an alien object; or else the decomposers that went with the excreta could act only at higher temperatures. What has been the precise cause? It would be quite interesting to discover the answer.

There is another interesting point that needs investigation and which has a special relevance to human dwelling in a situation, where occur prolonged days and nights, as on Antarctica. It is already established that serotonin is the precursor for melatonin, which is sleep inducing neurotransmitter, and this conversion is mediated by the pineal body; and this part of the human brain is quite sensitive to light. Keeping these facts in mind, the general incidence of sleeplessness needs to be investigated. There is also a need to investigate other cybernatically operating factors influencing sleep or sleeplessness in Schirmacher. This knowledge will be both of fundamental and practical value.

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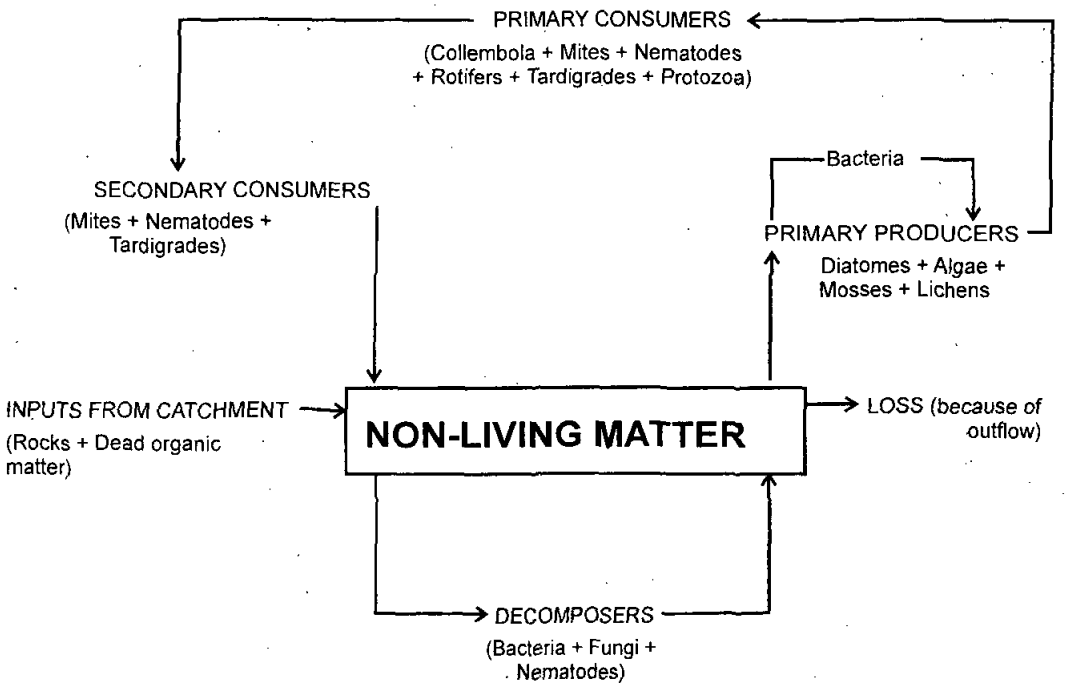
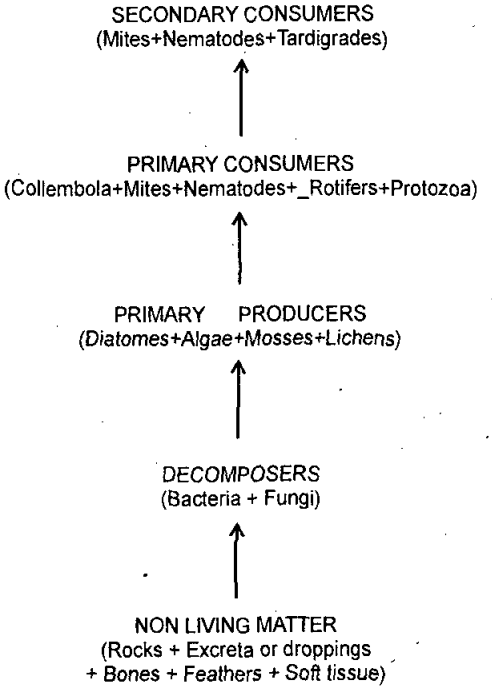
Fig. 1



A. Food - chain prevailing in Schirmacher Ecosystem.

Appendix I (B)



B. Trophic Pyramid in Schimacher Ecosystem

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CHARGE TRANSFER IN ENDOHEDRAL Na DOPED C_{240} MOLECULE

***Ranjan Kumar[1] , Harkiran Kaur[2], and Keya Dharamvir[1]**

[1]Department of Physics, Panjab University, Chandigarh – 160 014

[2]U. C. I. M., Panjab University, Chandigarh – 160 014

Abstract

C_{240} is a hollow iolecule of carbon atoms. It is a large nearly spherical molecule having mean radius of about 7.11Å. It may accommodate guest atoms inside it. Therefore a number of Na atoms may be doped inside it. We have used the model potential calculations to investigate the stability and charge transfer when Na atoms are doped inside it. In our calculations, the number of the Na atoms doped inside C_{240} varies from 4 to 9. The binding between Na atoms has been modeled using Gupta potential. The interaction between Na atoms and C_{240} is modeled using 6-exp potential. We find that the charge transfer depends upon the number of Na atoms. For smaller clusters, charge transfer is energetically favorable compared with relatively large clusters. Therefore ionic character decreases with the size of cluster. The binding energy of the cluster also increases as the number of Na atoms increase.

Key Words ; Charge transfer, C_{240}, Fullerens.

1. INTRODUCTION

Fullerene is a large molecule composed exclusively of carbon atoms and having the shape of an empty cage with a minimum of 12 pentagons (Dresselhaus, M. S. *et al.*, 1996). These Carbon Fullerenes commonly refers to a molecule with 60 carbon atoms, C_{60}, and with an icosahedral symmetry, but also includes larger molecular weight fullerenes C_n (n>60) [Dresselhaus *et al* 1996]. Examples of larger fullerenes are C_{70}, C_{80}, C_{240} and higher mass fullerenes, which possess different geometric structures. The carbon atoms are arranged in pentagons and hexagons within a fullerene molecule. In C_{60}, 60 carbon atoms are located at the vertices of a regular truncated icosahedron and every carbon site is equivalent to every other site. The average nearest neighbor C-C distant in C_{60} is 1.44 Å (Dresselhaus, M. S. *et al.*, 1996) and each carbon atom inside C_{60} is trigonally bonded to other carbon atoms. The carbon atoms are arranged in pentagons and hexagons within a fullerene molecule.

Three dimensional assemblies of these molecules form solids which have very interesting electronic and mechanical properties. The solid thus formed has large voids available for doping. These are known as exohedrally doped solids. While the bonding within a C_{60} molecule is covalent (mixture of sp^2 and sp^3), the inter-fullerene bonding in the solid is recognized to be of Van der Waals type, making the solid C_{60} a loosely bound condensate. Because of the large size of fullerene molecules, the interstitial cavities in a C_{60} lattice are large too, and can accommodate various guest species (Yang Wang *et al.*,1993). The alkali metal doped C_{60} solid has attracted a great deal of attention as M_3C_{60} systems (M represents alkali metal) were found to be superconducting (R.C. Haddon, 1992) with T_c around 30K or larger. Subsequently, $M1_xM2_{3-x}C_{60}$ (M1, M2 being different alkali metals) systems were extensively studied as it was found that T_c can be increased considerably with a suitable M1-M2 combination. For these reasons, a lot of interest in structure and stability of these compounds was generated.

A fullerene is a hollow molecule which may accommodate guest atoms inside it. This process is known as endohedral doping. An endohedrally doped fullerene molecule has modified electronic and mechanical properties. This in turn modifies the properties of the solid formed with these molecules. Therefore one can mimic electronic and mechanical properties with different number and type of dopants. Small alkali atoms, alkaline earth metals and rare earth metals may be doped inside fullerene molecules. For example La atom might be trapped inside a C_{60} molecule to form an endohedral fullerene (D.M. Poirier, 1994). The studies on alkali metal doped endoheral $A@C_{60}$ shows complete charge transfer from impurity to the C_{60} molecule (J.M. Cabrara-Trujillo *et al.*, 1996). It has been speculated that the substitution of C_{60} by $A@C_{60}$, could cause the solid to exhibit superconductivity (J. Ciosloswski *et al.*, 1992), as was the case of exohedral alkali doped C_{60}. Moreover it may used for the storage of smaller atoms or their clusters. Ferromagnetic atoms/clusters may be trapped inside fullerene as an isolated spin system, which may be used for device applications. As the novel form of fullerene-based materials, endohedral fullerenes represent a novel type of nanostructures, which are

**Corresponding Author: ranjan@pu.ac.in*

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characterized by a robust fullerene cage with atoms, ions, or clusters trapped in its hollow. Because of the electron transfer from the encaged species to the fullerene cage, this new type of molecules has opened many possibilities for research and has been attracting the wide interest not only in physics and chemistry but also in such interdisciplinary areas as materials and biological sciences.

In principle, many different atomic species can be inserted within a large fullerene molecule. This is why we take relatively large fullerene C_{240} as a host for endohedral dopants. We have studied the interaction between the endohedral clusters and the cage by using an approximation in which both the Na and C atoms are frozen at the same positions as they have in the pure Na_N clusters and the C_{240} fullerene. The endohedral cluster $(Na)_N$ is placed such that its centre of mass coincides with the center of C_{240}. To start with structural stability is one of the important aspects to investigate. Presently, we have done model potential calculations to study the stability of Na clusters with various No. of atoms inside C_{240}. The equilibrium is obtained with minimization with charge and size of the each cluster. The size of C_{240} is not allowed to change.

2. THEORETICAL FORMALISM

C_{240} fullerene molecule is considered as a spherical cage where the carbon atoms are distributed in a similar way as in the corresponding truncated icosahedrons fullerene; each carbon atom is placed on the vertices of slightly distorted pentagonal and hexagonal rings distributed on a spherical hollow cage with radius R=7.11Å (Jian Ping Lu *et al.*, 1994). Endohedral doping of Na atoms to C_{240} molecule may result in charge transfer from Na atoms to C_{240} molecule. We can expect that one or more electrons may be transferred from the Na cluster to the fullerene cage. In our calculations, the No. of atoms in the cluster varies from 4 to 9. Various interactions between Na atoms and Na and Carbon atoms of the C_{240} has been considered to calculate total cohesive energy of the system and hence the stability of clusters of Na atoms (cluster) inside C_{240}. The various components of the total cohesive energy are as under.

(i) Interaction between sodium atoms in the cluster

Let the number of Na atoms in the cluster is N. To model the metallic bonding in sodium cluster we have used the many-body Gupta potential (R.P. Gupta, 1981 and Juan A. Reyes-Nava *et al.*, 2003), which is based on the second moment approximation of a tight-binding Hamiltonian. It uses exponential functions rather than powers of the separation. Its analytical expression is given by (F. Cleri *et al.*, 1993).

$$V_{GP} = V_{GP}^{REP} + V_{GP}^{ATR}$$

$$= \frac{1}{2}\sum_{i=1}^{N}\left(A\sum_{i\neq j}\exp\{-p(\frac{r_{ij}}{r_0}-1)\} - \xi\left[\sum_{i\neq j}\exp\{-2q(\frac{r_{ij}}{r_0})-1)\}\right]^{\frac{1}{2}}\right) \quad (1)$$

where r_{ij} is the distance between Na atoms of the clusters and $\mathbf{r_0}$, **A**, **ξ**, **p** and **q** are adjustable parameters (Y. Li *et al.* 1998) (Blaisten-Barojas and Papaconstantopoulos, 1998). For sodium clusters, these parameters have been fitted to band structure calculations. (Y. Li *et al.* 1998) The values are: A = 0.01595 eV, ξ = 0.29113 eV, r_0 = 6.99 bohr, p = 10.13, q = 1.30

This potential has been already used to study the structure and thermodynamic properties of sodium clusters (Juan *et al.*, 2003; Cleri and Rosato, 1993) The Coulomb interaction between Na Atoms is given by

$$V_{COL} = \frac{1}{2}\sum_{\substack{i,j \\ i\neq j}}^{N} K\frac{qx_i \times qx_j}{r_{ij}} \quad (2)$$

where, K is the constant, qx is the charge on each Na atom of the cluster and r_{ij} is the distance between Na atoms of the clusters. Combining Eq. 1 and 2, we have

$$V_{CLST} = V_{GP}^{REP} + (1-qx)V_{GP}^{ATR} + V_{COL} \quad (3)$$

In equation 3, we have controlled the covalent contribution to the binding energy with the charge transferred to the C_{240}. For no charge transferred binding is purely covalent, as qx increases covalent character in the binding of cluster decreases.

(ii) Interaction between Na clusters and C_{240}

Now we will consider the interaction between Na atoms with the carbon atoms of C_{240} molecule. Let q be the charge transferred to C_{240} molecule. We consider that q is uniformly distributed among all carbon atoms on the

C_{240} molecule. Therefore the charge on each C atom is $q_c = q/240$. Coulomb interaction may be superimposed with van der Waals interaction used earlier in endohedral doped Na_xC_{60} compounds [14]. The resultant contribution to the energy is

$$V_{NaC240} = \frac{1}{2}\sum_{i}^{N}\sum_{j}^{240}\left[\frac{kqx_i q_c}{r_{ij}} - \frac{A}{r_{ij}^6} + B\exp(-\alpha r_{ij})\right] \quad (4)$$

Where A=6.95, B=1520, α=3.60, qx =charge on each Na atom, q_c= charge on each C_{240}, r_{ij} is the distance between Na atom of the clusters and C atom of C_{240}.

(iii) Interaction due to C_{240}

The interaction between a pair of C atoms on C_{240} is considered as Coulomb type only, which arises due to charge transfer from the Na cluster.

$$V_{240} = \frac{1}{2}\sum_{\substack{i,j \\ i\neq j}}^{240} k\frac{q_{ci}\times q_{cj}}{r_{ij}} \quad (5)$$

where, q_c is the charge on each C atom.

The cohesive energy may be written as sum of all the contributions described above.

$$V_{COH} = V_{CLST} + V_{NaC240} + V_{C240} \quad (6)$$

Apart from this, the electron affinity of C_{240} and ionization potential Na needs to be considered to discuss the stability of cluster in these systems. The SAPS calculation [3] of the electron affinity, defined as $A(C_{240})=E(C_{240})-E(C_{240}^{-1})$, gives the value $A(C_{240})=3.81$ev. Subsequent addition of electron will modify the higher electron affinity of C_{240}. We have estimated it by adding on shell Coulomb repulsion (φ) to it. The contribution to the cohesive energy is given by

$$U = -(q\times EA) + V\frac{1}{2}q(q-1) + q\times IP \quad (7)$$

Where q is charge on C_{240}, EA is Electron Affinity, IP ionization potential of Na and equals to 5.14 eV and

$V = \frac{9\times 1.6021}{7.05}$ Now, the total cohesive energy is obtained by adding Eqn. 6 and 7.

$$V_{TCOH} = V_{COH} + U \quad (8)$$

The Total cohesive energy V_{TCOH}, contains terms which depends upon the shape and size of the cluster of Na atoms (Eqn. 6). We can also vary the fraction of charge transferred to C_{240} molecule. Minimization of V_{TCOH} results in equilibrium value of size of the cluster and charge on it. The C_{240} molecule is assumed to be rigid.

3. RESULTS AND DISCUSSION

We minimize total cohesive energy, V_{TCOH} with charge and size of the clusters. First we take a cluster of 4 atoms. We find that with EA=3.81 eV and V = 2.04 eV, total charge transfer is favored (see Fig. 1) i.e. qx = 1. But, J. M. Cabrera-Trujillo *et al.* have shown that a charge transfer of two electrons takes place in this system. Now, to see whether our model support it or not we further look in to the possibility of charge transfer less than 4 by varying the values of EA and V. It is justified to fit these parameters as these are either estimated or calculated values. Fig.1 shows the variation of on shell Coulomb repulsion, v while EA is kept constant. We observe that with EA=3.81 and V = 4.85 V_{TCOH} gives a minima at two electron charge transfer but it is not a global minima. So we further refine EA as well as v to find global minima in V_{TCOH} for partial charge transfer. Fig.2 shows different sets of these parameters used. We find that for EA = 4.0, which is slightly higher from reported value 3.81 and V = 4.96, there is a global minima in V_{TCOH} at qx = 2.25. It means our model calculations confirm to the reported results with this set of EA and v. Now assuming these as the appropriate values for our model, we minimize the V_{TCOH} for other clusters doped in C_{240}. The results have been summarized in Table 1. From table 1, it is clear that a charge transfer 0.5 electrons is favorable for $Na_5@C_{240}$. For larger clusters value decreases to 0.25 and finally for $Na_9@C_{240}$ no charge transfer is favorable. Therefore, for smaller clusters interaction is mostly ionic and as the cluster grows binding becomes more and more covalent. This is in good agreement with other theoretical investigations. The details of the structure of the metal clusters have been summarized in the

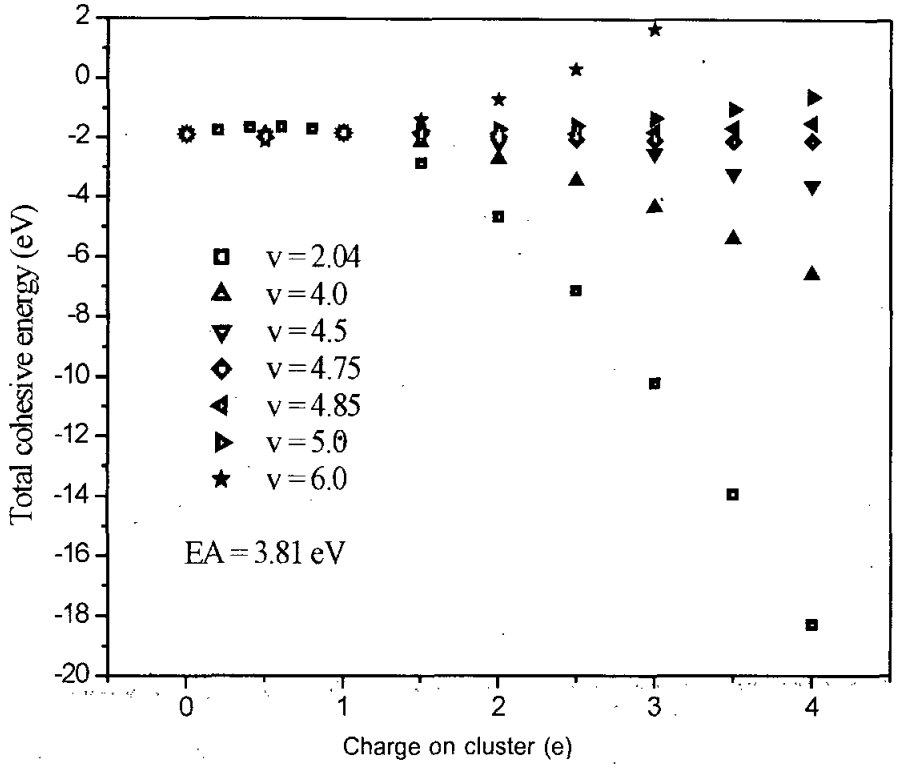

Fig. 1. Variation of V_{TCOH} with Charge on the Cluster. Electron affinity of C_{240} is constant and on shell coulomb repulsion is varied from 2.04 -6.0 eV.

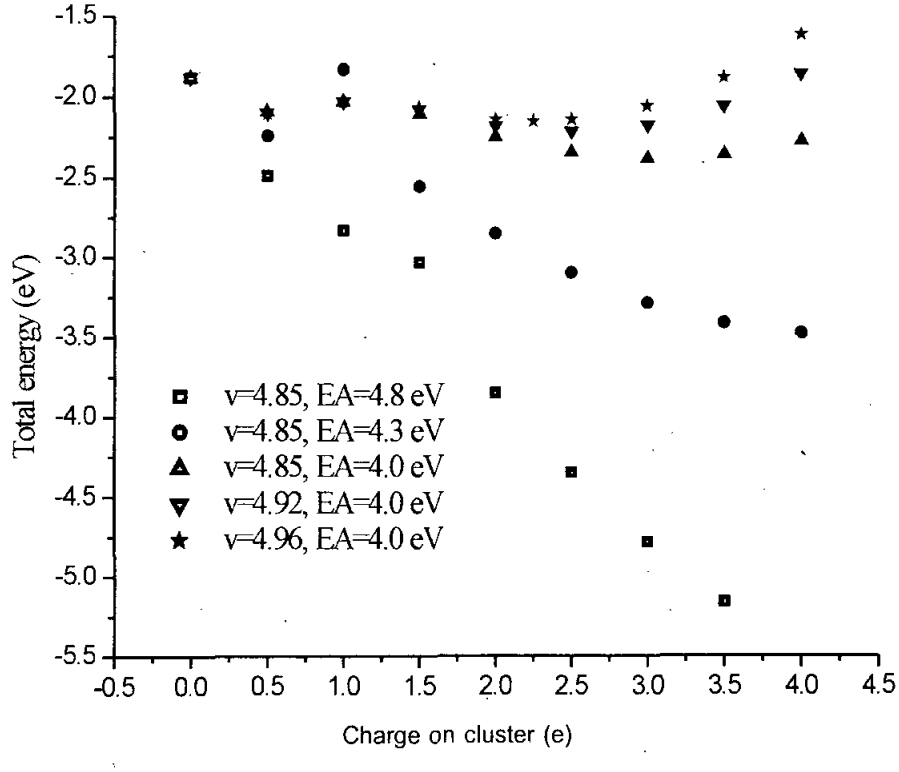

Fig.2: Variation of V_{TCOH} with Charge on the Cluster. Electron affinity of C_{240} and on shell coulomb repulsion have been varied.

same table. The coordinates of the clusters are written as coordinates assuming unit length of the rectangular Cartesian system multiplied with a number *c*. In table 1, *the size of cluster implies the value of c. Binding energy of the cluster increases with no. of atoms, but* not monotonically. Moreover total cohesive energy per atom also increases with number of atoms, which shows that there is a tendency of the clusters to grow in size inside C_{240} and is energetically favorable.

We conclude that charge transfer to C_{240} molecule is favorable for small clusters. As the cluster grows in size (number of the atoms increase), charge transfmr is not favorable. The binding energy of large clusters is *dominated by covalent contribution cs it should be. The binding energy in general increases with number of atom* in the cluster but does not show a systematic variation. Further it would be interesting to see the stability and structure of much larger clusters, mixed metal clusters, clusters placed off centre and clusters inside other fullerenes including silicon fullerenes.

