1. INTRODUCTION

1.1. Food as a vital resource

Nutrition is one of mankind's greatest benefits on earth and its promotion deserves the utmost priority. Food in the stomach is like fuel in machines. Hunger is defined mainly in terms of calorific intake, whether people consume 1710 to 1960 kilo calories (Kcal) needed each day to meet the basic requirements for a healthy and active life. The main reason for hunger is poverty. People go hungry because they lack the means to procure or purchase food. Every state in this globe has an obligation to ensure at the very least that people do not starve. As such this is intrinsically linked to the right to live.

In terms of numbers, there are more chronically hungry people in Asia, but a higher proportion of the population is undernourished in Sub-saharan Africa. Eighteen of the 23 countries facing the most severe problems are Africa, Afghanistan, Bangladesh, Haiti, Mongolia and North Korea. A total of 792 million in developing countries remain chronically hungry. Around three-quarters of them live in rural areas (FAO, 2000).

1.2 World Food security

In 50 years, when the earth's population reaches ten billion, the biggest challenge of this planet will be what we eat? Rather than where we sit?

The United Nations' Food and Agriculture Organization (FAO) which had held the 194 nation five-day summit, during 13-17 November, 1996 in Rome (www.fao.org) said that the world will have to produce 75% more food in the next
30 years to feed three billion more people as the population jumps from 5 to 7 billion to 8.7 billion by 2030. (UN, 1996). By 2050, a staggering 9.3 billion is predicted (Appendix 1) to find a way of farming which is both sustainable and productive.

In the past, most governments and international institutions advocated a large-scale, technological approach to agriculture, while non-governmental organisations favoured smaller-scale methods using fewer chemicals. A healthy agriculture depends on an integrated agricultural system, not just on one method