Table1. Charge transfer and structure of various clusters inside C_{240}

S. No	No. of atoms	Structure of Na cluster	Size of cluster, *c*	Charge on C_{240}	V_{TCOH} (eV)	Energy Per Na atom (E/N)
1	4	Tetrahedron	4.65	-2.25	-2.149	-0.54
2	5	Tetrahedron+ centre	3.80	-0.50	-2.677	-0.53
3	6	Octahedron	4.65	-0.25	-4.282	-0.71
4	7	Octahedron + centre	4.60	-0.25	-4.523	-0.65
5	8	Simple Cube	3.25	-0.25	-7.240	-0.91
6	9	Simple Cube+ centre	3.55	0.00	-8.947	-0.99

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EFFECT OF TEAM COMPOSITION IN DEVELOPMENT EFFORT ESTIMATION HAVING REUSABLE COMPONENTS

*[1]Jyoti Mahajan, [2]Vinod Sharma, [2]Devanand, and [2]V. Mansotra

[1]Computer Engineering Department, Govt. College of Engg. & Technology, Jammu
[2]Lecturer (SG), Department of Computer Science & IT, University of Jammu, Jammu

Abstract

In software engineering there is a need for developing and using paradigms that will significantly promote decrease in efforts for developing software products, increase in quality of software products and reduce time-to-market the software product. Decreased efforts and increased quality will help in decreasing the overall cost of software and also decrease the time-to-market of the software. All the work in the field of software reuse has concentrated mainly upon the amount of reuse and the libraries involved. The objective of this work is to implement a model for analysis and assessment of software reuse based on the values of reused code, amount of glue code and composition of team developing the application. It justifies the effect of the team composition, interconnection standards and the component scale of the libraries on the productivity and quality of the developed application.

Key words : Software reuse, LOC, RLOC, Software quality.

INTRODUCTION

Reuse has been defined in a number of ways. In general it is defined as "the systematic practice of developing software from a stock of building blocks, so that the similarities in requirements and/or architecture between applications can be exploited to achieve substantial benefits in productivity, quality and business performance" [1]. The process of creating software systems from predefined software components is also termed as reuse, which in turn implies the use of previously existing software artifacts. Artifacts include all products of a software development process and include planning the data, requirements of data, designing the data, source code, configuration management records, quality assurance records and verification of data.

It is desired to reuse the existing components without using extra resources in refining the reusable components for the desired product. Development for reuse implies expanding resources specifically to increase the reusability of components. In many cases, this process might follow the development with reuse where components generated during normal system development are made more reusable by generalization and improvement [2]. Thus we believe that the normal mode of production of reusable components should be, to take existing components and to add reusability to them. This extra cost for reuse is taken as an organizational cost rather than a project responsibility. In fact, reusing the software also results in reduction in costs associated with design, coding and testing. This in turn helps in better understanding the code as, in all likelihood, the code is already tried and tested by the user. Reusability is an attribute which can be added at any level from the specification to the implementation stage.

Estimation Process and Reuse Analysis

Estimation begins by projecting the amount of software to be produced. Software size may be estimated in terms of functional size (the amount of capability to be delivered), physical size (the amount of software product to be delivered), or both [3]. Effort estimation is the best understood part of the estimation process, as it is the focus of most traditional estimation models. This step converts the software size estimate into an estimate of effort by applying an appropriate estimation relationship. Some estimation models use a non-linear relationship between size and effort, assuming that as software size increases the effort required per class also increases [4]. If multiple types of software (e.g., reused and newly developed) are included in the estimate, then the effort for each type must be estimated separately and the results are added together. Alternatively, the sizes can be converted to a common unit by weighting algorithm, and then used as the basis for effort estimation. Reducing cost by increasing reusable components provide one of the strongest motivations for adopting object oriented techniques. The amount of reused software expected is estimated separately during the sizing step. Most of the efforts associated in reusing software comes from

*Corresponding Author : Vibhakar Mansotra
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integrating that software with the developed code rather than from designing or coding. Modifying the reusable software will increase the effort required significantly.

A six step formal reuse analysis and implementation approach is given below:

i. Clearly Identify Goals and Purpose
ii. Catalog & analyze existing or proposed artifacts.
iii. Compare & contrast alternative approaches.
iv. Select optimal approach.
v. Strategy modification.
vi. Risk mitigation.

Rigorously following these steps will allow for lower development risk and help ensure successful, profitable software development [5]. Types of Reuse vary according to the reasons for reuse as well as the character of the elements to be reused. However, the reuse analysis and incorporation is the same.

Cost is the most important metric in software development and it can be viewed as the sum of the following costs:

1. Cost of developing new custom components for the target software.
2. Cost to assemble the components into a system (i.e., integration or plumbing costs)
3. Cost to remove the defects from the target system.

Among the various independent factors, the factors like the degree to which the domain is understood, the breadth of the domain chosen and the specific kind of reuse technology, have an effect on the three key dependent factors given below as suggested by Biggerstaff and Richter [5]:

1. The amount of reuse within the target application.
2. The scale of the components being reused, and
3. The inter component connection standards.

These factors in turn affect several elements of the total cost. The larger the amount of reuse, the lesser will be the expenditure on developing new components for the target application. Similarly, the larger the proportion of reused components in an application, lesser will be the efforts in removing the defects.

The scale of components typically affects the cost to assemble the components. Assembly of large-scale components requires less plumbing and introduces fewer plumbing errors, both of which reduce costs.

Inter-component standards reduce plumbing costs mainly by reducing the amount of specialized code that must be developed to hook components together. The more highly standardized the interconnections, the less effort is required to assemble the application. The choice of reuse technology significantly affects two of the most important factors that influence cost – the scale of components and the percent of the application that can be built by using reusable components.

The earlier models were used to predict the effects of component scale and inter-component standards on the plumbing costs and thus leading to profitability due to reusable components. These models [6] observed that:

1. Library standards (most often expressed in terms of application domain data structure and protocol standards) are effective in promoting reuse.
2. Large components reduce the relative effort to interconnect reusable components in all but such libraries are not properly standardized.

Thus, the authors have made an attempt to incorporate few more parameters to the already existing model as suggested by Biggerstaff and Perks [7]. In this model the authors suggest that the team involved in the application development does create a significant effect on the amount of reuse.

Proposed Model

In the model as proposed by Biggerstaff [8], the authors are of the view that there is a significant relationship between the plumbing cost and the team composition. The composition of the team depends on various personal attributes of the team like Analyst Capability, Programming Capability and Programming Language Experience. Such attributes when provided with predefined library functions for reuse, does create a significant effect in developing the application. This can be proved by examining the proportion of glue code used on an average by a team member to connect the reuse component into a target application for various levels of component scale and interconnection standards. The common factors as suggested by Biggerstaff and Perks [7] related with software reuse are :

a) Amount of reused code.
b) Amount of glue code.
c) Composition of team developing the application.

The various input parameters as suggested by* Biggerstaff *are:

ACC – Average Complexity Connectivity (LOC/ Connection)
SC – Average scale (LOC)
AFI – Average Fan-In (Connections)
NLOC – New Lines of Code (LOC)
RLOC – Reused lines of Code (LOC)

The authors propose two new parameters which can also have a significant role in reducing the cost of developing the application using reusable components. These parameters are :

N_{fre} – No. of freshers in the team

N_{exp} – No. of experienced in the team

ACC characterizes the interconnection standards of the reused library. It is the average number of lines of code required to make use of a component in the target application. It is a measure of the code that wires together the new code and the data structures associated with the reused components.

SC is the average number of lines of code of the components in the library.

AFI is the average number of connections required for a typical component. For example, if a library has 'x' components and in target application there are 'y' calls to the library then AFI = y/x. for each connection ACC lines of code is required on an average.

NLOC is the number of new lines of code in the target application

RLOC is the number of reused lines of code in the target application.

The various output parameters as suggested by Biggerstaff are:

CLOC – Glue lines of code (LOC)

TLOC – Total lines of code (LOC)

The authors here also propose two new output parameters in the existing model suggested by Biggerstaff. These parameters are :

N_{glue} – No. of connection lines per total lines of code per person (dimensionless)

N_{reuse} – No. of reused lines per total lines of code per person (dimensionless)

CLOC is the number of lines of code required for connection of the reused components in the target application.

TLOC is the total number of lines of code in the application. TLOC is the sum of NLOC, CLOC and RLOC.

The authors also introduce an intermediate parameter in the existing model in order to compute the weighted team composition that also plays a significant role in proving the objective and requirement of the proposed parameters.

The intermediate parameter used is:

K – Weighted composition of team defined as:

$$K = \{(N_{fre} . W_{fre})/NOP + (N_{exp} * W_{exp})/NOP\}$$

W_{fre} - Weightage factor of a fresher (from empirical study)

W_{exp} - Weightage factor of an experienced (from empirical study)

W_{fre} and W_{exp} are calculated by multiplying the personal attributes of freshers and experienced respectively.

$$K = \left[\frac{N_{fre} * W_{fre} + N_{exp} * W_{exp}}{NOP} * 100 \right]$$

Where $NOP = N_{fre} + N_{exp}$

$$CLOC = \frac{RLOC * AFI * ACC}{SC}$$

$$TLOC = RLOC + CLOC + NLOC$$

$$N_{new} = \frac{NLOC}{TLOC * K}$$

$$N_{glue} = \frac{CLOC}{TLOC * K}$$

$$= \frac{RLOC * AFI * ACC}{TLOC * K * SC}$$

$$N_{reuse} = \frac{RLOC}{TLOC * K}$$

$$= \frac{SC}{[SC(1+NLOC/RLOC)+(AFI*ACC)] * K} \quad \text{..... (a)}$$

$$N_{glue} = \frac{N_{reuse} * AFI * ACC}{SC}$$

From eqn. (a)

$$N_{glue} = \frac{AFI * ACC}{[SC(1+NLOC/RLOC)+(AFI*ACC)]*K}$$

The above eqn. gives inverse relationship between N_{glue} and K for constant values of various library standards and target application parameters. The values associated with the parameters W_{fre} and W_{exp} are empirical values taken from Boehm Model and the values associated with N_{fre} and N_{exp} are hypothetical in nature chosen for

the purpose. Using the empirical and hypothetical data values for these parameters, the authors have tested the results using MATLAB for three different cases.

Case I: A library with poor interconnection standard. (SC is approx. equal to ACC)

$$N_{glue} = \frac{AFI}{[(1 + NLOC/RLOC) + AFI] * K}$$

Case II: A library with good interconnection standards but small components (ACC=1 and SC=AFI)

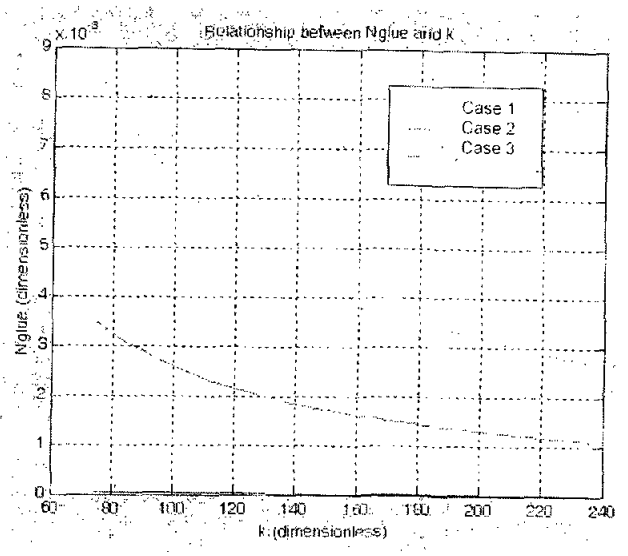
$$N_{glue} = \frac{1}{(2 + NLOC/RLOC) * K}$$

Case III: A library with good interconnection standards and large components.

ACC = 1

SC >> AFI i.e. SC is of the form 10^n * AFI

$$N_{glue} = \frac{1}{\left[10^n * (1+NLOC/RLOC) + 1 * K\right.}$$



OBSERVATIONS

The above graphs show that there is a very small change in N_{glue} for the value of K which corresponds to a team dominated by Freshers.

It can also be seen that for maximum value of K the number of Freshers in the team goes on increasing, thus affecting the cost of application development. It is interesting to note that graph for Case 3 almost coincides with the x-axis which means that for every value of K there is no significant change in the value of N_{glue}.

CONCLUSIONS

The model represents the effect of team composition on the development of the application having reusable components. It gives an insight into the role of the team involved in the development of the application on the plumbing costs. It can help a person to select a suitable composition for the team involved in the development of the application. This is done by studying the change in team composition in correspondence with the amount of change in the value of N_{glue}. So if one has the capability to understand where this model works, it can be a very powerful tool in one's arsenal of software development.

The observations of the model have been restricted to only two extreme cases for personal attributes i.e. people with very low and high experience. The model can be extended to include other intermediate cases also.

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STABILITY OF Na AND H ATOMS INSIDE C_{60} MOLECULE – DFT CALCULATIONS

Reena Devi and *Ranjan Kumar

Department of Physics, Panjab University, Chandigarh - 160 014

Abstract

We report ab-initio molecular dynamics simulations of Na and H atoms inside C_{60} using SIESTA. We have found that the C-C bond lengths are in agreement with 1.40 and 1.45Å values reported earlier. We studied the stability, geometries and charge transfer from the system of Na-atoms and H-atoms to the C_{60} molecule. We find that in case of $Na_n@C_{60}$ one can dope a maximum of four atoms inside a C_{60} molecule. In case of H doping we have been able to dope 10 atoms inside C_{60}, but it may accommodate more without adsorbing to the inner surface of C_{60}.

Key Words: DFT calculations, endohedral, fullerenes, Hydrogen clusters.

1. INTRODUCTION

Fullerenes and related materials have attracted attention because of their unique physical and chemical properties. The unique spherically shaped cages of C_{60} fullerene contain empty space that is large enough to incorporate atoms or molecules inside it, the presence of which can significantly affects the properties of the fullerene molecule/material. Fullerenes have revealed promising application in wide variety of very important technological processes such as in designing electronic devices, super fibers, catalytic materials, etc. Experiments suggest that fullerenes which incorporate alkali metals posses catalytic properties. From the point of view of theory, there are several *ab initio* calculations involving endohedral rare gas (e.g., He and Ne) (D.S. Bethune *et al.,* 1993) as well as metal (e.g., La, Ni, Na, K, Rb, and Cs) (B. Dunlap *et al.* 1992; O.D. Haberlun *et al.* 1992; and T. Guo *et al.,* 1993) atoms and in all cases, the electronic properties are found to depend sensitively on the internal dopant. Also alkali-doped C_{60} compounds with exohedral doping show superconductivity at reasonably high temperature (A.F. Hebard, *et al.,* 1991). Applications such as magnetic detectors and in magnetic recording technology are also being envisioned (C. Prados *et al.,* 2002) . Because of the large empty space inside a fullerene molecule, it may be used as storage material with high capacity and stability. The storage of hydrogen in fullerene has attracted much experimental and theoretical interest, to use in fuel cells for power generation. Therefore it becomes pertinent to study the properties of endohedral fullerenes by doping with different atoms. In the present work we use the code SIESTA (Spanish Initiative for Electronic Simulations with Thousands of Atoms) to study the stability, geometries and charge transfer of Na-atoms and H-atoms doped C_{60} fullerene by optimizing the atomic geometries. We performed MD simulation and used conjugate gradient technique for coordinate optimization. We find that in case of Na-atoms inside C_{60} ($Na_n@C_{60}$) the binding energy decreases with increase in number of Na-atoms and initially there is fractional charge transfer but after n = 3 no charge transfer is observed. In case of $H_n@C_{60}$, H-atoms form H_2 molecules inside C_{60} and these hydrogen molecules form structure such as triangle, tetrahedron, trigonal-bipyramidal etc. inside C_{60}. In other words we can say that there is a good possibility of storage of hydrogen gas inside C_{60}.

2. COMPUTATIONAL DETAILS

Calculations were performed using density functional theory within generalized gradient approximation (GGA), using the exchange-correlation potential developed by Perdew, Burke and Ernzerhof (PBE) (J.P. Perdew *et al.,* 1996). We used SIESTA (J.M. Soler *et al.,* 2002) code to perform *ab initio* DFT calculations using numerical atomic orbital as basis sets. Due to the requirements of high accuracy, we use multiple- z bases with polarization functions. Here in this case we used double- z bases with polarization function. For Na, this means that the basis contains one orbital to describe the 3*s* shell, and for H the basis contains 1s shell. The multiple- z orbitals are defined in the split-valence scheme. The core electrons were eliminated from the calculations, and their effect was accounted for by the inclusion of nonlocal, norm-conserving Troullier-Martins pseudopotentials (N. Troullier *et al.* 1991). These were

*Corresponding Author : ranjan@pu.ac.in

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generated by means of nonrelativistic, spin polarized atomic calculations. The pseudopotential radii used were 1.54 Bohr for C. For a given configuration of the ion cores, the valence electrons were treated selfconsistently within DFT, using the Perdew-Burke-Ernzerhof form of the generalized gradient approximation for the exchange-correlation potential (J.P. Perdew *et al.*, 1996). To obtain the cluster structures we carried out MD simulations using the conjugate gradient algorithm (M.P. Allen *et al.*, 1990). The clusters were allowed to relax until the inter-atomic forces were smaller than 0.04 eV/Å. The binding energies reported below were calculated by subtracting the sum of the energies for the individual atoms computed using the same basis sets and cell size as in the cluster calculations from the cluster energy.

We have performed two different simulations. At first, for Na-atoms inside C_{60} were allowed to CG (Conjugate Gradient) relaxed with respect to all degrees of freedom and without additional constraints. The calculation include atoms n=1-6. Secondly H-atoms were inserted into C_{60}, and then this system was optimized again using the CG algorithm with no additional constraints for n=1-10. The relaxation was always terminated when maximum atomic forces became smaller than 0.04 eV/Å.

3. RESULTS AND DISCUSSION

The radius of a relaxed empty C_{60} fullerene shell has been determined previously (G. Jungnickel *et al.*, 1996) and is found to be ~3.54 Å. The characteristic bond lengths are 1.40 Å and 1.45 Å for the bonds joining two six membered rings, and bonds joining one five membered ring and one six membered ring, respectively. Our calculations also give almost the same radius and similar bond lengths after complete relaxation of the molecule. We have considered two dopants which are very different from each other. One is sodium atom, which is an alkali metal and could be a good candidate to see charge transfer in endohedral fullerenes. Other atom doped inside C_{60} is H. It is very small and C atom may form bond with hydrogen easily. The results for these two types of dopants are presented below.

3.1 Na-atoms inside C_{60}

We assign initial atomic coordinates to Na-atoms and Carbon atoms of C_{60} molecule and then allow all the species (atoms of Carbon and sodium) to relax with respect to all the degrees of freedom without additional constraints. The structures investigated include Na atoms varying in number from 1 to 6. In Table 1 we list the charge transferred from Na-atoms to C_{60} cage and binding energy/Na-atom inside C_{60}. The lowest energy structures of $Na_n@C_{60}$ (n=1, 2 ...6) are shown in Fig 1. We find that in this case the Na-atoms inside C_{60} do not shows Na-Na bond up to n=3. The Na-atoms are separated by a large distance and there is no Na-Na bond (as shown in Fig 1). From table 1 it is clear that there is fractional charge transfer in Na doped C_{60} systems. Charge transfer for $Na_2@C_{60}$ is maximum i.e. $(Na_2)^{+0.628}@C_{60}^{-0.628}$. This charge transfer gives rise to Coulomb repulsion and hence prevents the formation of bond between Na atoms. Further increase in the number of Na atoms results in less charge transfer. Interestingly, in case of $Na_4@C_{60}$, four Na-atoms do not show bonding with each other but three Na-atoms out of four make bond with the carbon atoms of C_{60} molecule. As we further increase the number of Na-atoms inside C_{60} situation changes. For $Na_5@C_{60}$ and $Na_6@C_{60}$, Na-atoms makes bond with each other and also with the carbon atoms of C_{60} molecule (as shown in Fig 1). Five Na-atoms forms trigonalbipyramidal structure and six Na-atoms forms squarebipyramidal structure inside C_{60}. The binding energy of Na atoms becomes positive, which implies that the system is unstable. From fig. 3, it is clear that binding energy decreases monotonically with increase in number of Na atoms. Therefore even the bonding between Na atoms could not sustain the insertion of more and more Na atoms. Here it is interesting to observe that Na atoms like to make bond with C atoms first. It is important to mention here that earlier some authors have studies vibrational properties

Table 1: Charge and binding energies of Na-atoms inside C_{60} molecule

Number of Na atoms inside C_{60}	Charge transfer (Na to C_{60})	Binding Energy/Na atom (eV)
1	0.434	-2.046
2	0.628	-1.402
3	0.307	-0.733
4	0.006	-0.363
5	0.002	0.151
6	0.083	0.558

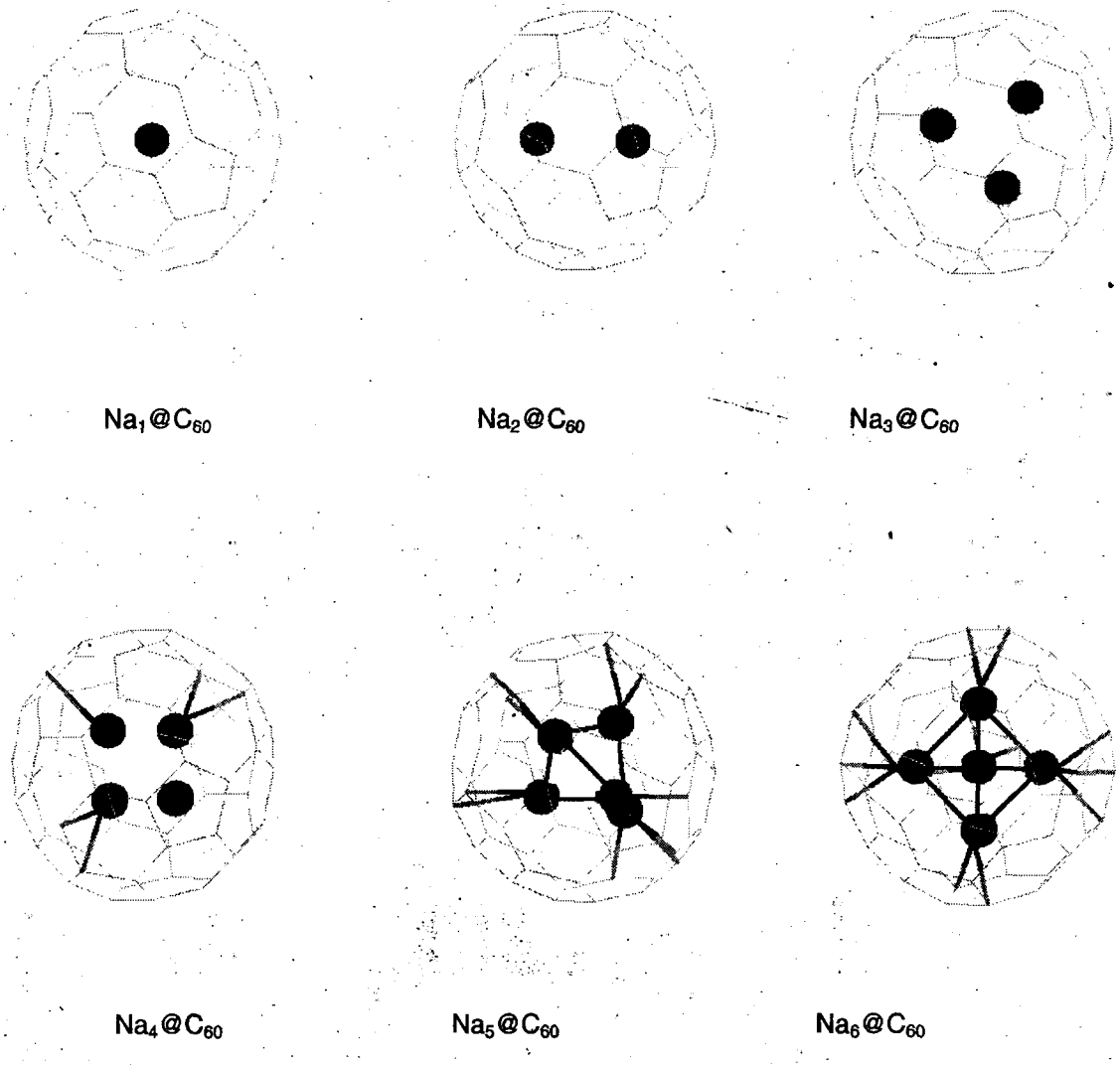

Fig. 1: The lowest energy structure of $Na_n@C_{60}$ for n = 1-6.

of Na ion inside C_{60} and electronic properties of $Na@C_{60}$ presuming a charge transfer of 1 unit charge from Na to C_{60}. We do not see the possibility of charge transfer of this magnitude. Further the possibility of more than one Na atom has been studied for the first time and we found that one can dope up to 4 atoms. However binding energy per Na atom is maximum for singly doped C_{60}. For $Na_4@C_{240}$ similar calculations (J.M. Cabrera-Trujillo *et al.*, 1996) show that a maximum of 2 electrons may be transferred to the C_{240} molecule. This really motivated us to see the ionic character of $Na_n@C_{60}$.

3.2 H-atoms inside C_{60}

Due to the storage capacity of fullerene they are also tested and studied for hydrogen storage (R.E. Barajas-Barraza *et al., 2002* and O.V. Pupysheva *et al.*, 2008). We have performed calculations with same simulation parameters as in the case of sodium. We consider hydrogen-atoms inside C_{60} with initial coordinates such that H atoms are separated by a distance of about one angstrom and let the system relax with respect to all degrees of freedom and without additional constraints. We have done calculations for a maximum of 10 H atoms inside C_{60}. It is observed that there is no cluster formation of H atoms inside C_{60} and interestingly H-atoms do not make bonds with the carbon atoms of C_{60} molecule. Encapsulated hydrogen atoms only exists in a molecular form (H_2) inside the C_{60} (as shown in Fig 2) and do not adsorb to the internal surface of the C_{60} cage. It is important to mention that initially H-atoms are separated by equal distance but after simulations the final lowest energy structure results in the formation

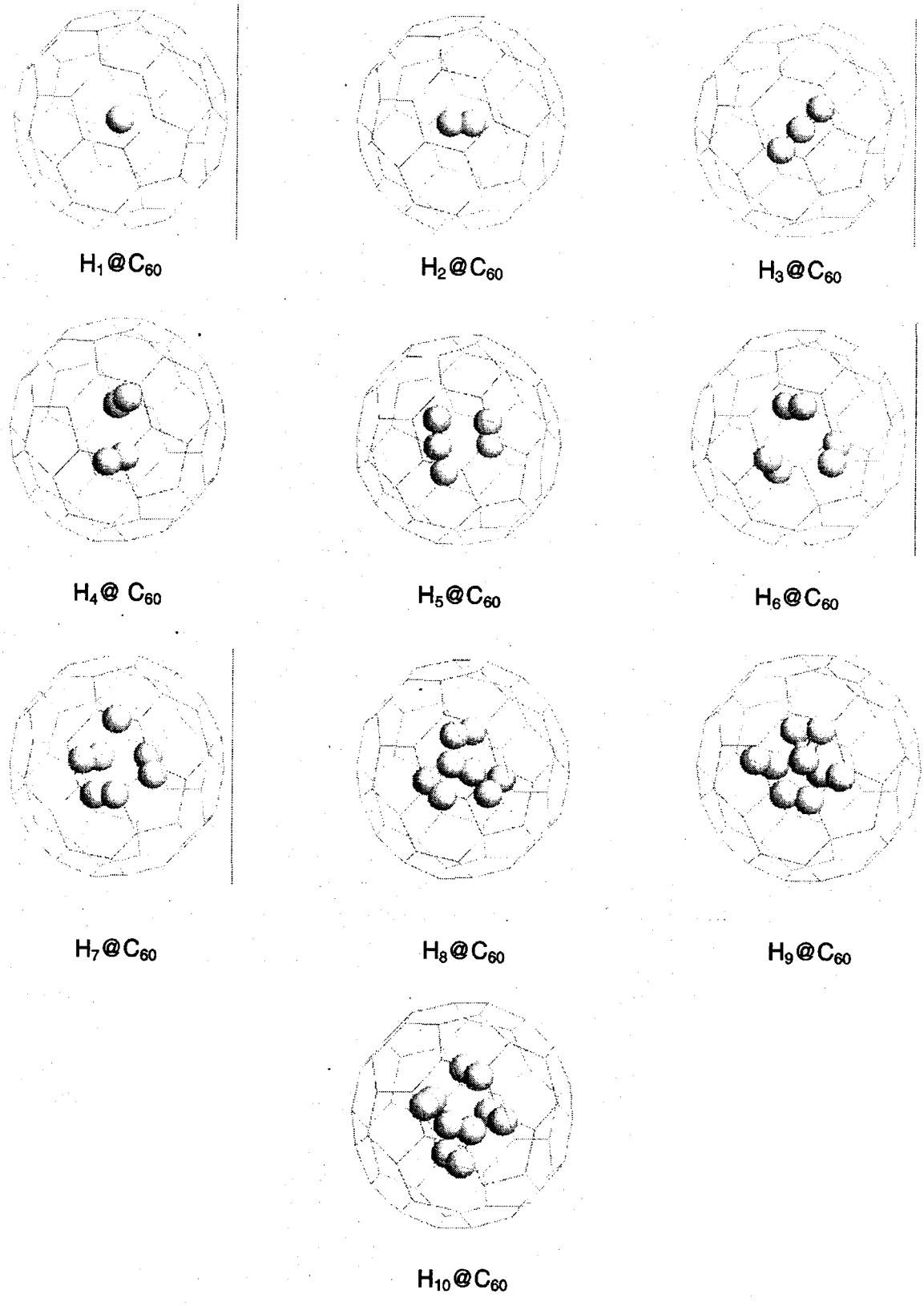

Fig. 2: The lowest energy structures of $H_n@C_{60}$ for n = 1-10

Table 2: The binding energies for H-atoms inside C_{60} molecule

Number of H-atom inside C_{60}	Charge transfer (C_{60}-H)	Binding Energy/H atom (eV)
1	0.161	-0.482
2	0.047	-3.691
3	0.083	-2.685
4	0.119	-3.540
5	0.157	-2.958
6	0.160	-3.444
7	0.164	-3.159
8	0.184	-3.374
9	-0.397	-3.127
10	0.235	-3.235

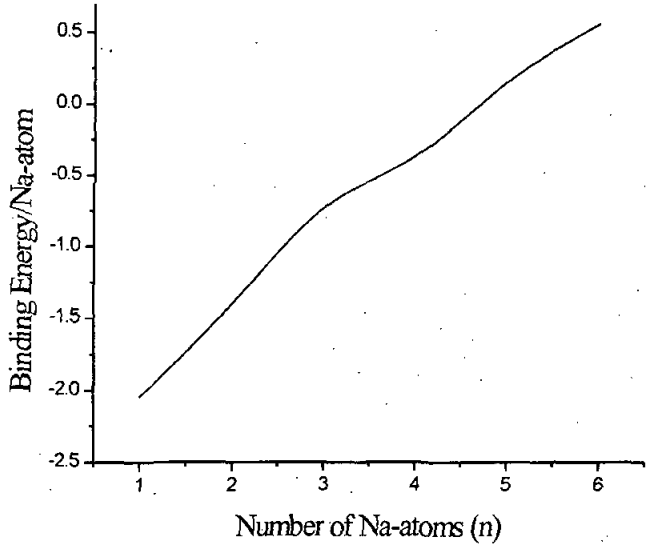

Fig. 3: Variation of binding energy of Na atomwith n, number of Na atoms inside $Na_n@C_{60}$.

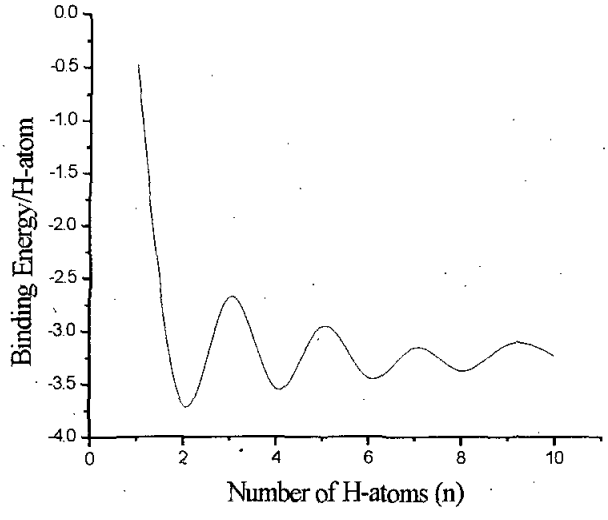

Fig. 4: Variation of binding energy of H atom with n, number of H atoms inside $H_n@C_{60}$.

of H_2 molecules. In all cases we found H-H bond lengths of 0.74-0.77Å. In Table 2 we list the charge transfer from carbon atoms of C_{60} molecule to hydrogen-atoms inside C_{60} molecule and binding energy/H-atom inside C_{60}. Charge transfer is also insignificant, which again implies inactivity of H atoms interacting with C atoms. The lowest energy structure of $H_n@C_{60}$ (n=1,2 ...10) are shown in Fig 2. The arrangement of hydrogen molecules inside C_{60} is not random rather correspond to triangular, tetrahedron and trigonal-bipyramidal structures of H_2 molecules. This observation is in complete agreement with other calculations [13]. Moreover binding energy per H atom shows interesting trend with number of H atoms doped inside C_{60}. From fig. 4, it is clear that even number H atoms have more binding energy per H atom compared with odd number of H atoms. This is because, for n = 1, the binding energy is just energy of single H atom where as for n = 2, molecule formation takes place and binding energy increases. For n odd, either we have one H atom or a cluster of 3 H atom along with H_2 molecules. So the binding energy for n odd should be less than for n even. Moreover as the number, n increases the difference between odd and even n binding energies decreases because relative contribution of single H atom keep decreasing. From table 2, it is seen that for $H_9@C_{60}$ the charge transfer is -0.397. It implies that 9 H atoms are deficit of .397 e charge and the same is transferred to C_{60} molecule. In all other H_nC_{60} systems charge transfer is small and opposite in nature. To explain this ambiguity in H_9C_{60} we have analysed structure and charge transfer in this molecule. We found that this is the only system which contains a triangular H_3 cluster. All other odd n systems have either linear H_3 configuration or H_2 and single H. Triangular H_3 unit in $H_9@C_{60}$ is itself deficit of 0.472 e charge. Out of this .472 e charge, 0.397 is transferred to C atoms and rest is distributed among remaining H_2 molecules of $H_9@C_{60}$. Therefore, unusual charge transfer in H_9C_{60} is due to the formation of triangular H_3 cluster. Moreover it may be inferred from table 2 that for n = odd there is more fraction of charge transfer compared with n = even systems. Charge transfer in $H_n@C_{60}$ molecule will modify the intermolecular interaction but probably will not result in n-type of semiconductor because H atoms become part of the C_{60} molecule. The charge transfer discussed here is basically an intra-molecular affair. So nothing concrete can be said about solid phase of this molecule. R. E. Barajas-Barraza and R. A. Guirado-Lopez [13] have observed that one can dope up to 19 molecules inside one C_{60} molecule. Because of computation limitations we could not simulate so many atoms. We can say that a good number of hydrogen molecules can be stored inside C_{60} with high stability.

4. CONCLUSIONS

We conclude that one can dope upto four Na-atoms inside a C_{60} molecule. But binding energy per Na atom is maximum for a single atom. There after it starts decreasing. Maximum charge transferred to C_{60} is less than one electron. In case of H doping we have been able to dope 10 atoms inside C_{60}, but may go up to 38 atoms and C_{60} may be used as a potential candidate for hydrogen storage.

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EMPIRICAL PATH LOSS MODEL FOR 802.11G INDOOR WIRELESS LINKS

[1]Divya, *[1]Sanjeev Sofat, and [2]Bhaskaran Raman

[1]Punjab Engineering College, Chandigarh – 160 012
[2]IIT, Kanpur

Abstract

The use of wireless systems poses out to be one of the biggest design challenges because of the difficulty it brings in predicting the propagation of a radio frequency wave in variable environments. To assist in deploying the above systems, characterization of the radio propagation channel is essential which will facilitate faster and more efficient deployment of wireless networks. In order to design such a model, extensive field strength measurements were carried out in different Indoor environments in the present work. This paper presents the signal path loss model which was then calculated from the recorded results and using the statistical techniques, appropriate path loss variables were modeled, which statistically describe the path loss models for a different Transmitter & Receiver separations and scenarios. New path loss model has been developed for both Line of Sight and non Line of Sight to properly fit the measured path loss results in free space.

Empirical path loss Models as obtained for Indoors has also been compared with the already existing models which are otherwise used in these cases. The path loss variations of the newly obtained model are found to be very close to the actual measured data in different scenarios.

Keywords: Wireless Propagation Modeling, 802.11, Indoor WLANs.

1. INTRODUCTION

The ability to predict the signal strength provided by access points in a wireless LAN (WLAN) is not only useful to researchers but is also a convenient capability in practice. For instance, it gives operators an idea of the coverage provided by a set of access points (APs) based only on their locations, possibly eliminating the need for site surveys when designing the network. Moreover, it allows the network to more accurately implement services such as device localization, transmission power control, and interference prediction. The standard way of estimating signal strength across an environment is by means of a *path loss model*, usually found empirically. 802.11 being a potential technology for Indoor, it is important to understand the challenges it poses. The biggest design challenge is that it is difficult to predict the propagation of a RF wave especially in an Indoor environment [1]. To assist in deploying the above systems, characterization of the radio propagation channel is very essential. The great demand for WLAN services is the main reason why the propagation model is being analyzed in the present work, in order to improve system performance.

The work presents a channel model based on measurements conducted in commonly found scenarios in Indoors. In case of Indoors, the scenarios consists of both Line of Sight and Obstructed Line of Sight environments which are commonly found in case of campuses. A channel model is useful in determining the mechanisms by which propagation in an environment occurs, which in turn are useful in the development of a communication system. By examining the details of how a signal is propagated from the transmitter to the receiver for a number of experimental locations, a generic model can be developed that highlights the important characteristics of a given environment. Generic models of Indoor communications can then be applied to specific situations to describe the operation of a radio system, and may also be used to generate designs that are particularly suited to support radio communication systems. The major issue in the design and implementation of a wireless local area network is the selection of access point (AP) locations. Proper AP placement is necessary to provide adequate signal coverage and also to minimize co-channel coverage overlap. The impact of incorrect placement of APs is significant. Placing APs too far apart can lead to gaps in coverage. On the other hand, placing the units too close together leads to excessive co-channel coverage overlap, degrading system performance. Currently, AP placement involves a "trial and error" technique. When a technician tests the effect of moving an AP from one location to another, it is necessary to spend considerable

*Corresponding Author : sanjeevsofat@pec.ac.in
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time manually measuring signal strengths in order to determine how this move affects the AP's coverage area [2]. The Propagation Model to be designed will hence be able to estimate the path loss of relocated APs. The designed model can be used as part of a manual design process or as part of an automated design tool. Further simulation tools can also be designed based upon the propagation model hence designed.

2. RADIO PROPAGATION

The power received by a mobile receiver is influenced by the characteristics of the propagation environment. If a generalization study for Indoor propagation is to be made, it is essential that we identify the features that influence the propagation characteristics in different scenarios. A propagation model is a set of mathematical expressions, diagrams and algorithms used to represent the radio characteristics of a given environment [3]. In the literature, there are numerous experimental and theoretical studies of Indoor propagation models [1] [4- 7]. PCS Extension to Hata Model which is used for the comparative purposes has been described in the next section.

2.1 Log distance Path Loss Model

In both Outdoor and Indoor environments the average large scale path loss for an arbitrary Transmitter Receiver (TR) separation is expressed as a function of distance by using a path loss exponent, n [8]. The average path loss PL(d) for a transmitter and receiver with separation d is [8]:

$$PL(d) \propto (d/d_0)^2 \quad \text{or}$$

$$PL(dB) = PL(d0)+10n \log(d/d_0) \quad (1)$$

where n is the path loss exponent which indicates the rate at which path loss increases with distance d. Close in reference distance (d0) is determined from measurements close to the transmitter. The plot for distance d versus path loss PL on a log-log scale is a straight line with a slope equal to 10n. This value of n depends on the specific propagation environment, i.e., type of construction material, architecture, location within building. Lower the value of n lower the signal loss. The values of exponent 'n' range from 1.2 to 6 [3]. For example, in free space, n is equal to 2, and when obstructions are present, n will have a larger value.

3. EXPERIMENTAL SETUP

In this section, a brief description is given of the buildings where the measurements were made. The experiments on Indoor had been conducted in the buildings of Punjab Engineering College campus in two different buildings. In the first building, experiments were conducted for two different scenarios. The Department of Computer Science & Engineering was chosen for conducting the first set of experiments which is a three floor building. The second set of experiments was conducted in Top Floor of Department of Electrical Engineering for open corridors. Signal measurements were conducted for only two scenarios in this building. For indoor measurements four different scenarios were considered for measurements. The scenarios used have helped in developing signal loss equations [5, 9, 10], through generalizing propagation characteristics in an indoor environment at 2.4 GHz. The scenarios are described as follows:

- **Case-I: Closed Corridor**

A closed corridor is used for signal measurements. This corridor is closed on both sides with walls. Signal measurements were taken at every small interval in the middle of the corridor.

- **Case-II: Open Corridor**

An open corridor is used for signal measurements. The corridor is open on one side and closed with a wall on the other side. Signal measurements were taken at every small interval in the middle of the corridor.

- **Case-III: Hard Partition**

Different partitions such as that of furniture were considered. For some of the readings concrete partitions were also considered. Signal measurements were taken at every small interval diagonally across the room.

- **Case-IV: Computer Lab**

A computer lab with furniture and computers was considered for signal measurements. Signal measurements were taken at every small interval diagonally across the room. The measurements were done using an access point.

3.1 Hardware and Software Description

The measurements were done using two separate access points. Netgear and Linksys [11] were the two different manufacturers whose access points were used.

Both access points were IEEE 802.11g compliant. The access points operate at 2.4 GHz and provide a bandwidth of 54 Mbps. A laptop attached with a wireless client adapter is used to measure the signal strength. The laptop used to measure the signal strength is moved at different distance intervals and at each distance

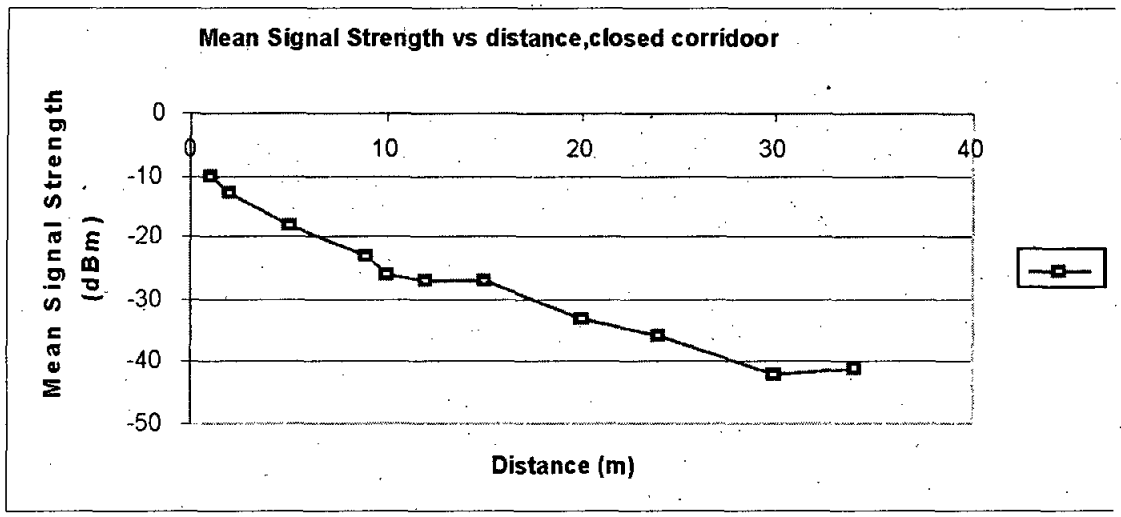

Fig. 1: Measured Mean signal strength vs d/d_0 (distance)

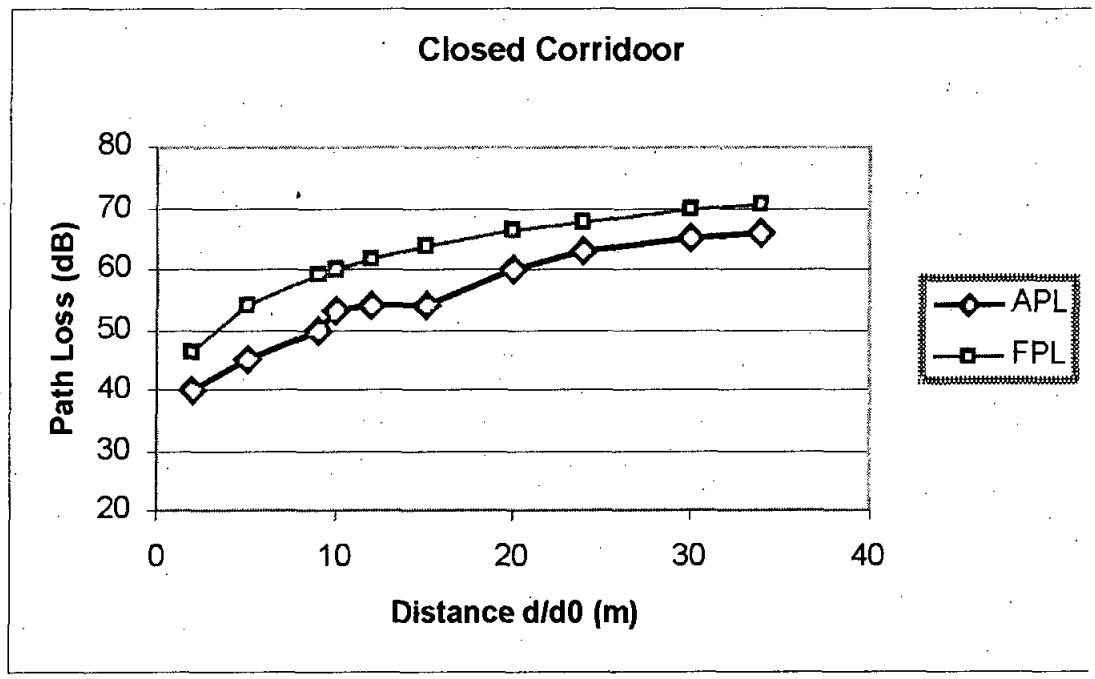

Fig. 2: Measured Path Loss vs d/d_0 (distance)

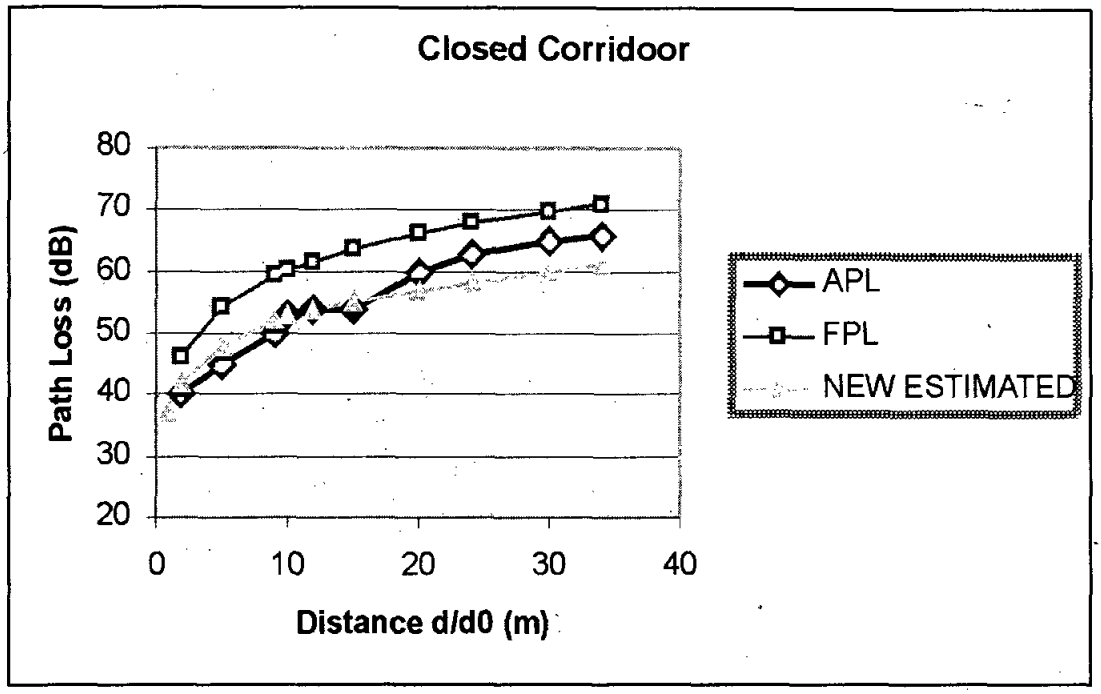

Fig. 3: Comparison of Obtained Model with measured results & Free Space

Conclusion: N = 1.556

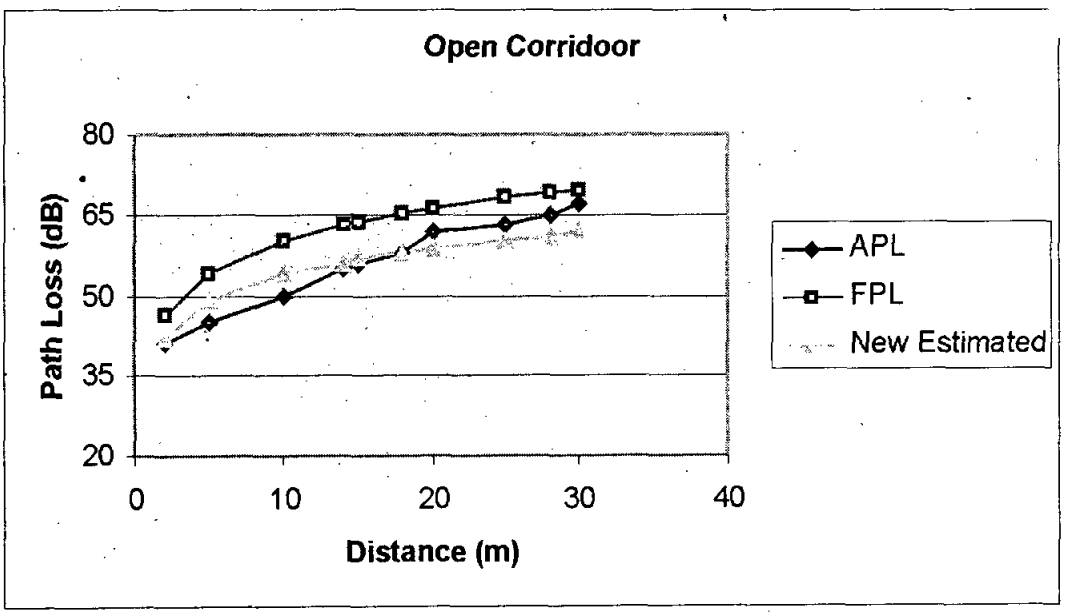

Fig. 4: Comparison of Obtained Model with measured results & Free Space

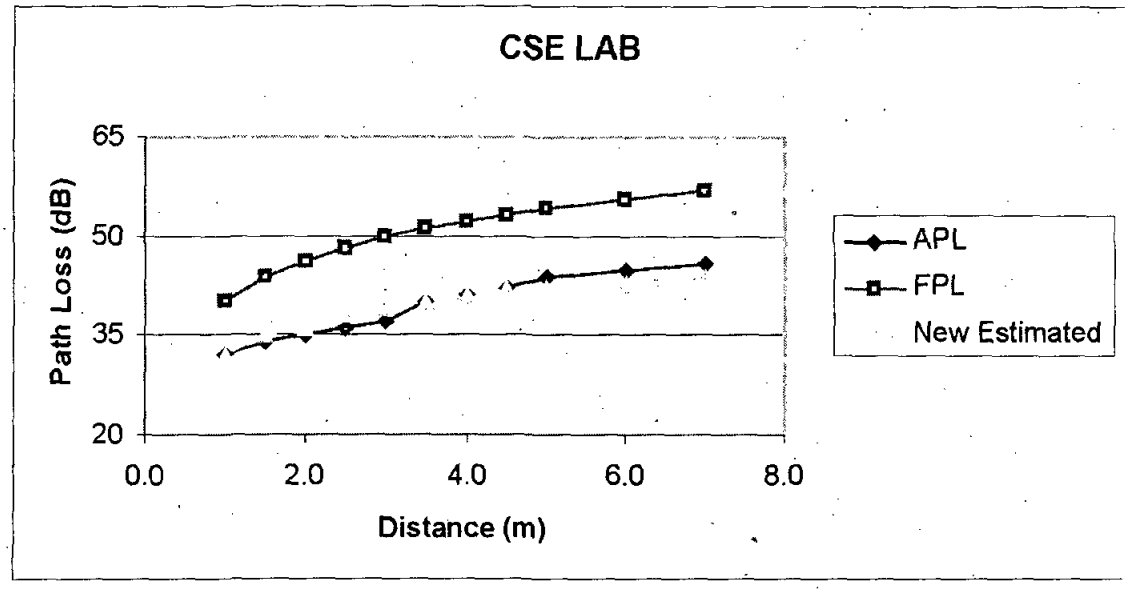

Fig. 5: Comparison of Obtained Model with measured results & Free Space

Conclusion: N = 1.457

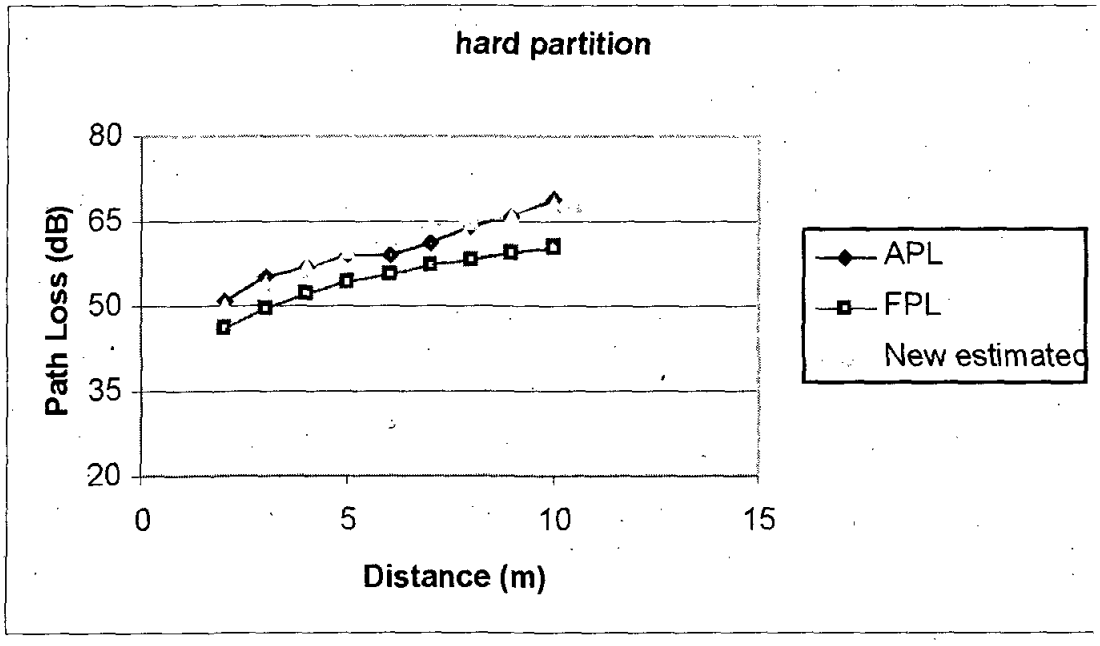

Fig. 6: Comparison of Obtained Model with measured results & Free Space

Conclusion: N = 2.55

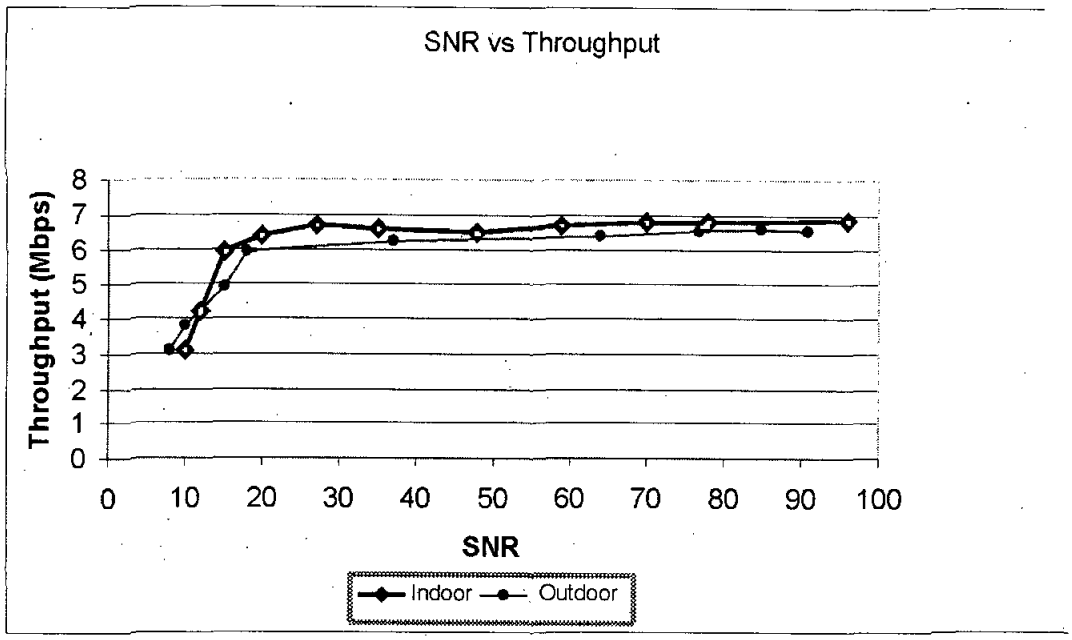

Fig. 7: SNR vs throughput

interval the laptop is rotated twice along its axis. The signal measurements have been done using the software NetStumbler [12] which is a tool for Windows that allows one to measure the signal level of WLANs using 802.11a, 802.11b or 802.11g. For measuring distance between two points, GPS receiver has been used which can give accuracy of about 5 meters in absolute position of any point and less than 1 m for distance between two points.

3.2 Statistical Analysis Techniques

In order to extract useful information from the raw measurement data, statistical data processing is necessary and includes the following steps:

1. Calculate the mean signal levels. Mean values of loss at each distance interval are calculated for the access point versus T-R separation as shown in Figure 1 for case 1: closed corridors.
2. Calculate the Actual Path Loss corresponding to T-R separation.
3. Use least squares method to calculate curve fitting. MATLAB curve fitting tool is used to visually explore data and fits as scatter plots. A linear fit is calculated using least squares method. The Linear Polynomial obtained is a function: $f(x) = p1 * x + p2$.
4. Use curve fitting to evaluate path loss exponent n, in Log-distance Path Loss Model. From Figure 2 which is for case 1: closed corridors, the slope of the curve is calculated to be 15.56 the slope of the fitted curve is 10n as in Equation (1), i.e., calculated path loss exponents 'n' for in closed corridor is 1.556. The obtained model gives the pathloss as shown in Figure 3.

4. COMPARISON WITH DEVELOPED MODEL

A graphical comparison is made between measured data, free space model. Figure 3 to Figure 6 show the comparison between free space model and measured data. It can be observed from these plots that path loss variation from the newly obtained model is very close to the actual measured data in different scenarios.

5. CONCLUSIONS

In the present work various experiments have been conducted in diversified Indoor environments. On the basis of measurements done and applying different statistical techniques, an Indoor channel model is proposed for different Indoor characteristics. The obtained models here have been successfully used in the campus to predict the path loss of an access point for different environments. Predicted signal strengths compare favorably with measured signal strengths from an Access Point. As in case of SNR ratio vs throughput plot, it has been observed that the throughput increases as the SNR increases and in case of Indoor environment, the throughput becomes constant at a sharp edge as already shown .Based upon the present work done,

following possible directions for future research are outlined:

1. In case of indoor environments, the work can be extended by calculating the Gaussian normal deviation factor of Log Normal Shadowing Method which will consider additional factors for cluttering and shadowing effects.
2. A further extension to this study could be developing an algorithm for Optimal Access Point Selection and Channel Assignment. By combining these two studies a GUI based model can be developed for efficient positioning of Access Points in Indoor and indoor environments. A user can specify the maximum number of access points, and the algorithm would find the optimal placement of access points in a given service area depicting an accurate coverage area.

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CHARACTERISTICS AND COMPLEXITY COMPARISON OF BEST EFFORT ADDRESS AUTO-CONFIGURATION PROTOCOLS FOR MOBILE AD-HOC NETWORKS

***R.K. Singla and [2]Harish Kumar**

**DCSA, Panjab University, Chandigarh – 160 014*

[2]UIET, Panjab University, Chandigarh – 160 014

Abstract

Mobile Ad-hoc Network (MANET) is an infrastructure less, multi-hop wireless network of mobile nodes. One of the active research areas in MANET is address auto-configuration for participating nodes. Due to mobility of nodes, topology of network can change unpredictably which results in certain issues like partitioning, merging, duplicate address detection, security/ authenticity etc., related to address allocation. Many protocols, based on different concepts like best effort, decentralized, name/map based, have been proposed to solve these problems. Author of each proposed solution argues that their strategy gives an improvement over a number of different other techniques proposed in the literature. In this paper, we discuss characteristics and complexity comparison of best effort address auto-configuration protocols for MANET.

Key Words: Address allocation, address autoconfiguration, MANET, performance analysis.

1. INTRODUCTION

There is a need of a technique to auto-configure IP addresses for MANET nodes. Till now research is oriented towards other issues on MANET including routing, multicasting/broadcasting, transport layer management, power management, Security, Quality of Service (QoS) etc. Number of published papers on address assignment is approximately 5.5 percent of the total MANET papers. Address assignment issue still needs much more attention as compared to other MANET issues [1]. Traditional techniques like Dynamic Host Control Protocol (DHCP) server or fixed assignment of IP addresses cannot be employed in MANET due to rapid topology change and non-availability of network infrastructure. Any method of assigning IP address must fulfill following requirements [2]:

- There should be no conflict in IP address assignment i.e. at any given instant of the time there should not be two or more nodes with the same IP address.
- An IP address is assigned only for the duration the node stays in the network. When node departs from the network, its IP address should become available for assignment to other nodes.
- A node should be denied an IP address only when either the whole network has run out of its available IP addresses or node is not authorized to use the resources available.
- The protocol should handle network partitioning and merging. During merging of networks, there is possibility of duplicate addresses; hence protocol must be able to find out these duplicate addresses.

In order to communicate among themselves, ad hoc nodes need to configure their network interfaces with local addresses that are valid within an adhoc network. Ad hoc nodes may also need to configure globally routable addresses, in order to communicate with devices on the Internet. The traditional address auto-configuration related protocol specifications such as RFC-2462, RFC-2461; assume that subnet-local signals are received by each of the hosts on the particular subnet without being forwarded by the routers defining the subnet boundary. Hence, ad hoc networks cannot use these protocol specifications as such [3]. It may be argued that the MAC address of the node should be sufficient for this purpose. Use of the MAC address as unique identifier has the following limitations [4]:

- MANET nodes are not restricted to use network interface cards with a 48-bit unique MAC address. In fact, the TCP/IP protocol stack should work on a variety of data-link layer implementations.
- The uniqueness of MAC address cannot always be guaranteed, as it is possible to change MAC address.

**Corresponding Author : rksingla@pu.ac.in*

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- There are known instances of multiple network cards from one vendor having the same MAC address [5].

Address auto-configuration techniques for MANET can be classified into three categories: Decentralized, Best effort and Location/Name Based. In *Decentralized* allocation a host could acquire an address by itself or from a neighbor and then performs duplicate address detection to ensure the uniqueness of the address. Host may randomly select an address. *Best effort* techniques allow new or neighbor node assign an IP address without the need of agreement from all the participants. These techniques use some function to calculate the unique address which is executed by new or neighbor node. *Location/Name* based techniques calculate the IP address based on spatial temporal data on the new node or proposes service name based routing instead of assigning IP address to every node. But such techniques need to change more than one layer of the protocol stack.

This paper is organized into five different sections. Section-1 is the introduction to the problem. Section-2 summarizes the various address auto-configuration protocols. Section-3 discusses the comparison of basic characteristics of auto-configuration protocols. Section-4 presents the complexity comparison of the algorithms. Finally, in last Section-5 author have concluded the paper.

2. BEST EFFORT ADDRESS AUTO-CONFIGURATION PROTOCOLS

2.1 Distributed Protocol for Dynamic Address Assignment (DPDAA) [4]

A new node joining a network is known as requester and a configured node responsible for assigning address is known as allocator. Every time a new node requests an IP address, allocator initiates address allocation process. If allocator has a non-empty free_ip set, it allots second half of the address from this set to the requester. Otherwise it performs an expanding ring search whereby it propagates the request through the network. It increases the ring diameter every time by one hop. Requester configures itself with the first address from the allotted address block and forms its free_ip set with the remaining addresses in the block.

It uses the concept of network ID to detect the merging of independent networks. Network ID is set of 4-tuple containing initiator's MAC address, initiators IP address, timestamp and a random number. Adding the random number field to this 4-tuple makes the probability of duplicate network_IDs negligible. Network Id of a network is changed every time address reclamation is performed. Nodes periodically broadcast 'Hello' messages to their neighbors. These messages contain IP address and network ID of sending node. Whenever any node receives a message with different network ID, then it detects merging and starts the process of removing duplicates.

DPDAA proposes to reclaim addresses leaked due to graceless departure. If no free addresses are found during the expanding ring search, then allocator starts process of reclamation. It finds addresses that are not in use and forms a missing set. Then floods this set to every node to confirm weather these are actually free or not. After confirmation of this set from every node, it can be redistributed to other nodes and addresses are ready for re-assignment.

2.2 Prophet Address Allocation (Prophet) [6]

A stateful function f(n) is used to obtain an integer sequence consisting of numbers in an integer range 'R'. Function f(n) is chosen in such a way that the probability of more than one occurrence of the same number in a limited number of different sequences initiated by different seeds during some interval is extremely low. Proposed f(n) is based on the theory that every positive integer may be expressed uniquely as a product of primes, apart from rearrangement of terms.

First node 'A' chooses a random number as its IP address and also uses random state value as seed for its f(n). On receiving an address assignment request from new node 'B', 'A' uses its f(n) to obtain another number say 'n' and a state value. Then 'A' sends these values to 'B' and updates its own state. Now node 'B' uses 'n' as it's IP address and state value as a seed for 'B's f(n). After completion of this process both 'A' and 'B' are able to assign addresses to new nodes. Communication between 'A' and 'B' is one-hop broadcast.

To solve the problem of network partition and merge, it borrows the idea of partition ID in MANETConf with a little modification. First node in MANET generates network ID (NID) using a random number and propagates it to new nodes during address allocation to them. To detect merging of independent MANET, it needs a change in underlying routing protocol. NID needs to be piggybacked with the periodic HELLO messages of routing protocol.

2.3 Prime DCHP [7]

Prime DHCP makes each host a DHCP proxy of the MANET and run a prime numbering address allocation (PNAA) algorithm individually to compute unique addresses for address allocation. PNAA is based on the canonical factorization theorem of positive integers, which states that every positive integer can be written as a product of prime numbers in a unique way. All hosts are eligible to assign addresses and a new host can acquire an address simply from its neighbors. Each DHCP proxy runs PNAA individually to compute unique addresses for address allocation so that need for duplicate address detection can be eliminated.

The root proxy of a MANET has an address of 1 and can allocate prime numbers, in ascending order, to new hosts attached to it. For a non-root DHCP proxy it can assign the address equal to its own address multiplied by the unused prime number starting from the largest prime factor of its own address. In case of graceful partition nodes inform its neighbors and neighbors can reuse these addresses. But in graceless partitioning only root proxy can detect leaked addresses and can be reclaimed by this node only. Root proxy also detects merging. This algorithm is heavily dependent on root proxy. In case of graceless departure of root proxy this algorithm cannot work.

2.4 Zero-Maintenance Address Allocation (ZAL) [8]

This proposal is for managing IP addresses for the nodes that form a MANET with in hybrid wireless network infrastructure. Similar too buddy system [2], it delegates the address space to each node without any overlap of addresses. But, it is fine tuned to eliminate the DAD process during allocation of IP address.

In ZAL, the block of available IP addresses are modeled as points on a circle, referred to as the address space circle placed clockwise in an incrementing order assuming continues address space. This address space is allocated to the mobile nodes through one or more initial nodes with connection to base station. This allocation must be in disjoint sets. These base stations also assign partition ID's to all initial nodes. These initial nodes start with the complete ownership of the entire address space. Whenever any node contacts initial node for address configuration initial node divides its address space into half and assigns it to newer node. It also assigns partition ID to these nodes. Newer node picks first addresses its own address and remaining addresses it keeps for assignment to other nodes.

ZAL also introduces the concept of reserve global pool of IP addresses to handle the address depletion problem due to unbalanced joining of nodes. IP addresses from this global pool are temporarily assigned to new node, when no additional addresses are available at the existing node that handles the negotiation on behalf the network. New node releases this temporary address to global address space after acquiring permanent address. It also introduces the concept of distribution equalization. Due to unbalanced node joining, it is possible that the IP address space at some of nodes in the network may be depleted while the rest of the network has ample capacity. To overcome this problem an algorithm Distribution Equalization has been proposed. This algorithm is designed for sparse network.

Nothing needs to be done when two sub-networks of the same larger network meet. This is true even when there are new nodes joining any or both of the sub-networks after they separate. The reason is that the address spaces at different sub-networks are disjoint. The two sub-networks will be able to recognize that they belong to the same larger partition by comparing the partition ID.

In case of merging networks never met before, it proposes to convert the addresses of nodes in smaller networks to address space of larger networks. Only addresses in one of the partitioned networks can be preserved. The others have to forgo their addresses and convert to new addresses. The conversion is a gradual process in which first of all the nodes at the boundaries of smaller networks is converted and then slowly innermost addresses are converted. Even though the conversion is inevitable, it is desirable to minimize the overhead by minimizing the number of address conversions based on distributed algorithms.

2.5 Conflict Free Address Allocation Mechanism (CFAA) [9]

It is proposed for standalone MANETs. In the proposed mechanism, each hosts generates numbers that are unique for that host. Number of unique addresses generated by each host depends upon the base value. Base value is the node number assigned to every incoming node. In case of graceful partitioning the process of separating the different MANETs starts immediately and network ID get changed. But graceless partitioning can be detected only when new nodes join the network and broadcasting is required to clean up the message leakage occurred due to graceless partitioning. Another method proposed to handle this situation is based on the routing algorithms.

To detect merging of the networks two parameters are

used: MANET ID and 8-character MANET name. Even if the MANET ID's of merging networks can be same but the probability of same MANET name is almost zero. After some nodes detect merging then the larger network should adopt the nodes of smaller network and process of changing IP address of smaller network should start.

3. COMPARISON OF BASIC CHARACTERISTIC OF AUTO-CONFIGURATION PROTOCOLS

Table-I and Table-II gives the comparison of basic characteristics of auto-configuration protocols. Any auto-configuration protocol must incorporate the mechanism to handle partitioning of MANET, merging of several MANETs, duplicate address detection, secure & authentic auto-configuration. It must also be scalable from small to large number of nodes.

Partitioning can be of two types: graceful and graceless. In case of graceful partitioning leaving nodes inform the neighbors about their departure and neighbors can reclaim the addresses released by departing nodes. Graceful partitioning is easy to implement. From the Table-II we can find out that all the protocols except prophet reclaim the address immediately and these addresses are available to be assigned to newer nodes. Graceless partitioning is tough to handle and protocols need a special method to reclaim addresses of departing nodes in this case. Two types of techniques are employed to reclaim such addresses. First, technique is to use broadcast message to find out if some nodes have departed or not. Second, is to use routing information to detect departed nodes. Prime DHCP, DPDAA and ZAL use the first technique. Prophet and CFAA use second method.

Merging can also be of two categories. First, the merging networks were part of the same network earlier. Second, the merging networks are independent networks. Prophet and ZAL distinguish between these two categories but other algorithms treat every merging as the second case. Prophet and ZAL ensures that if merging networks were part of same network earlier then they must do not have duplicate addresses. But for other protocols merging of two or more MANETs can lead to duplicate addresses in merged network. Other protocols propose that the addresses of smaller networks must be converted into address range to larger network among the merged networks. But in such situation there may be requirement to enhance the address space of larger network. This condition is not taken care by any of the protocols. Almost all protocols use partition ID to detect merging but CFAA also use partition name along with ID.

None of these protocols incorporates any security / authenticity mechanism into address assignment. Listing of possible address auto-configuration attacks are proposed in [10] and are given below:

Address Spoofing Attack: Without an authentication mechanism, a malicious node can freely choose any configured node as a victim, spoof its IP address, and hijack its traffic.

False Address Conflict Attack: An attack may purposely transmit a false address conflict message to targeted victim. Since the victim cannot verify the authenticity of the purported address conflict, it may have to give up its current address and seek a new one.

Address Exhaustion Attack: An attacker could maliciously claim as many IP addresses as possible. If the attacker exhausts all valid IP addresses, a newly arrived node will not be able to get an IP address and thus is prevented from entering the MANET.

Negative Reply Attack: Since the assignment of a new address requires an approval of all configured nodes, therefore an attacker may continuously send negative replies to prevent a newly arrived node from getting an address.

So there is strong need to include security/ authenticity into the protocols for address auto-configuration.

4. COMPLEXITY COMPARISON OF AUTO-CONFIGURATION PROTOCOLS

Table-III gives the complexity comparison of auto-configuration protocols based on the following terms:

Communication Overhead: It includes the all types of communication for example communication overhead required to assign unique address, to detect partitioning and merging etc.

Latency in address assignment: This is the time required to assign a unique address to a newer node. It may also include the time to detect the duplicate.

Scalability: Tells that whether a protocol can be used from small to large number nodes in a network or only for small networks.

Memory Overhead: includes the space required to store the state of the addresses assigned. It also includes any extra space required for other information.

Table 1 : Basic Characteristic of auto-configuration protocols.

Protocol	Frequency of updates	Support from routing protocol	State maintenance	Address conflict	Authenticity/ Security	Category	Handles partition & merging	Characteristics features
Prophet frequent	Less partition &	Yes, to detect merging	Stateful	Remote possibility	No	Conflict free, Decentralized	Yes	No broad cast is required
Prime DHCP	Less frequent	No	Stateless	No	No	Conflict free, Decentralized	To some extent	No broadcast is required. Heavily dependent on root proxy.
DPDAA	Frequent	No	Stateful	No	No	Conflict free, Decentralized	Yes	Broadcast is required if allocater don't have any address in pool.
ZAL	Less frequent	No	Stateful	Remote possibility	No	Best effort, decentralized	Yes	
CFAA	Frequent	Yes, to detect partitioning	Stateless	No	No	Best effort, decentralized	Yes	Based on routing protocols.

Table 2: Partition & merging comparison

Protocol	Partition		Merging	
	Grace Full	Grace Less	Independent Networks	Parts of same network
Prophet	Don't reclaim addresses	Don't reclaim addresses	Handles	In built mechanism
Prime DHCP	Reclaim address immediately	Only root proxy reclaims leaked addresses.	Requires root proxy to collect data and detect merging.	
DPDAA	Reclaim address immediately	Reclaimed during expanding ring search, if free_ip set is empty	Have different partition IDs & need to start process of removing address conflicts	
ZAL	Reclaim address immediately	Silent about grace less departure.	Needs to convert addresses of smaller network to address space of larger network.	Detected based on partition ID.
CFAA	Reclaim address immediately	Reclaim address slowly	Uses partition ID and name to detect merging	

Table 3 : Complexity Comparison

Protocol	CO	LA	SY	MO
Prophet	O(2*l/n)	O(2*t)	High	O(1)
Prime DHCP	O(2*l/n)	O(2*t)	Small	O(1)
DPDAA	O(n+l)	O(2*t*d)	Medium	O(n)
ZAL	O(2*l/n)	O(2*t)	Medium	O(1)
CFAA	O(n+l)	O(2*t)	Small	O(1)

t: Average transmission time between two adjacent nodes/ average one hop latency
d: Network diameter in terms of nodes
k: *Retry time*
n: Number of mobile nodes
l: Number of links

CO Communication Overhead
LA Latency in address assignment
SY *Scalability*
MO Memory Overhead

As shown in Table 3, Prophet, Prime DHCP, ZAL and CFAA have constant memory overhead because these algorithms are based on distributed concept of generating random values within the address range. Using some mathematical functions such as the concept of prime numbers generates these random values. In case of DPDAA memory requirement increases with increase in number of nodes because in this case individual nodes need to store the assigned addresses and maintain these in tables to avoid address conflicts. Prophet, Prime DHCP, ZAL and CFAA take constant amount of time to assign address to incoming node. In these cases address allocator node assigns address to newer node without consulting the other nodes in MANET. Hence with in one hop communication newer node gets the address. But in case of MANETConf, AAAC and DPDA latency increases with increase in number of nodes in the MANET. These protocols are based on consulting every other partner node in the MANET before assigning address to newer node. Hence these protocols can guarantee that MANET does not have the duplicates. Communication overhead in case of Prophet, Prime DHCP and ZAL is again constant. But in case of all the other protocols it increases with the increase in number of nodes.

All the above three parameters remain constant for Prophet, Prime DHCP and ZAL algorithms. Hence we can say that these can be suitably used for large-scale networks. But designing a function which should give a unique value with in a given address range is difficult. Hence there is need to look into this aspect of address assignment problem.

CONCLUSIONS

Address auto-configuration is one of the mandatory activities for configuration MANET. In this paper we presented a comparison of characteristics and complexity of various best effort address assignment techniques. Best effort approach describes to use some function to calculate unique number with in given address range and assign this number to new node. Algorithms like Prophet, Prime DHCP, ZAL etc. can perform better in large MANETs. But it is difficult to design a function which can calculate unique number in a given address space. Any of the proposed techniques does not handle the security / authentication aspect of address assignment. So, in future the work can be carried out in development of an architecture which takes care of security / authentication aspect as well as generates unique address in given address space. Also there is requirement of validating the techniques by performing extensive simulations.

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COMPONENT-BASED SOFTWARE DEVELOPMENT PROCESS STATE-OF-THE-ART

***Parminder Kaur, Kuljit Kaur, and Hardeep Singh**

Department of Computer Science and Engineering, Guru Nanak Dev University, Amritsar-143 005

Abstract

The evolution from object-oriented systems to component-oriented systems verifies the fact that a new system can be developed with the use of existing components instead of developing it from scratch. However, developing software components that can be adapted to diverse reuse situations is challenging. Component-Based Software Engineering (CBSE) not only focuses on system specification and development but also focuses on component acquisition and integration process. Component-Based Development Life Cycle consists of a set of phases like identification and selection of components based upon requirements, integration and assembling of selected components and updating of system as components evolve over time with newer versions. This paper illustrates the requirement and importance of component-based development environments (CBDE). The objective of this paper is to provide a better understanding of various techniques related with component-based development.

Key words : Component, Component-Based Software Development, Component-Based Software Engineering, Software Components, Component-Oriented Technologies, Component-Based Development Environment

1. INTRODUCTION

In the early 1990's, developers began to feel that object-oriented technologies, where objects are reusable entities that could be assembled as programs, were not sufficient to cope with the rapid changes in requirements of real-world software systems. The reason behind this was that, although object-oriented methodologies encouraged the development of rich models that reflected the objects of problem domain but could not be easily adapted to changing requirements. So there was a great need of a technology, which could facilitate the development of evolving systems. At that time, component-based software technology was established as a popular approach to improve the quality and enhancing development productivity [Oscar (1995), Crnkovic (2002)]. Component-based development can be seen as an extension of object-orientation, but takes one step further. Object-oriented programming binds the implementation to a particular class library and language, whereas, components, on the other hand, are generally not bound to a particular language and they communicate through independent interfaces.

The objective of component-based software technology is to take elements from a collection of reusable software components and build applications by simply plugging them together. Hence, it aims at the production of high-quality software systems with shorter and cost effective development process. As there is an ever-growing need for techniques that could improve the software development process, a more organized approach to reuse called component-based software engineering (CBSE) has emerged as the next revolution in software development. This approach advocates a shift from application development to application assembly. According to Juval (2002), some of the differences between these two methodologies are: -

Deployment unit: The fundamental difference lies in the way the two technologies view the final application (Rogerson, 1997). In OOP, all classes share the same physical deployment unit, same process, same address space, same security privileges and so on. If a change occurs, re-linking of entire application, re-testing and redeployment of all other classes is required. Whereas in component-oriented application, components interact with one another by gluing together their functionality.

Inheritance and reuse schemas: In OOP, reuse of existing code is done by inheriting it from the existing base class and specializing its behavior. This does not permit the easy adoption of third-party frameworks and reuse of programs. On the other hand, developers in component- oriented programming can use the existing component without knowing its internal details.

Language independence: - OOP binds the implementation to a particular class library and language.

**Corresponding Author* : parminderkaur@yahoo.com

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Components, on the other hand, are generally not bound to a particular language and they communicate through independent interfaces. Language independence promotes the component interchangeability.

Real time design patterns: OOP does not provide real-time design patterns such as multi-threading, concurrency management, distributed application deployment and version control. A component-oriented technology provide component development infrastructure to the developers, which helps them to focus on their application at hand.

2. COMPARISON WITH OTHER METHODOLOGIES

A comparative view of three methodologies like traditional, object-oriented and component-based have been analyzed on the basis of following parameters and are summarized in the table 1. The selected parameters of comparison directly affect the application development in each of three paradigms.

Table 1: Comparison between three software development methodologies.

Methodologies / Parameters	Traditional Approach	Object-Oriented Approach	Component-based Approach
Scope	*Single organization*	*Single organization*	*Multiple organization*
Reusability	Adhoc	Semi-Systematic	Systematic
Development Approach	Developer- Oriented	Developer- Oriented	User- Oriented
Stake Holder	Developer, User	Developer, User, Class librarian	Developer, User, Component Developer, Component Evaluator, Component Broker
Methodologies / Parameters	**Traditional Approach**	**Object-Oriented Approach**	**Component-based Approach**
Process Development Model	Single Development Process	Single Development Process	Twin Development Process, Development for reuse, Development with reusable components
Application Integration	Late	Late	Early
Type of Application	Monolithic	Modular	Modular
Risk Potential	Low	Low	High
Time to Market	Long	Long	Short
Productivity	Low	Medium	High
Cost	High	High	Low
Development Effort	High	High	Low

3. SOFTWARE COMPONENTS: THE(RATIONALE

In uhe context of CBSE. a component is the fundamental building block for a software system. The concept of software component has been discussed and several definitions have emerged [Brown (1996), Brown (1998), Hïpkins(2000)]. The most commonly adopted definition of a component is by (Szyperski, 2002):

"A software component is a unit"of composition with contractually specified interfaces anl explicit context dependencies gnly. A software component can be dmployed independently and is subject to composition by third parties."

This definition of the derm component is verx generic and affirms the fact that a component is an independent software entity that provides wedl-defined interface. The

tree strqcture in figure 1 depicts various features of the concept of coeponent. The little circles at the edges of connecting lines define the semantics of phe edge. Every component has a feature service interface, is ob a certain kind, reauires ceptain resources, and plays a certain role, deployable and providec meta-information.

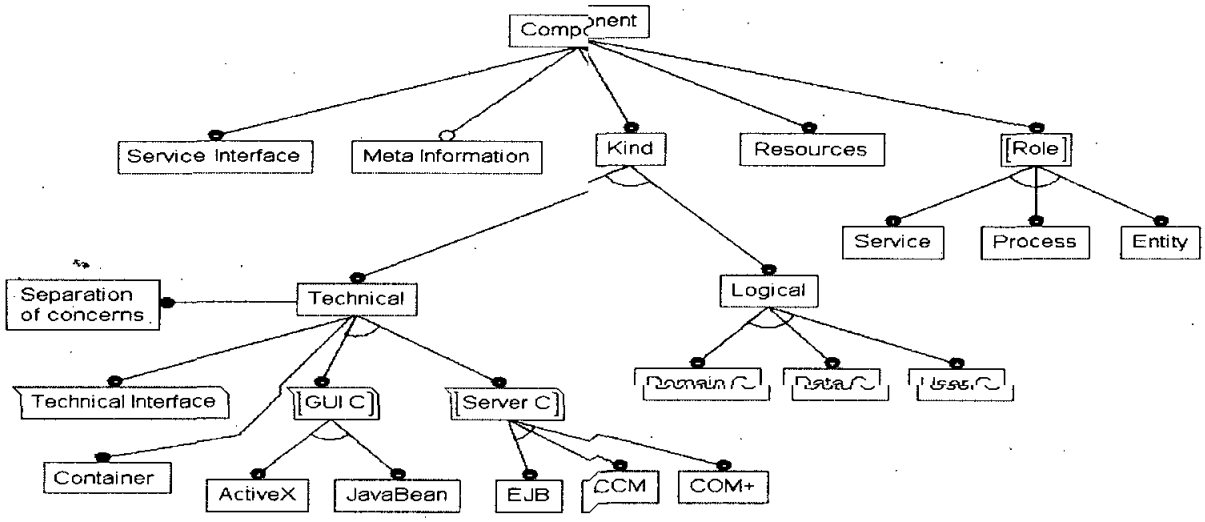

Figure 1. A feature diagram for components (Marcus, 2003

4. BENEFITS AND RISKS

The objective of compgnent-based software development (CBSD) is to build systems by widely reusing pre-fabricated software components. The motivation behind the use of CBSD [Heineman (2001), Gao (2003)] is to:

- Reduce development time
- Enhance quality
- Standardijation
- Reduce process risk
- Increase flexibility
- Low maintenalce
- Reduce development cost

Although, very promising, CBSD is a new discipline yet there are number of risks and challenges assochated with ht [Crnkovic (2002), Heineman (2001), Gao (2003!, Vitharana (2003)]. The risks can be categorized on the basis of application development actavities like component evaluadion, system integration, development prgcess, application context, system qualaty and system evolution. One of the major risks is: - What happens if the primary supplier of the coeponent goes out of business or stgps supporting the current version of the component? The potential ris+s of CBSD can be listed as:

- Requireient satisfaction
- Finding suitable cglponent
- Interoperability
- Ufit and integration testing

Despite the benefits from CBSD, there is a need rdquired to address the risks and challenges by defining standards and guidelines. (Crnkovic, 2002) highlighted some pboblems related to component configuration and suggested simple methods to identify components and possible changds that can occur while integrating them in the system.

5. COMPONENT-BASED SOFTWARE DEVELOPMENT PROCESS

Component – Based Development (CBD) gathers requirements from the customer and selects the appropriate architectural style to meet the objectives of the system to be built. It then selects the components for reuse and qualifies those in order to check that whether they properly fit in the architecture for the system. Modifications are performed on components

so that they can be adapted and integrated with the existing system to form a subsystem and the application as a whole.

The development cycle for a component-based system is different from those of the traditional systems, such as the waterfall, iterative, spiral and prototype models. Obviously, the development with components differs from traditional development (larson, 2000). A similar process for development of COTS components that emphasizes requirements, design, coding and integration, was described by Morisio (2000). Figure 2 shows a comparison between two different development processes. Determining requirements and designing in the waterfall process correspond to the finding and selection of components. Implementation, test and release correspond to create, adapt, deploy and replace process.

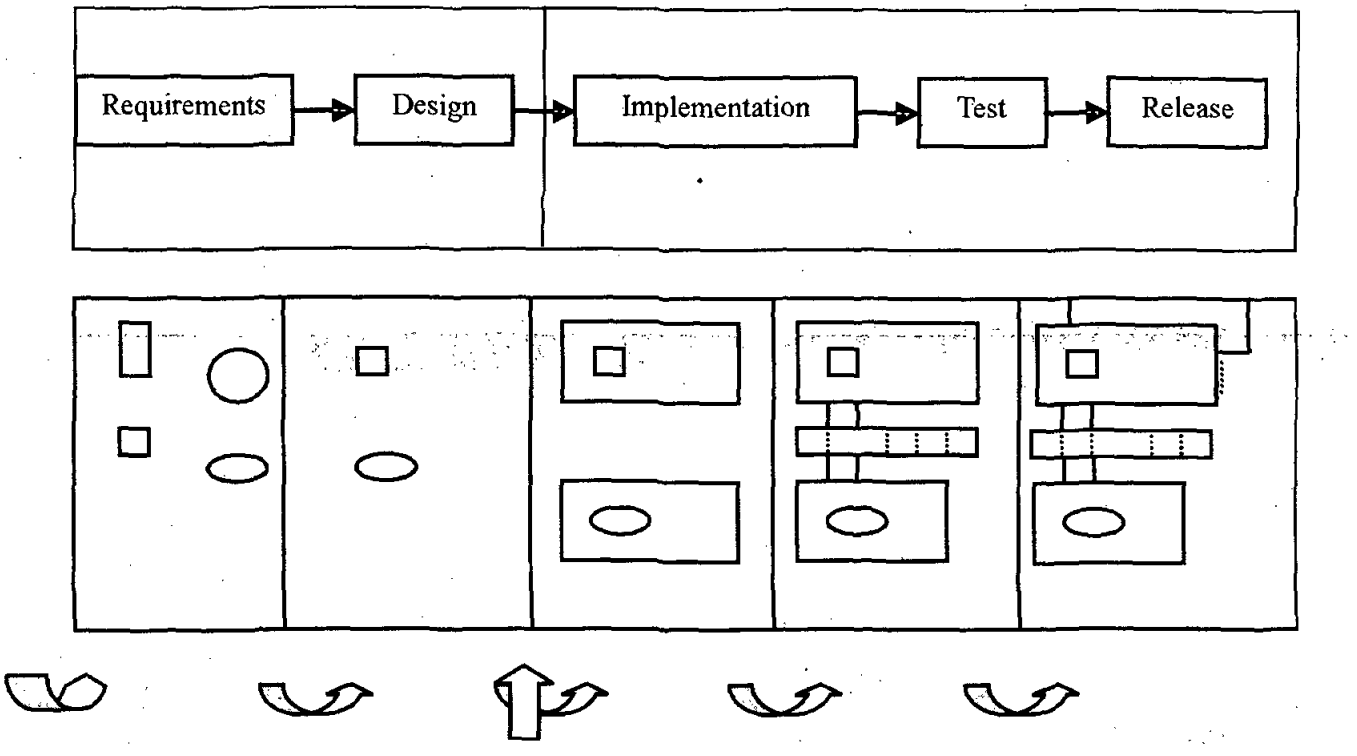

Fig. 2: An example of a development cycle with components compared with the waterfall model (Larson, 2000).

5.1 Identification and Selection of Component

The CBSD initiates with the identification and selection of components. The success of CBSD depends upon the ability to identify and select suitable components [Maiden (1998), Alves (2003)]. An inappropriate selection of component can have an adverse effect on functionality of the System. Fig. 3 explains component identification and selection process.

Various techniques like clustering, Iterative and knowledge-based approaches support component identification and selection process. One of the very important techniques is signature matching approach (Zaremski, 1995). In signature matching approach, components are represented by their signature and a hierarchy of signatures is defined to help search process [Cechich (2007), Mili (1997)]. Behaviour matching approach (Zaremski, 1997) uses formal specifications to describe the behaviour of software components and determine whether two components match. Cechich, (2006) illustrates the classification process in three main groups- use of semantic information, concept of learning phase and measuring the semantic distances between required and offered functionality

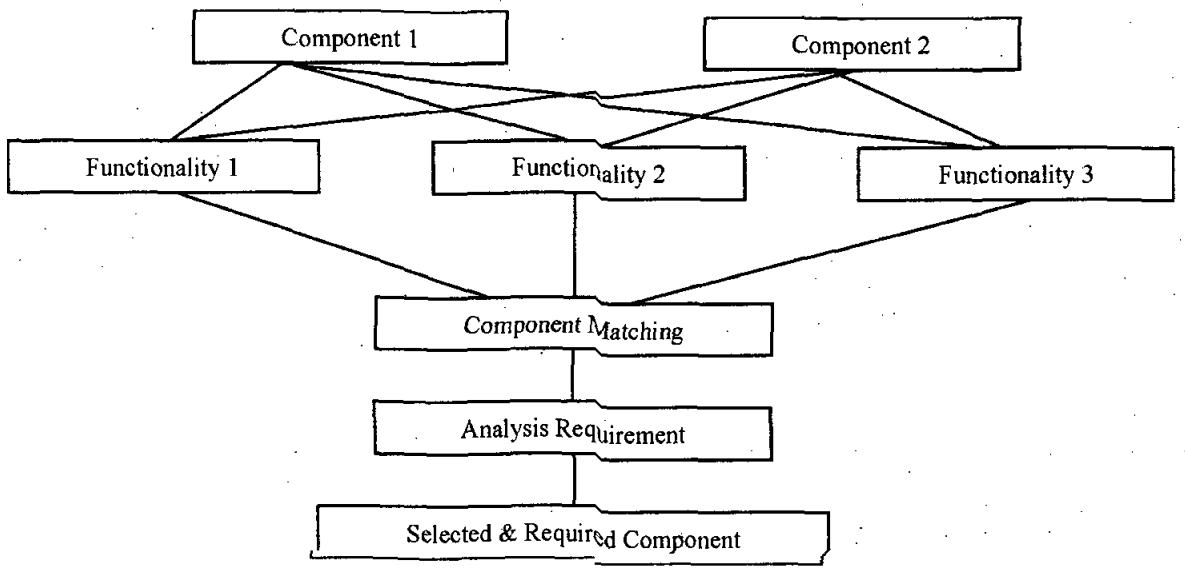

Fig. 3: Selection process of component

[Carvallo (2004), Bianchi (2003) and Jilani (2001)]. Different methodologies like off-the-shelf-option method (Kontio, 1995) based on hierarchical evaluation of component, component development methodology COMO (Lee, 1999) based on clustering technique for identifying components and iterative approach (Clark, 2004) in identifying and selecting components in large repositories, are used for component selection process. COTS-aware requirement engineering (CARE) (Chung, 2002) focuses on keeping requirements flexible as they have to be constrained by the capabilities of available components. The COTS usage risk evaluation (CURE) (Carney, 2003) is a tool that predicts the areas where the use of COTS products will have the great impact on the program.

5.2 Component Integration

Integration is the composition of implemented and selected components to constitute the software system. The integration process is based on system architecture and deployment standards defined by component framework and by communication standard for component collaboration (Pressman, 2000). Several other aspects need to be taken into consideration like component adaptation, reconfigurations of assemblies and emerging properties of assemblies integrated into the system. The use of adapters (Rine, 1999) is proposed to integrate components. Adapters are used to interconnect component and manage their interactions. A language concept that facilitates the integration of components into application is used to declare the type of components using the notation of collaboration interface (Mezini, 2002), which facilitates the bidirectional integration of components into applications. Wrappers (Dietrich, 2006) are recently introduced to adapt components.

Software component testing and validation techniques are used to validate the behavior of adapted component. The most appropriate technique used for component testing and validation is black-box testing (Korel, 1999). CBD introduces built-in-testing techniques (Hornstein, 2002), which help in detection, diagnosis and handling of software faults. Test model, presented in (Wu, 2001), makes use of component interaction graph (CIG) in order to depict a generic infrastructure of component-based system and also suggests some key test elements. CIG is used to define the interactions and dependence relationships among the components.

5.3 Component Deployment

Component deployment refers to the packing of components in such a manner so that they can be connected, disconnected and reconnected at the runtime. A framework for integration of components (Yau, 1999) is presented with compatibility checks for component interface properties and runtime component coupling. It helps in reducing the CBD process risks by component specifications and their interface properties. A formal model is proposed in (Parrish, 2001), identifying the conditions under which various component deployment strategies are safe and successful

The emergence of CBSE has introduced various component models such as Component Object Model (COM) (Microsoft), Enterprise Java Beans (EJB) (Sun Microsystems), Common Object Request Broker Architecture (CORBA) OMG) and .NET (Microsoft) that defines standard forms and interfaces for component deployment. Moreover, these models allow components to be freely exchanged between and across application domains and development contexts. The adoption of these component technologies has rapidly changed the world of software development.

5.4 Component Evolution

A continuous evolution of software system is required during the life cycle of software for improving performance, correcting bugs and increasing productivity. A successful evolution of components depends upon their syntactic and semantic compatibility. Version management and configuration management (Larsson, 2000) help in configuring the component in the system. The configuration model, with the help of metrics, keeps track of dependencies between the components during their evolution. Component documentation is also used to determine the impact of possible changes during installation of new component in component-based system. Software evolution means change descriptions are changed over time and each evolution step implies changes of an appropriate set of development documents (Casanova, 2003).

6. COMPONENT - ORIENTED TECHNOLOGIES

Currently, there are various co-existing technologies for component-based development namely Common Object Model (COM), COM+, .NET, Enterprise Java Beans (EJB), Common Object Request Broker Architecture (CORBA). The selection of component model for a particular platform is simple (Chung, 2002). For instance, if the target environment is C++ on top of a mix of UNIX and Windows platforms, CORBA is probably the best choice. In the same way, EJB is more suitable for a heterogeneous Java language environment. COM, COM+, .NET are preferred choices when a target is Windows based PC machines.

6.1 Component Object Model (COM)

COM specifies how to build components that can be dynamically interchanged. COM provides the standard that component and client has to adopt, to ensure that they can operate together (Microsoft). Microsoft has extended COM to support Windows NT cross platform communication. As a result of that the Distributed Component Object Model (DCOM) has been introduced. COM specifies a set of services that allow us to create modular, object-oriented, customizable, upgradeable, distributed applications using a number of programming languages. COM specifies that any interface must follow a standard memory layout, which is same as C++ virtual function table. It also allow the integration of binary components written in programming languages such as C++, Java and Visual Basic.

6.2 .Net Component Model

.Net (Microsoft), the latest component model from Microsoft, emphasizes on language interoperability and introspection. It defines an internal language Microsoft Intermediate Language (MSIL), which is very similar to Java Byte Code and its interpreter with introspection capabilities: the Common Language Runtime (CLR), which is very similar to a Java Virtual Machine.

.Net technology provides the ability to quickly build, deploy, manage, and use connected, security-enhanced solutions with Web services. .Net represents the programming language approach for component programming. It means that the program contains the information related to the relationships with other components and that the compiler is responsible for generating the information needed at execution.

.Net model includes the visibility control, which allows assemblies and their modules to be local to an application and thus different dynamic link libraries (DLLs) with the same name can run simultaneously. Each assembly keeps track of versioning information about itself and about the assemblies it depends on, provided either in the form of attributes in the code source or as command- line switches when building the component descriptor.

6.3 JavaBeans Component Model

The JavaBeans component model (Sun Microsystems) was proposed by Sun Microsystems in 1997. The main objective of JavaBeans APIs is to define a software component model for Java so that third party can create and ship Java components that can be composed together into applications by end users.

Enterprise Java Beans is a component-architecture for server-side components used to build distributed systems with multiple clients and servers. EJB provides support for transactions and security over a neutral object communication protocol, which gives the user the opportunity to implement the application on top of a protocol of choice. EJB is part of the Java2 Platform Enterprise Edition (J2EE), which includes many other technologies such as remote method invocation (RMI),

naming and directory interface (JNDI), database connectivity (JDBC), server pages (JSP) and messaging services (JMS).

Both JavaBeans as well as Enterprise Java Beans (EJB) are specifications, based on the object oriented programming language Java. Java maps classes to single files and packages to directories in a file system. A Java package is a physical organization of classes, resources and a manifest. It refers to a unit of deployment, which can be seen as a component.

6.4 Common Object Request Broker Architecture (CORBA)

The Object Management Group (OMG) is the founder of the Common Object Request Broker Architecture (CORBA) (OMG) with a view to establish industry guidelines and object management specifications that provide a common framework for distributed object and component-based application development. CORBA was designed to make it possible to communicate between multiple languages on multiple platforms. CORBA is the basic architecture for communication between heterogeneous objects on heterogeneous platforms.

In CORBA, every object instance has its own unique object reference, an identifying electronic token. Clients use the object references to direct their invocations, identifying to the ORB the exact instance they want to invoke. The client acts as if it is invoking an operation on the object instance, but it's actually invoking on the IDL stub which acts as a proxy. Passing through the stub on the client side, the invocation continues through the ORB (Object Request Broker), and the skeleton on the implementation side, to get to the object where it is executed.

7. THE DESIRED FEATURES OF CBDE

A number of specialized technologies have been introduced to facilitate the various benefits of component programming and reuse. In order to provide comprehensive, integrated environment support for life cycle activities of component-based development, seven requirements are suggested in (Rogerson, 1997) that must be undertaken in CBD: -

Modular Design: - A component should be divided into a public part and private part according to the principle of information hiding or encapsulation. The public part contains the self-description of the component and instantiation mechanism whereas private part contains implementation part. The CBDE should support a separation between public and private parts of a component.

Self-Description: - Components should be able to provide information about them in a systematic way. The environment should support self-description and meta-information that is required to reuse the component.

Global Namespace of Interfaces: - Component interfaces should be formally specified to ensure their semantic compatibility. A global namespace of interfaces, which provides a method to name interfaces in a globally unique way, solves the problem of ensuring the consistency between the semantics of provided component and semantics of required component.

Component Development and Application Composition: - CBDE should support development process consisting both parts - component development and application composition. Along with the traditional development of components, the environment should excel in application composition to support the business aspects of an application.

Connection and Adaptation: - Component configuration helps in connecting the components for their reuse and easy connectivity. Adaptation increases the value of components. The more flexible and adaptable component is, the more often it will be used. The CBDE should support connection and adaptation of components.

Multiple Views: - The CBDE should support multiple views including a development view and a composition view to represent public and private features and a type view and an instance view to represent the dependencies between components and overall architecture of the application.

Reuse by Reference: - The environment through reuse should address the maintenance problems associated with component developed by reference, which is supported via access to remote, searchable component repositories. Component repositories should adhere to a standard that makes close integration with CBD environments possible.

8. DRAWBACKS OF COMPONENT-BASED DEVELOPMENT

In CBD, software systems are built by assembling components already developed and prepared for integration. This leads to many advantages like effective management of complexity, reduced time to market, increased productivity, improved quality, a greater degree of consistency and a wide range of usability (Brown, 2000). However, CBD has several disadvantages and

risks that can jeopardize its success: -

Time and Effort Required for Development of Components: - Among the factors that can discourage the development of reusable components is the increased time and effort required to build reusable units [Crnkovic (2000), Szyperski (1998)].

Unclear and Ambiguous Requirements: - In software development process, one of the major problems comes from unclear, ambiguous, incomplete and insufficient specifications. Reusable components are to be used in different applications, some of which may yet be unknown and requirements of which cannot be predicted. This refers to both functional and nonfunctional requirements. This makes more difficult to identify the requirements properly and hence to design and build components successfully [Maiden (1998), Lamsweerde (2000)].

Conflict Between Usability and Reusability: - In order to make component reusable, it must be sufficiently general, scalable and adaptable. It leads to another development approach, e.g. a design on a more abstract level, which may reduce its ultimate flexibility and ability to be fine-tuned [Crnkovic (2000), Szyperski (1998)].

Component Maintenance costs: - As the component is designed to provide functionality in different applications, working in different environments, require different levels of maintenance support, thus increasing component maintenance costs (Crnkovic, 2000).

9. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This paper makes an attempt to present a review of component-based software development process. The aim of component identification and selection techniques is to identify and select the components, which best meet the stakeholder requirements. The future work should emphasis on collaborative processes, which acts as a trade –off between stakeholder requirements and limitations of candidate component. In the same manner, component integration focuses on component compatibility and checking of component compatibility against open standards. But still there is a need to analysis the risk factors associated with integration, interoperability and deployment of component. To accomplish overall system quality, more accurate component models are to be constructed for component-based systems. The review of various component-based development environments also shows the inadequate facility to maintain the log of the life-time activities of a component or a group of components. In other words, a lot more emphasis is required of versioning and version control mechanism to control the functionality of a component over period of time especially in large and complex systems.

Besides, the behavior of a component with respect to the other components in a system needs to be investigated in greater details. As systems become very large and complex, the controlled behavior of a component can be helpful for better results from the system. The study of this type can further be expanded for the distributed systems.

This paper also discusses the various available component-oriented technologies and their choice according to particular platform. Differences between OOP and component-oriented programming verify the fact that component-oriented software development technology improves the implementation efficiency and makes the easy extendibility and maintenance of large software systems. A comparative analysis of three paradigms suggests that component-based development, despite its high maintenance cost, and possible risk potential, still scores over other technologies. Several requirements for CBDE illustrate the fact that there is still need for a new generation of software environments to support the special needs of component-based development.

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IMPLICATIONS OF SUPERSYMMETRIC RESTRICTED QUANTUM CHROMODYNAMICS (SRCD) ON DYONIC SOLUTIONS.

J. M. S. RANA

Department of Physics, HNB Garhwal University, (Tehri-Garhwal)

Abstract

The Restricted Quantum Chromodynamics (RCD) formulated in terms of connections on global spaces has been supersymmetrized, in a general manner, taking only the topological part into considerations. Dyonic supermultiplets have been obtained for the N=1 supersymmetry quantum mechanically as well as in the supersymmetric version of Georgi-Glashow model for vanishing linear momentum and in the Clifford vacuum. Incorporating the Dyonic color charge and color spin induced as a result of fermion fractionization in Georgi-Glashow model(in presence of an isovector fermion field)into the Supersymmetric Restricted Chromodynamics in N=1 SUSY limit,the Lagrangian density has been constructed and SUSY Dyonic solutions have been obtained . Furthermore, the classical mass of the Dyon has been calculated by minimizing the background potential of theory. The eigen value equations of bosonic and fermionic fluctuations have been obtained in the dyonic background gauge and the corresponding one-loop corrections to the Dyonic mass are calculated and it has been shown that one-loop quantum corrections lead no change in classical mass of Dyon.

Key word : Dyonic solutions, QCD.

1. INTRODUCTION

Although the nature does not seems to display exact electromagnetic duality[1],realistic theories could be judiciously broken version of exact gauge theory in which sufficient structure survives to explain the puzzles such as quark confinement, as has been advocated by Seiberg and Witten[2]. QCD formulated in terms of quarks and gluons, which we believe are the basic constituents of hadronic matter, is most viable and elegant theory of strong interactions. Nevertheless, the theory still defied of proper explanation to various non-perturbative phenomena. Furthermore, there are difficulties in calculating the entire hadron spectrum from the first principle and hence various models have been proposed. However, the non-trivial topological structure [3] and corresponding classical solutions [4] of non-Abelian gauge theories, enforces us to speculate the existence of built-in-duality in such theories which may play an important role in understanding some non-perturbative aspects of QCD e.g. chiral symmetry breaking and quark confinements etc. It is conjectured[5] that the non-Abelian gauge theories may express an exact electro-magnetic duality that exchanges solitons with elementary quanta and weak coupling with strong coupling. Based on these ideas QCD has been formulated as a dual gauge theory called Restricted quantum chromodynamics (RCD) [6] which exhibits built-in-dual structure and the dual dynamics between color iso-charges and topological charges has been developed. Considering quark as dyon, RCD has been shown to produce dynamical dyonic condensation for its vacuum where the built-in-dual dynamics guarantees the confinement of colored fluxes associated with dyonic quarks through the mechanism of generalized Meissner effect. The dyonically condensed vacuum obtained as a result of dynamical breaking of magnetic symmetry leads to the state of (chromo)-dyonic superconductivity. The full spectrum of QCD

*Corresponding Author : ranajms@gmail.com

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i.e. the extended gauge theory has been obtained by re-activating the suppressed dynamical degrees of freedom for both non-supersymmetric and supersymmetric limits.

Supersymmetric field theories have the remarkable property that some of the perturbative effects are cancelled between bosons and fermions and provide [7] a natural resolution of gauge hierarchy problem of Grand unified theories (GUT's). Analyzing the supersymmetric generalization of monopoles in the limit of Prasad and Sommerfield [8] and Bogomoln'yi [9] and using the supersymmetric version of Georgi-Glashow model with vanishing potential, it has been shown [10] that the quantum corrections to the mass of the monopole are vanishing. However, some controversies have been raised [11] about the exact cancellation of perturbative effects between bosons and fermions, Bogomoln'yi bound saturation and the quantum correction to the physical monopole mass in N=2 supersymmetric Yang-Mills theory. Moreover, if the Jackiw-Rebbi zero modes exist independently of supersymmetric zero modes the dyonic states are enriched by further degeneracy with different charge and spin states, consequently the supersymmetry becomes very much involved and cumbersome. Unfortunately an explicit demonstration of Jackiw-Rebbi zero modes are extremely difficult. In the light of these difficulties associated with existing supersymmetric GUT's it is fair to have an alternative approach[12] to understand supersymmetric dyons. Keeping these motivations in view, in the present work dyonic supermultiplets in N=1 SUSY are obtained quantum mechanically in the topological part of the RCD. Constructing the Lagrangian density in the N=1 supersymmetric RCD(topological part only) in terms of the isotriplet gauge field and its fermionic superpartner, supersymmetric dyonic solutions are obtained and the classical mass of the dyon is calculated by minimizing the background potential of the theory. Separating the bosonic part of this Lagrangian in the dyonic background gauge and adding the gauge fixing and Faddeev-Popov ghost term to it, the eigenvalue equations of bosonic fluctuations are derived and the corresponding one-loop corrections to dyonic mass is calculated. Although our main emphasis at present is supersymmetric RCD, however for the readability of the manuscript we briefly review the RCD in the following.

2. Restricted quantum chromodynamics (RCD) – A brief review:

The mathematical foundation of RCD lies in the observation that the non-Abelian gauge symmetry does allow an extra internal symmetry, called magnetic symmetry, which restricts and reduces the dynamical degrees of freedom of the underlying theory while keeping full gauge degrees of freedom intact. This is to say that in (4+n) –dimensional metric manifold P (four-dimensional space-time manifold M and n-dimensional internal space G), the gauge symmetry can be viewed as n-dimensinal isometry which allows us to view P as principal fibre bundle P(M,G) with M=P/G as base manifold and G as structure group, the magnetic symmetry may be imposed by insisting on the following gauge covariant condition;

$$D_\mu \hat{m} = \partial_\mu \hat{m} + q^* V_\mu \times \hat{m} = 0 \qquad (1)$$

Where, $\hat{m}$ is an arbitrary multiplet, which constitute an adjoint representation of group G whose little group is assumed to be Cartan's subgroup at each space-time point. Mathematically, this implies that a connection on P(M,G) admits left isometry H, which formally forms a subgroup of G but commutes with G(the right isometry). The magnetic symmetry thus restricts the connection to those whose holonomy bundle becomes

P(M,H). Normalising $\hat{m}$ (i.e. $\hat{m}^2 = 1$) and choosing G=SU(2), the gauge covariant condition in eq. (1) gives the following form of generalized restricted gauge potential;

$$V_\mu = -iV_\mu^* \hat{m} - \frac{1}{q^*} \hat{m} \times \partial_\mu \hat{m} \tag{2}$$

Such that $\hat{m}.V_\mu = -V_\mu^*$ is the unrestricted Abelian component of restricted gauge potential, while the remaining part of V_μ is completely determined by magnetic symmetric requirement. Notice that the restricted potential constructed here comparing two four-potentials ($V_\mu = A_\mu - iB_\mu$) avoids any string singularity in the theory [13] and yields the following decomposition of electric and magnetic gauge potential;

$$V_\mu = A_\mu = B_\mu \hat{m} - \frac{1}{e} \hat{m} \times \partial_\mu \hat{m} \tag{3}$$

$$B_\mu = A_\mu \hat{m} - \frac{1}{g} \hat{m} \times \partial_\mu \hat{m} \tag{4}$$

Such that $\hat{m}.A_\mu = B_\mu, \hat{m}.B_\mu = A_\mu$ and $q = e - ig$ is the complex coupling constant of the theory. This demonstrates that the generalized gauge potential has been constructed in terms of magnetic vector on global sections containing color electric and color magnetic potentials in a completely dual symmetric way. The unrestricted part of the gauge potential describes the color flux of topological charges of symmetry group G. In such a construction the magnetic symmetry inevitably chooses the color direction by selecting generalized color electric potentials of Carten's subgroup and hence circumvent the non-Abelian gauge theories.

The generalized restricted gauge field strength corresponding to V_μ can be constructed in the following form;

$$\begin{aligned} G_{\mu\nu} &= \varsigma_{\mu\nu} + q^* [V_\mu \times V_\nu] \\ &= (-iF_{\mu\nu} + H_{\mu\nu})\hat{m} \end{aligned} \tag{5}$$

where,

$$\varsigma_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu \tag{6}$$

and

$$F_{\mu\nu} = \partial_\mu V_\nu^* - \partial_\nu V_\mu^* \tag{7}$$

$$H_{\mu\nu} = -\frac{1}{q^*}\hat{m}.(\partial_\mu \hat{m} \times \partial_\nu \hat{m}) \qquad (8)$$

Identifying $F_{\mu\nu}$ and $H_{\mu\nu}$ in eqs. (7,8) as generalized electric and magnetic field strengths, respectively, the striking duality between electric and magnetic fields is obviously manifested in the theory. As such we have the identity

$$[D_\mu, D_\nu] = q^* G_{\mu\nu} \times \hat{m} \qquad (9)$$

This holds for an arbitrary gauge group G. Thus, we conclude that $G_{\mu\nu}$ is parallel to $\hat{m}$ and hence nonvanishing components of $G_{\mu\nu}$ satisfying magnetic symmetric requirement are necessarily those of little group H of $\hat{m}$.

One of the virtues of magnetic symmetry is that it can be used [14] to describe the topological structure of the gauge symmetry. The scalar multiplet $\hat{m}$ may be viewed as to define the homotopy of the mapping $\Pi_2(s^2)$ i.e.

$$\hat{m} \quad ; \quad S_R^2 \to S^2 = SU(2)/U(1) \qquad (10)$$

Where, S_R^2 is two-dimensional sphere of three dimensional space and S^2 is the group coset space fixed by $\hat{m}$. So the topological structure of $\hat{m}$ may be identified with the topological point-like objects of the underlying non-Abelian gauge symmetry. As such, when the second homotopy $\Pi_2(G/H)$ defined by $\hat{m}$ is nontrivial the gauge potential V_μ became sort of dual so that the part of it, which is completely fixed by magnetic symmetric requirement, describes point-like colored topological structure while the unrestricted part describes the convensional dyonic objects (quarks) [6].

The duality, discussed above, can be made more explicit in magnetic gauge obtained by rotating $\hat{m}$ to a prefixed space-time independent direction (say $\hat{\xi}_3$ in isospin space) by imposing a gauge transformation U, such that:

$$\hat{m} \quad \underline{U} \quad \hat{\xi}_3 \quad = \quad (0,0,1)^T . \qquad (11)$$

In this gauge the restricted gauge potential and field strength can be written in the following form;

$$V_\mu \quad \underline{U} \quad V'_\mu \quad = \quad (-iV^*_\mu + W_\mu)\hat{\xi}_3 \qquad (12)$$

and

$$G_{\mu\nu} \ \underline{U} \ G'_{\mu\nu} = (-iF_{\mu\nu} + H_{\mu\nu})\hat{\xi}_3 \qquad (13)$$

Where, W_μ is precisely given in the following form

$$W_{\nu,\mu} - W_{\mu,\nu} = H_{\mu\nu} \qquad (14)$$

Therefore, W_μ can be identified [14] with potential of the topological dyons in RCD and is completely fixed by $\hat{m}$ up to the Abelian magnetic gauge degrees of freedom. Consequently, in the magnetic gauge one may indeed bring the topological properties of $\hat{m}$ down to the dynamical variable W_μ by removing all nonessential gauge degrees of freedom.

In terms of restricted gauge potential and field strength the gauge invariant SU (2), RCD lagrangian may be written in the following form;

$$L_R = -\frac{1}{4}G_{\alpha\mu\nu}G^{\alpha\mu\nu} + i\bar{\psi}^\alpha\gamma^\mu D_\mu\psi_\alpha - m\bar{\psi}^\alpha\psi_\alpha \qquad (15)$$

Where, ψ is the usual quark doublet. In the magnetic gauge this lagrangian yields the following dual symmetric field equation

$$F_{\mu\nu,\mu} = j_\nu \quad \text{and} \quad H_{\mu\nu,\mu} = -\kappa_\nu \qquad (16)$$

Where, j_ν and κ_ν are generalized color electric and color magnetic four-current densities which constitute the generalized dyonic super current.

The foregoing analysis demonstrates the inherent built-in-dual structure of RCD in magnetic gauge and that the magnetic symmetry can be regarded as genuine Noetherian symmetry and topological charge as dual of Noether charge. Following Mandelstam [15] and 't Hooft [16] we have described [6] the dyonic source in RCD by a complex field operator ϕ , as a result the RCD lagrangian (eq. (15)) is modified to

$$L_R = l_R + l_C \qquad (19)$$

Where l_C is obtained in the following form by minimal coupling of complex scalar field ϕ with V'_μ (guided by the week duality : in order to maintain ultraviolet finiteness of theory) with the strength $\frac{4\pi}{|q|}$ i.e.

$$\ell_C = \left|(\partial_\mu + i\frac{4\pi}{|q|}V'_\mu)\right|^2 - V(\phi^*\phi) \tag{20}$$

Where, $V(\phi^*\phi)$ is the effective potential and is introduced by hand [6]. Such an assumption is needed in fixing the form of L_C so that dynamical breaking of magnetic symmetry be induced. Thus, we obtain the following phenomenological lagrangian, in the magnetic gauge,

$$L_R = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}H_{\mu\nu}H^{\mu\nu} - \frac{i}{2}(H_{\mu\nu}F^{*\mu\nu} - F_{\mu\nu}H^{*\mu\nu})$$

$$+\bar{\varphi}_+ i\gamma^\mu\left\{\partial_\mu + \frac{q^*}{2}(-iV^*_\mu + W_\mu)\right\}\varphi_+ + \bar{\varphi}_- i\gamma^\mu\left\{\partial_\mu - \frac{q^*}{2}(-iV^*_\mu + W_\mu)\right\}\varphi_- + m(\bar{\varphi}_+\varphi_+ + \bar{\varphi}_-\varphi_-)$$

$$+\left|\left\{\partial_\mu + i\frac{4\pi}{|q|}(-iV^*_\mu + W_\mu)\right\}\phi\right|^2 - V(\phi^*\phi) \tag{21}$$

This lagrangian can be used to represent the intractions between quarks and dyons in the theory and also can be viewed as effective lagrangian to describe the dual dynamics of RCD (at phenomenological level), just as the Ginzburg- Landau langrangian is used in the theory of superconductivity.

Now with this lagrangian in hand, we have two phases in our theory, namely the unconfining phase where the magnetic symmetry is preserved and the confining phase where the magnetic symmetry is indeed broken by effective potential. In the first phase, not only the quarks but also the dyons will appear as the physical particles while in the second phase both quarks and dyons disappear from the physical partical spectrum and theory contains two generalized magnetic glueballs as massive collective mode of the condensed vacuum. In order to understand this confinement mechanism explicitly, let us write the lagrangian in eq. (21) in the absence of quarks (generalized isocolor charged objects of theory) as follows;

$$L_R = -\frac{1}{4}H_{\mu\nu}H^{\mu\nu} + \left|(\partial_\mu + i\frac{4\pi}{|q|}W_\mu)\phi\right|^2 - V(\phi^*\phi) \tag{22}$$

Identifying the dyon field oprator ϕ, as the order parameter and generalized magnetic potential W_μ as the electric potential, the lagrangian (eq. (22)) resemble with Ginzbueg-

Landau lagrangian for theory of superconductivity. Consequently, an identical sort of condensation (in parallel with Cooper pair formation of superconductivity) occurs here also. More precisely speaking the dynamical breaking of magnetic symmetry by effective potential, introduced here, induces the dyonic condensation of vacuum and gives rise to the generalized dyonic supercurrent (the contribution comes from the dyon-antidyon pair in vacuum). The real part of this supercurrent (electric constituent) screens the electric flux and confines the magnetic color iso-charges, thus giving rise to usual Meissner effect. However, the imaginary part of this supercurrent (magnetic constituent) screens the color magnetic flux and confines the color isocharges via the dual-Meissner effect. As such the dynamical breaking of magnetic symmetry in this theory ultimately induces some sort of generalized Meissner constituent as dual-Meissner effect. In conclusion, the dyonic condensation in RCD vacuum leads to the generalized Meissner effect which dictates the mechanism for the confinement of color electric and magnetic fluxes associated with dyonic quarks in present theory.

Thus, from the foregoing analysis it is clear that the RCD governs a subdynamics of QCD by characterizing the vacuum structure of the theory. Of particular importance is the built-in-dual structure of RCD where the dynamical breaking of magnetic symmetry leads to the confinement of any colored flux of theory via generalized Meissner effect in a dyonically superconducting vacuum. However, a deeper insight in this problem could be gained in exploring more about the behaviour of coupling constant q^*, iso-color and topological charge interactions and hence the vacuum structure of RCD in more detail.

Supersymmetric field theories have the remarkable property that some of the perturbative effects are canceled between bosons and fermions and provide a natural resolution of the gauge hierarchy problem of grand unified theories (GUT's).

Analyzing the supersymmetric generalization of monopoles in the limit of Prasad and Sommerfield and Bogomolny and using the supersymmetric version of the Georgi-Glashow model with vanishing potential, it has been shown that the quantum corrections to the mass of a monopole are vanishing. However, some controversies have been raised about the exact cancellation of perturbative effects between bosons and fermions, Bogomolny-bound saturation, and quantum corrections to the physical monopole mass in N=2 supersymmetric Yang-Mills theory. Keeping these motivations in view, in this

paper, dyonic supermultiplets in N=1 supersymmetry are obtained quantum mechanically in the topological part of restricted quantum chromodynamics. Constructing the Lagrangian density in the N=1 supersymmetic version of restricted quantum chromodynamics (RCD) (topological part)in terms of the isotriplet gauge field and its fermionic superpartner, supersymmetric dyonic solutions are written and the classical mass of the dyon is obtained by minimizing the background potential of the theory.

3. Supersymmetric Dyons and Restricted Gauge Theory:

Dyonic color charge and the color spin induced by fermion fractionization in George-Glashow model in the presence of an isovector fermionic field can be restricted quantum chromodynamics (RCD)[17,18] where the unrestricted part of the gauge potential given in eq. (2) describes the dyonic flux of color isocharges and the restricted one describes the flux of topological charges. The generalized field strength of gauge fields in this restricted chromodynamics describing non-Abelian dyons given by eq. (5).

In the gauge potential and field strength, the V_μ vector is the isotriplet of the generalized four-vector and $\hat{m}$ is isotriplet with constant length

$$\hat{m}^2 = const = v^2/2 \tag{23}$$

In the external four-dimensional space, the multiplet $\hat{m}$ behaves as a massless scalar field, components m^a $(a = 1,2,3)$ constitute isotriplet $\hat{m}$ in SU(2) internal space.

The unrestricted part of the gauge potential V_μ, has the Abelian origin, and it has been ignored as being unnecessary in our recent work,[13] where only the restricted part of this potential has been shown responsible for quark confinement through the mechanism of dyonic condensation. The dyons appear in the restricted chromodynamic theory only through this part of the potential. As such, ignoring the unrestricted part here also, the gauge potential and field strength radon in the following form:

$$V_\mu = -\frac{1}{|q|}\hat{m}\times\partial_\mu\hat{m} \tag{24}$$

and

$$G^a_{\mu\nu} = \frac{1}{|q|}(2\varepsilon^{abc}\partial_\mu m_b\partial_\nu m_c + m^a\varepsilon^{bcd}m_b\partial_\mu m_c\partial_\nu m_d) \tag{25}$$

where

$$|q| = (e^2 + g^2)^{1/2} \tag{26}$$

is the dimensionless coupling constant made up of electric and magnetic coupling strengths e and g, respectively. Here the massless isovector field V_μ has been constructed out of the isotriplet scalar $\hat{m}$ and hence the independent bosonic degree of freedom is only 1. As such, the supersymmetric generalization of RCD may be obtained by modifying the Lagrangian density into the form:

$$L = -\frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a + \frac{1}{2} \bar{\lambda}^a \gamma^\mu D_\mu \lambda_a + \frac{1}{2} D_\mu m^a D^\mu m_a + \frac{1}{2} |q| \varepsilon_{abc} m^a \bar{\lambda}^b \gamma_5 \lambda^c - V(mm^*), \tag{27}$$

where λ^a constitutes the isotriplet of fermionic field, γ^μ are Dirac matrices, $\gamma_5 = \gamma_1\gamma_2\gamma_3\gamma_4$, and the covariant derivative D_μ is defined as:

$$D^\mu = \partial^\mu + qV^\mu \times \tag{28}$$

with the symbol $\times$ for cross product in internal SU(2) space. The background potential $V(mm^*)$ in eq. (27) has been constructed in the form

$$V(mm^*) = |q|^2 [(m^a m_a^*)^2 - (m^a m_a^*)(m^b m_b^*)] \tag{38}$$

Using Eq. (24) for the topological gauge potential in Eq. (28) we have the following expressions for the covariant derivatives of iso-triplet fermionic field λ and isotriplet scalar field $\hat{m}$:

$$\begin{aligned} D_\mu \lambda^a &= \partial_\mu \lambda^a + (m^a \partial_\mu m^b \lambda_b - m^b \partial_\mu m^a \lambda_b), \\ D_\mu m^a &= \partial_\mu m^a + (m^a \partial_\mu m^b m_b - m^b \partial_\mu m^a m_b) \end{aligned} \tag{30}$$

Substituting these equations along with Eq. (25) into Eq. (27) we get the Lagrangian of the topological part of the restricted gauge theory in the form

$$L = -\frac{1}{|q|^2}[\Gamma_{\mu\nu bc}(\Gamma^{\mu\nu bc} - \Gamma^{\mu\nu cb}) + \frac{1}{2}\varepsilon_{ajk}\varepsilon^{bcd}m^a m_b \Gamma_{\mu\nu cd}\Gamma^{\mu\nu jk}$$
$$+\frac{1}{2}\varepsilon^{abc}\varepsilon_{jkl}m_a m^j \Gamma_{\mu\nu bc}\Gamma^{\mu\nu kl} + \frac{1}{2}\varepsilon^{bcd}\varepsilon_{jkl}m_b m^j \Gamma_{\mu\nu cd}\Gamma^{\mu\nu kl}]$$
$$+\frac{1}{2}\bar{\lambda}^a\gamma^\mu[\partial_\mu\lambda_a + (m_a\partial_\mu m_b\lambda^b - m_b\partial_\mu m_a\lambda^b)] \qquad (31)$$
$$+\frac{1}{2}[\partial_\mu m^a + (m^a\partial_\mu m^b m_b - m^b\partial_\mu m^a m_b)]^2$$
$$+\frac{1}{2}|q|\varepsilon_{abc}m^a\bar{\lambda}^b\gamma_5\lambda^c - V(mm^*),$$

where $\Gamma_{\mu\nu bc}$ has been written for $\partial_\mu m_b \gamma_\nu m_c$; μ,ν are the indices in the four dimensional space and a,b,c etc.,. are those in internal iso-space. In this Lagrangian, λ^a are superpartners of the isotriplet gauge field V_μ^a [or in turn the superpartners of isotriplet scalar multiplet m^a through Eq. (24)]. Since the theories which transform as linear representations of supersymmetry must have the same number of bosonic degrees of freedom, the Lagrangian (31) sould be supersymmetric. In order to check the supersymmetric invariance of this Lagrangian, let us apply the following supersymmetric transformations:

$$\delta m^a = \bar{\alpha}\gamma_5\lambda^a,$$
$$\delta V_\mu^a = -\frac{1}{|q|}\varepsilon^{abc}\bar{\alpha}(\gamma_5\lambda_b\partial_\mu m_c + m_b\gamma_5\partial_\mu\lambda_c), \qquad (32)$$
$$\delta\lambda^a = \frac{1}{|q|}\alpha\sigma^{\mu\nu}(2\varepsilon^{abc}\Gamma_{\mu\nu bc} + m^a m_b\varepsilon^{bcd}\Gamma_{\mu\nu cd}) - i\alpha\gamma_5\gamma_\mu m^a m_b\gamma^\mu m^b.$$

Under these transformations,

$$\delta L = 0 \qquad (32a)$$

Provided we assume the supersymmetry conditions

$$\lambda_5(\bar{\lambda}\times\partial_\mu\hat{m} + \hat{m}\times\partial_\mu\bar{\lambda}) = -i|q|\gamma_\mu\bar{\lambda},$$
$$[m_b,\bar{\alpha}] = 0, \quad [m_b,\gamma_5] = 0 \qquad (33)$$

which give the generalization of the Majorana condition and the Weyl condition. Condition (32a) shows that the Lagrangian density is supersymmetric for the topological part of restricted gauge theory constructed in terms of magnetic symmetry.

The background potential given by Eq. (29) has two types of minima:

$$m^a = 0 \quad \text{and} \quad m^a = \frac{v}{\sqrt{2}} x^a .$$

For both these cases the value of potential is zero, as required by supersymmetric theories. For the second value of m^a, the symmetry SU(2) breaks down to U(1) and the dyonic solutions occur with the following Julia-Zee[19]time-dependent solutions:

$$V^{ai} = -\frac{1}{|q|}\frac{\varepsilon^{abi}}{r}\hat{X}_b[1-K(r)],$$

$$V_0^a = \frac{\hat{X}_b}{|q|r}J(r), \tag{34}$$

$$\sqrt{2}\,\mathrm{Re}\,m^a = \frac{\hat{X}_b}{|q|r}H(r), \qquad \mathrm{Im}\,m^a = 0$$

where $\hat{X}^a = x^a/r$ is unit vector in the internal space. These solutions satisfy the coupled differential equations

$$r^2H'' = 2HK^2,$$

$$r^2K'' = K(K^2-1)+K(H^2-J^2), \tag{35}$$

$$r^2J'' = 2JK^2.$$

A solution of these equations is given by

$$J(r) = \alpha[cr\coth(cr)-1], \quad H(r) = \beta[cr\coth(cr)-1],$$

$$K(r) = cr/\sinh(cr), \tag{36}$$

with the condition

$$\alpha^2 - \beta^2 = -1 \tag{37}$$

From the Lagrangian density we get the following form energy-momentum density tensor

$$T^{\mu\nu} = D^\mu m_a D^\nu m^a + \frac{1}{2}G_a^{\mu\lambda}G_\lambda^{a\nu} - g^{\mu\nu}[-\frac{1}{4}G_{ij}^aG_a^{ij} + \frac{1}{2}\bar{\lambda}^a\gamma^iD_i\lambda_a$$

$$+\frac{1}{2}D_im^aD^im_a + \frac{1}{2}|q|\varepsilon_{abc}m^a\bar{\lambda}^b\gamma_5\lambda^c - V(mm^*)]. \tag{38}$$

Setting $\mu = \nu = 0$ in this relation, integrating

T^{00} over three-space, and using relation (34) and (36), the classical mass of the dyon comes out to be

$$M = \frac{v}{\sqrt{2}}|q| = M_{classical} \tag{39}$$

showing that the dyons appear in the theory only through the restricted part of the potential, which carries the topological charges. A one-loop correction to this mass may be obtained by calculating the energies of Bose and Fermi fluctuations:

$$M_B = \frac{1}{2}\sum \omega_B \tag{40}$$

and

$$M_F = -\frac{1}{2}\sum \omega_F \tag{41}$$

Let us choose the dyonic background gauge field defined by Eq. (34), where the fluctuation equation is given as the normal eigen value equation. This choice of gauge is necessary because the fluctuation equation takes a particular form in this gauge. Moreover, one may calculate one-loop diagrams with exact propagations of all particles in the background of a dyon.

In the dyonic background fields

$$V^a_{\mu D} = V^a_\mu - \delta V^a_\mu, \qquad m^a_D = m^a - \delta m^a, \tag{42}$$

which satisfy Eq. (34), the bosonic part of the Lagrangian density (31) may be written as

$$\begin{aligned} L_B = L_D &- \frac{1}{2}\left|(D_\nu \delta V^a_\mu)\right|^2 + \frac{1}{2}(D_\mu \delta V_\nu)(D^\nu \delta V^\mu)^* - \frac{1}{4}|q|^2\left|(\delta V_{\mu b}\delta V_{\nu c})\right|^2 \\ &- \frac{1}{2}\mathrm{Re}[|q|\varepsilon_{abc}G^a_{\mu\nu D}V^{*\mu b}\delta V^{*\nu c}] - \frac{1}{2}(D_\mu \delta m^a)(D^\mu \delta m_a)^* - \frac{1}{2}|q|\varepsilon_{abc}(D_\mu m^a)V^{*\mu b}m^c \\ &+ \frac{1}{2}|q|\varepsilon_{abc}(D_\mu \delta m^a)\delta V^{*\mu b}\delta m^c + \frac{1}{2}|q|\varepsilon^{abc}(D^\mu m_a)^*\delta V_{\mu b}m_c + \frac{1}{2}|q|^2[\delta V_{\mu b}m_c \\ &+ \frac{1}{2}|q|^2[(\delta V_{\mu b}m^a)^2 - (\delta V_{\mu b})^2(m_a)^2], \end{aligned} \tag{43}$$

where L_D is the dyonic background Lagrangian given by

$$L_D = -\frac{1}{4}G^a_{\mu\nu D}G^{*\mu\nu}_{aD} + \frac{1}{2}(D_\mu m^a_D)(D^\mu m_{Da}) - V(m^{*a}_D m_{Da}) \tag{44}$$

and D_μ is the covariant derivative given by Eq. (28) with V_μ replaced by V^μ_D. To this Lagrangian let us add the following gauge-fixing term and Faddeev-Popov ghost term.

(i) Gauge-fixing term: Under an infinitesimal transformation θ, which keeps the background configuration $V^a_{\mu D}$ and m^a_D fixed, we may write the following variations of δV^a_μ and δm^a up to the lowest order in θ:

$$\delta V^{\theta a}_\mu = -\frac{1}{|q|}\varepsilon^{abc}(\delta m^\theta_b \partial_\mu m_c + m_b \partial_\mu \delta m^\theta_c)$$

$$= \delta V^a_\mu - \frac{1}{|q|} m_c \theta^a \partial_\mu m_c - \frac{1}{|q|} m_b \partial_\mu m^a \theta^b - \frac{1}{|q|} m_b m^a \partial_\mu \theta^b \tag{45}$$

and

$$\delta m^{\theta a} = \delta m^a + \varepsilon^{abc} m_b \theta_c, \tag{46}$$

where the background gauge has been defined by the condition

$$f^a = (D^\mu \delta V_\mu)^a - |q|\varepsilon^{abc} m_b \delta m_c \tag{47}$$

such that

$$\frac{\delta f^a}{\delta \theta^b} = \frac{1}{|q|}[D^\mu (m^a \partial_\mu m_b + m_b \partial_\mu m^a) + |q|^2 (m^a m_b - m^2 \delta^a_b)]. \tag{48}$$

Thus the gauge-fixing term is given by

$$L_{gf} = -\frac{1}{2} f^a f_a$$

$$= -\frac{1}{2}(D_\mu \delta V^\mu)^2 + |q|\varepsilon^{abc}(D_\mu \delta V^\mu)_a m_b \delta m_c + |q|^2 (m^a m_b - m^2 \delta^a_b)\delta m_a \delta m^b. \tag{49}$$

(ii) Faddeev-Popov ghost term: This term is given by

$$L_{FP} = -c^*_a (\delta f^a / \delta \theta^b) c_b, \tag{50}$$

where Faddeev-Popov fields denoted by c and c^* are vectors in isospace. Using Eq. (48), we may write this term as

$$L_{FP} = c^*_a \left[\frac{1}{|q|}[D^\mu (m^a \partial_\mu m^b + m_b \partial_\mu m^a)] + |q|^2 (m^a m^b - m^2 \delta^{ab})\right] c_b \tag{51}$$

Using Eqs. (43), (49) and (51), the total Lagrangian for the bosonic part may be written as

$$L = L_B + L_{gf} + L_{FP}. \tag{52}$$

In these equations for L_B, L_{gf} and L_{FP}, we may use the following matrix notation for the covariant derivative

$$D_\mu = \partial_\mu + i|q|V^D_{\mu a}T^a \tag{53}$$

is the dyonic background where T^a are usual generators of the internal gauge group SU(2).

Let us construct a three-vector B^D in the dyonic background as

$$B^D_j = \frac{1}{2}\varepsilon_{ijk}G^{Dik}_b T^b \tag{54}$$

and identify the spatial part δV_j and temporal part δV^0_j of δV^μ_j as vectors in isospace. Then we may straight away get the following equations of motion from the Lagrangian density given by Eq. (43)

$$[D_\mu D^\mu - |q|^2 m^2 - 2|q|\sigma_k B^{Dk}]\delta\xi = 0, \tag{55}$$

$$[D_\mu D^\mu - |q|^2 m^2]\delta V_0 = 0, \tag{56}$$

$$[D_\mu D^\mu - |q|^2 m^2]c = 0, \tag{57}$$

where we have chosen

$$\delta\xi^a = \delta m^a + i\sigma^i \delta V^a_i \tag{58a}$$

and

$$m^2 = (T^c m_c)^2. \tag{58b}$$

For getting the eigen value equations for the Bose fluctuations, let us take the following Fourier transform with respect to time t,

$$\delta\xi^a = \sum_{\omega_B}\delta\xi^a \exp(i\omega_B t), \qquad \delta V^a_0 = \sum_{\omega_{B_0}}\delta\tilde{V}^a_0 \exp(i\omega_{B_0} t),$$

$$\delta c^a = \sum_{\omega_G}\delta\tilde{c}^a \exp(i\omega_{B_0} t). \tag{59}$$

Then Eqs. (55), (56) and (57) may be written in the following manner:

$$(D_i^2 - |q|^2 m^2 + 2|q|T_k V^{Dk})\delta\tilde{\xi} = -\omega_B^2\delta\tilde{\xi}, \tag{60a}$$

$$(D_i^2 - |q|^2 m^2)\delta\tilde{V}_0 = -\omega^2_{B_0}\delta\tilde{V}_0, \tag{60b}$$

$$(D_i^2 - |q|^2 m^2)\tilde{c} = -\omega_G^2\tilde{c}, \tag{60c}$$

where ω_B, ω_{B_0} are bosonic fluctuation frequencies and ω_G is the ghost term frequency. From these fluctuations, the one-loop contributions to dyonic mass can be written as

$$\Delta M_{Bose} = \Delta M_B = \sum \omega_B + \frac{1}{2}\sum \omega_{B_0} - \sum \omega_G, \tag{61}$$

where the negative sign for the ghost contribution denotes the anticommuting nature of ghost fields. Since $\sum \omega_B = \sum \omega_G = \sum \omega_{B_0}$, we may write Eq. (61) as

$$M_{Bose} = \frac{1}{2}\sum \omega_B \tag{62}$$

Fermi fluctuations may be obtained from the following fermion equation of motion which follows from the fermionic part of the Lagrangian (27):

$$\gamma^\mu D_\mu \lambda^a + |q|\varepsilon^{abc} m_b \gamma_5 \lambda_c = 0, \tag{63}$$

where the covariant derivative has been defined by Eq. (53). Using Majorana representation and taking the Fourier transform of λ^a with respect to t as

$$\lambda^a = u^a \exp(-i\omega_F t)\ , \tag{64}$$

Eq. (54) reduces to

$$(D_i^2 - |q|^2 m^2)u = -\omega_F^2 u\ , \tag{65}$$

where u is a vector in isospace with its components given by u^a. The contribution of this fluctuation to the dyon mass is

$$\Delta M_F = M_{Fermi} = -\frac{1}{2}\sum \omega_F. \tag{66}$$

Combining Eqs. (62) and (66), we get the following one-loop quntum correction to the dyonic mass:

$$\Delta M = \Delta M_B + \Delta M_F = \frac{1}{2}\left[\sum \omega_B - \sum \omega_F\right]. \tag{67}$$

In other words, the dyonic mass up to one-loop quantum correction is given by

$$M = M_{classical} + \frac{1}{2}\left[\sum \omega_B - \sum \omega_F\right], \tag{68}$$

where the classical mass of dyon ($M_{classical}$) is given by Eq. (39).

Because of the similar nature of second-order differential equations (60a), (60b) and (65), the bosonic and fermionic fluctuations have the same spectrum of nonzero eigenvalues,

$$\sum \omega_F = \sum \omega_B. \tag{68a}$$

The equality between ω_B and ω_F leads to the result that the mass of the dyon is not charged by quantum corrections. In other words, in the supersymmetric limit, the non-Abelian theory of dyons in RCD falls apart, in the correct way, into degenerate supermultiplets.

RESULTS AND DISCUSSION

The Lagrangian density given by Eq. (27) is supersymmetric under the transformations (32), subject to the condition (33), which are a generalization of Majorana and Weyl conditions[19] It leads to supersymmetric dyonic solutions with classical mass given by Eq. (39) when the symmetry SU(2) breaks down to U(1) by minimizing the potential (29). This value of dyonic mass agrees with that predicted by Julia and Zee[20].This result shows that the dyons appear in the theory (RCD) only through the restricted part of the potential given by Eq. (2). Only this part, carrying the topological charges, is relevant in dyonic theory, while the unrestricted part of this potential, which is Abelian in nature, does not contribute anything to dyonic solutions. We have also demonstrated in our recent work[17] that it is only the restricted part of this potential which is responsible for quark confinement in RCD through the mechanism of dyonic condensation. On the other hand, the unrestricted part of the potential becomes confined as a result of condensation of topological charges. Due to these reasons the unrestricted part of the potential has been ignored in Eq. (24) while writing the supersymmetric Lagrangian (27) which carries only one bosonic degree of freedom and one fermionic degree of freedom. In case this unrestricted part of the potential is not ignored, one will have to introduce two fermionic degrees of freedom in this Lagrangian. It will not lead to any new physics and the mathematical calculations will become unnecessarily cumbersome, leading to difficulty in constructing the background potential of Eq. (29).

Choosing the dyonic background field defined by Eq. (42), the bosonic part of the Lagrangian of supersymmetric theory in the gauge restricted by magnetic symmetry has been obtained in the form given by Eq. (43). Equation (60) gives the bosonic fluctuations with the same frequency for the spatial bosonic field, temporal bosonic field, and the ghost field, which lead to total one-loop fluctuations and a correction to the dyonic mass in the form given by Eq. (62). The fermionic part of the Lagrangian leads to the equation of the motion (63), which in turn yields the fermionic fluctuation (64) in the one-loop approximation. Because of the similar nature of second-order differential equations (60a), (60b) and (64), the bosonic and fermionic fluctuations have the same spectrum of nonzero eigenvalues. Equations (66), (67) and (68) show that the classical mass of the dyon is not charged by quantum corrections, and hence it may be concluded that, in the supersymmetric limit, the non-Abelian theory of dyons in the restricted chromodynamics falls apart, in the correct way, into degenerate multiplets. In other words, in the supersymmetric generalization of RCD, the physical dyonic mass does not receive quantum corrections. The introduction of the supersymmetric dyonic model in this way and the vanishing of the quantum corrections may be used for proving the interesting conjecture proposed by Montonen and Olive[21] All these results of the supersymmetrized version of RCD agree with conclusions drawn by D'Adda et al[10] by using dimensionally reduced supersymmetrized pure Yang-Mills theory in six dimensions. Using this method of dimensional reduction, we may get a two-dimensional theory from the four-dimensional supersymmtric theory prensed in the preceding section by interpreting two of the spatial dimensions as internal degrees of freedom.

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A BRIEF NOTE ON VACUUM STRUCTURE OF RESTRICTED QUANTUM CHROMODYNAMICS (RQCD)

J. M. S. RANA

Department of Physics, HNB Garhwal University (Tehri-Garhwal)

Abstract

The isocolor charge-dyon interactions have been studied, in Restricted Quantum Chromodynamics (RCD), in terms of current-current correlation in magnetic gauge using the dielectric and permeability parameters of the associated vacuum. In the state of dyonic superconductivity, it has been shown that the dual propagators behave as 1/k4 (for small k2), which in analogy with superconductivity (dual superconductivity) leads to the confinement of colored fluxes associated with dyonic quarks vide generalized Meissner effect. Based on semi-quantitative analysis of vortex solutions of RCD and by calculating the masses for the massive collective modes of the condensed vacuum, the expressions for the London penetration depth, coherence length and the associated flux energy functions for the type I and type II superconducting media have been obtained. It has further been demonstrated that in the type I medium, vortices tend to coalesce and hence are attractive, while the energy function supports repulsive forces between vortices in the type II superconducting medium.

Key words : Dyonic solutions, QCD.

1. INTRODUCTION

QCD formulated in terms of quarks and gluons, which we believe are the basic constituents of hadronic matter, is most viable and elegant theory of strong interactions. The non-trivial topological structure [1] and corresponding classical solutions [2] of non-Abelian gauge theories, enforces us to speculate the existence of built-in-duality in such theories which may play an important role in understanding some non-perturbative aspects of QCD. Based on these ideas QCD has been formulated as a dual gauge theory called Restricted quantum chromodynamics (RCD) [3] which exhibits built-in-dual structure and the dual dynamics between color isocharges and topological charges has been developed. Considering quark as dyon, RCD has been shown to produce dyonic condensation for its vacuum where the built-in-dual dynamics guarantees the confinement of colored fluxes associated with dyonic quarks through the mechanism of generalized Meissner effect. The dyonically condensed vacuum obtained as a result of dynamical breaking of magnetic symmetry leads to the state of (chromo) dyonic superconductivity. This work has further been extended[4] and dyonic solutions have been obtained for N=1 SUSY. It has been demonstrated hat in the supersymmetric generalization of RCD, the physical dyonic mass does not receive quantum corrections. Our work in progress, on susy dyonic model with vanishing quantum corrections may be useful for probing the interesting conjecture proposed by Montonen and Olive[5]. All these results of SUSY RCD agree with conclusions drawn by D'Adda et al[6]. From our work it is clear that the RCD governs a subdynamics of QCD by characterizing the vacuum structure of the theory. Of particular importance is the built-in-dual structure of RCD where the dynamical breaking of magnetic symmetry leads to the confinement of colored flux of theory via generalized Meissner effect in a dyonically superconducting vacuum. However, a deeper insight in this problem could be gained by exploring the behaviour of coupling constant q, isocolor and topological charge interactions and hence the vacuum structure of RCD in more detail. Keeping electromagnetic duality as vital guide in the following we study the duality in particularly relevant to the RCD vacuum as (chromo)dyonic superconducting medium, the detail implications of which is under progress and will be communicated soon.

2. VACUUM STRUCTURE OF RCD

We, artifact that the RCD vacuum is the relativistic electric medium and such properties of RCD vacuum, in non-perturvative regime, may play an important role in establishing quark confinement. However, in the present model, in case of the magnetic symmetric contribution in theory, obviously the counter term for dielectric function is given by permeability function in order to maintain the relativistic invariance. It implies that in a simplest long distance approximation RCD $(x \geq \frac{1}{\Lambda_{QCD}})$ vacuum behaves as relativistic dielectric medium consisting of virtual quanta of the Yang-Mills fields. Thus, it is worth to further explore the long distance behavior of RCD having built-in-dual structure to get some insight into the study of quark confinement in QCD. We consider the following form of RCD action in translationally invariant medium (in magnetic gauge);

$$S = -\frac{1}{4}\iint F^{\mu\nu}(x)\varepsilon(x-y)F_{\mu\nu}(y)d^4xd^4y$$

*Corresponding Author ; ranajms@gmail.com

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$$-\frac{1}{4}\iint H^{\mu\nu}(x)\mu(x-y)H_{\mu\nu}(y)d^4xd^4y + \text{Other remaining part} \quad (1)$$

Where, the remaining part of the action consists of all other nonquadratic terms in the potential (higher nonlinear terms). $\varepsilon(x-y)$ and $\mu(x-y)$ are the electric and magnetic permeability functions, respectively, which in lowest order perturbation theory are delta functions $\delta(x-y)$. These functions provide an effective or macroscopic description of complicated microscopic interactions of quarks and dyons in RCD vacuum. In the spirit of relativistic invariance, dielectric and magnetic permeability functions satisfy the following relation;

$$\int \varepsilon(x-y)\mu(y-z)d^4y = \delta(x-z) \quad (2)$$

In the most general case, where the colored objects in the theory are dyonic in nature, it is more likely to formulate the theory in terms of generalized potentials containing both electric and magnetic potentials in a dual symmetric way. Then the color electric constituents of the supercurrent are those which interact via the unrestricted part of the gauge potential V_μ and may be written as

$$\langle j_\mu(x)\rangle = i\frac{\delta S}{\delta V_\mu^*} \quad (3)$$

Which lead to the following form of current-current correlation functional;

$$\langle j_\mu(x), j_\nu(y)\rangle = -\frac{\delta^2 S}{\delta V_\mu^*(y)\delta V_\mu^*(x)} = (\text{W}\delta_{\mu\nu} - \partial_\mu\partial_\nu)\varepsilon(x-y)$$

$$= -\int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}(\delta_{\mu\nu}k^2 - k_\mu k_\nu)\varepsilon(k^2) \quad (4)$$

Where,

$$\varepsilon(x-y) = \int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}\varepsilon(k^2) \quad (5)$$

Now the corresponding magnetic constituent of supercurrent is one which couple with the restricted part of the gauge potential, determined completely by the magnetic symmetric requirement, is given by,

$$\langle \kappa_\mu(x)\rangle = \frac{\delta S}{\delta W_\mu(x)} \quad (6)$$

and the corresponding magnetic current-current correlation functional for same RCD medium is expressed as follows;

$$\left\langle \kappa_\mu(x), \kappa_\nu(y) \right\rangle = -\frac{\delta^2 S}{\delta W_\nu(y)\delta W_\mu(x)} = (\text{W}\delta_{\mu\nu} - \partial_\mu\partial_\nu)\mu(x-y)$$

$$= -\int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}(\delta_{\mu\nu}k^2 - k_\mu k_\nu)\mu(k^2) \tag{7}$$

where, again $\mu(k^2)$ is Fourier transform of $\mu(x-y)$ i.e.

$$\mu(x-y) = \int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}\mu(k^2) \tag{8}$$

Relativistic invariance fixes the following relation for these two functions in accordance with eq. (2)

$$\varepsilon(k^2).\ \mu(k^2) = 1$$

As we know that $\varepsilon(k^2) = 1 = \mu(k^2)$ is the free electromagnetism in the vacuum. Thus, for perturvatively small contribution to dielectric and permeability functions we write; $\varepsilon(k^2) = 1 + \nabla(k^2)$

$$\varepsilon(k^2) = 1 - \nabla'(k^2) \tag{9}$$

and hence the corresponding permeability functions may be written as,

$$\mu(k^2) = 1 - \nabla(k^2)$$

$$\mu(k^2) = 1 + \nabla'(k^2) \tag{10}$$

where, the $\nabla'(k^2)$ is written for the magnetic constituent. These equations are in perfect agreement with the earlier work [7, 8, 9] and demonstrate clearly that any constituent of field screens its own direct potential (to which it is minimally coupled) and anti-screens the dual potential. The condensation of (chromo)-dyons leads to drastic changes in the dielectric properties of RCD vacuum resulting in the confinement of colored fluxes associated with charged particles in accordance with generalized Meissner effect. The dyon-antidyon pair embedded in this nontrivial RCD vacuum is not easily described as interacting by gluon exchange. A better description involves strings (type II superconductor) or bags (type I superconductor). Now comparing with usual superconductivity we write the following expressions, keeping in mind the fact that the penetration depth is inverse to the mass of propagating field quanta,

$$\mu(k^2) = k^2\lambda_L^2 \quad \text{and} \quad \lambda_L = \frac{1}{m_L(e)} \tag{11}$$

$m_L(e)$ is the mass of the photon. Obviously $\varepsilon(k^2) = \frac{1}{k^2\lambda_L^2}$ so as to obey the requirement $\mu(k^2)\,\varepsilon(k^2) = 1$. Under these circumstances the color electric and magnetic current-current correlations, be written as follows;

$$\left\langle j_\mu(x), j_\nu(y)\right\rangle = -\int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}\left(\delta_{\mu\nu} - \frac{\kappa_\mu\kappa_\nu}{\kappa^2}\right)\frac{1}{\lambda_L^2} \tag{12}$$

$$\left\langle \kappa_\mu(x), \kappa_\nu(y)\right\rangle = -\int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}\left(\delta_{\mu\nu} - \frac{\kappa_\mu\kappa_\nu}{\kappa^2}\right)\kappa^4\lambda_L^2 \tag{13}$$

From above equations it is clear that electric constituent quanta of the generalized field acquires a mass equal to $m_L(e)$ and can only propagate over the distances comparable to London penetration depth and at the same time the dual field quanta (magnetic constituent) of generalized field propagates as $\frac{1}{k^4}$ at least for small momentum limit. However, in case of magnetic constituent of generalized Meissner effect, where electric part is confining and can penetrate inside the chromo-dyonic superconductor up to the distances comparable to some sort of London penetration depth, the above conditions would be given in the following form;

$$\varepsilon(k^2) = k^2\lambda_L^2 \quad \text{and} \quad \lambda_L = \frac{1}{m_L(g)} \tag{14}$$

where, $m_L(g)$ is mass of magnetic photon, also $\mu(k^2) = \frac{1}{k^2\lambda_L^2}$. For these specifications the current-current correlations may be written as follows;

$$\left\langle j_\mu(x), j_\nu(y)\right\rangle = -\int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}\left(\delta_{\mu\nu} - \frac{\kappa_\mu\kappa_\nu}{\kappa^2}\right)\kappa^4\lambda_L^2 \tag{15}$$

$$\left\langle \kappa_\mu(x), \kappa_\nu(y)\right\rangle = -\int \frac{d^4k}{(2\pi)^4} e^{ik(x-y)}\left(\delta_{\mu\nu} - \frac{\kappa_\mu\kappa_\nu}{\kappa^2}\right)\frac{1}{\lambda_L^2} \tag{16}$$

These equations show that the magnetic constituent of field quanta become massive and propagates only up to sort of London penetration depth while the associated electric field quanta propagates like $\frac{1}{k^4}$. Thus, making use of duality in superconductivity incorporates

deviation in values of $\varepsilon(k^2)$ and $\mu(k^2)$ from unity and consequently include the fully nonperturbative effects in RCD. Therefore, eq.s (12, 13) can be straightforwardly used to explain color magnetic flux confinement while eq.s (15, 16) may explain color electric flux confinement in QCD. It may be instructive, now,by comparing two confinement mechanisms (i.e. with usual superconductivity) that a better description of dyon-antidyon in RCD vacuum involves strings and bags. The bags find their natural habitat in type I superconductor while strings exist more comfortable in type II superconducting medium. In the following section we tried to present a semi-quantitative description for this idea based on a discussion of vortex solutions in the Higgs-Ginzburg -Landau theory for present model.

3. Vortex Solutions of RCD

The Ginzburg-Landau equations, describing a superconductor, are well known in their relativistic form as the Higgs model. However, in the present model it is the magnetic symmetry which has been used to specify the global topology $\Pi_2(G/H)$ of the gauge symmetry rather than the scalar triplet as in Higgs type theory. Consequently, as has been discussed earlier, we are left with the following form of Lagrangian in the absence of quarks, in magnetic gauge, as the relativistic generalization of Ginzburg-Landau Lagrangian for RCD as Higgs model.

$$L_R = -\frac{1}{4} H_{\mu\nu} H^{\mu\nu} + D_\mu \phi D^\mu \phi - V(\phi^* \phi) \tag{17}$$

where,

$$D_\mu \phi = (\partial_\mu + i \frac{4\pi}{|q|} W_\mu)\phi \tag{18}$$

and $V(\phi^*\phi)$ is the effective potential. Following Coleman and Weinberg [10] it has been shown [8] that the effective potential obtained in one-loop approximation can actually break the magnetic symmetry dynamically in the strong coupling limit and has the following form,

$$V_{eff} = \frac{24\pi^2}{|q|^4} \left\{ v^2 + (\phi^*\phi)^2 (2 \ln \frac{(\phi^*\phi)}{v^2} - 1) \right\} \tag{19}$$

where, $\langle \phi^* \phi \rangle^{1/2} = v$ is the vacuum expectation value of the ϕ field. Such a dyonically condensed vacuum is characterized by the presence of two massive collective modes of

condensed vacuum, namely, scalar and an axial vector. The mass of the scalar mode (m_s) determines how fast the perturbative vacuum around a colored source reaches the condensation and that of the vector mode (m_s) determines the penetration length of the colored flux. The masses of these glueballs may be estimated [8] by evaluating the string tension of classical string solutions of colored quark pairs and the following form of quartic potential is most suitable from phenomenological viewpoint;

$$V(\phi^*\phi) = \frac{48\pi^2}{|q|^4} P(\phi^*\phi - v^2)^2 \tag{20}$$

where, P is a number and can have any integer value. Thus, with this effective potential $V(\phi^*\phi)$ in Lagrangian(17), there exists a strict parallelism between standard Higgs mechanism in its relativistic generalization to RCD. Therefore, the masses of these massive modes may be expressed as follows;

$$m_s^2 = 2\frac{96\pi^2}{|q|^4} P v^2 \tag{21}$$

$$m_a^2 = 2\frac{16\pi^2}{|q|^2} v^2 \tag{22}$$

The effective potential eq.(20) fixes the following ratio of these masses in terms of a dimensionless parameter;

$$K_{RCD}^2 = (\frac{m_s}{m_a})^2 = \frac{3}{2\pi\alpha_R} P \tag{23}$$

where, $\alpha_R = \frac{|q|^2}{4\pi}$ is the fine structure constant of RCD. In the present model, in parallel with Ginzburg-Landau theory, one may identify the London penetration depth ($\lambda_L = \frac{1}{m_a}$) and the coherence length ($\varsigma_R = \frac{1}{m_s}$) as measure of the distance over which superconductivity becomes established, one may therefore have,

$$K_{RCD}^2 = \frac{3}{2\pi\alpha_R} P = \frac{\lambda_L^2}{\varsigma_R^2}$$

such that,

$$\lambda_L^2 = (\frac{|q|}{4\pi})^2 \frac{1}{2v^2}, \tag{24}$$

$$\varsigma_R^2 = \frac{1}{2^2 P}(\frac{|q|}{2\sqrt{\pi}})^4 \frac{1}{3v^2} \tag{25}$$

Keeping in view these discussions, in the following we discuss the static finite energy solutions of the equations of motion, followed from Lagrangian eq.(17) which are expected (to an approximation) to be the vortex lines. From this Lagrangian we get the following equation of motion in cylindrical coordinates (r,θ,z) system [11].

$$\left(\nabla^2 - \frac{32\pi^2}{|q|^2}\right)\vec{W} = -i\phi^*\nabla\phi \tag{26}$$

$$\left(\nabla^2 - i\frac{4\pi}{|q|}\right)^2 \phi = \frac{96\pi^2}{|q|^4}\phi(\phi^2 - v^2) \tag{27}$$

where, we have chosen Coulomb gauge $\nabla.\vec{W} = 0$ with $W_0 = 0$ and $P = 1$, for simplicity. Now for these static equations of motion we choose the following substitution in cylindrical coordinate basis,

$$\vec{W}(r,\theta) = \hat{\theta}W(r)$$

$$\phi(r,\theta) = \phi(r)e^{in\theta} \tag{28}$$

with,

$$W(r) = \frac{n|q|}{4\pi r}(1 - X(r)).$$

With the eq.s (28) we find that,

$$\nabla\times\vec{W} = \hat{z}\frac{n|q|}{4\pi r}X'(r). \tag{29}$$

which may be thought of electric constituent of generalized field. With these simplified substitutions, it is interesting to see that the integer 'n' in eq. (28) and eq. (29) turns out to be number of flux quanta contained in the vortex. With these ansatz the static equations of motion can be written in the following form,

$$X''(r)=\frac{X(r)}{r}-2\left(\frac{4\pi}{|q|}\right)^2\phi X(r)=0 \tag{30}$$

$$\phi''(r)+\frac{\phi'(r)}{r}-\frac{n^2X^2(r)}{r^2}-6\left(\frac{2\sqrt{\pi}}{|q|}\right)^4\phi(r)(\phi^2-v^2) \tag{31}$$

For the present semi-quantitative analysis, instead of direct solutions we follow the variational approach for the solution of the equations of motion. Notwithstanding, the consistencies of these equations of motion impose the following boundary conditions on the functions $X(r)$ and $\phi(r)$ in the limit of r approaching to zero.

$$X(r)=1-\frac{r^2}{\lambda^2}$$

$$\phi(r)=Ar^n \tag{32}$$

With $X(\infty)=0,\phi(\infty)=v$. The energy per unit length of the static solution may be given as follow;

$$E=4\pi\int_0^\infty rdr\left\{\left(\frac{n}{2r}\right)^2\left(\frac{|q|}{4\pi}\right)^2(X'(r))^2+\frac{1}{2}\left(\frac{n}{r}\right)^2X^2(r)\phi^2(r)+\frac{1}{2}(\phi'(r))^2+\frac{3}{2}\left(\frac{2\sqrt{\pi}}{|q|}\right)^4\left(\phi^2(r)-\right.\right. \tag{33}$$

The test functions $X(r)$ and $\phi(r)$ must be consistent with the boundary conditions in eq. (32) and flux quantization condition (X(0) = 1). Such discussions lead to the following general form for these functions, in a limiting case with respect to the conditions on 'r';

$$X(r)=\begin{cases}1-\dfrac{r^2}{\lambda^2}, r\ \mathrm{p}\ \lambda\\ 0, r\ \mathrm{f}\ \lambda\end{cases}$$

$$\phi(r)=\begin{cases}v\left(\dfrac{r}{\varsigma}\right)^n, r\ \mathrm{p}\ \varsigma\\ \varsigma, r\ \mathrm{f}\ \varsigma\end{cases} \tag{34}$$

A comparison of these functions to Ginzburg-Landau theory supports our parallel with superconductivity. Obviously, in eq. (34) the parameter ς is something like London penetration depth giving the distance over which electric flux or magnetic flux extends in dyonic superconductor. Similarly, the parameter λ is something like coherence length

over which the dyonic superconducting state is established. Thus, it is clear that any function with ansatz eq (34) will minimize the static energy density functional eq.(33). The interesting thing which comes out is that these solutions are independent of coupling and hence are independent of type of flux confinement which makes them suitable to discuss generalized Meissner effect in present theory. However, a more rigorous and actual solution may be obtained by minimizing the action with respect to λ and ς which in term will be able to give true expression for λ and ς (from numerical point of view), and hence the vortex properties. This statement in superconductivity is the differentiation between type I and type II superconductors, which may further be distinctly established by calculating the energy functional, for both of them, for different relations on λ and ς. Thus, the analogy with type of medium and corresponding estimation of masses of scalar and vector modes and resulting mass ratio, as RCD mass scale parameter, may play a crucial role in deciding the type of model, bag or string, for hadrons in QCD and vice-versa. The detailed calculations are under progress and will be communicated soon.

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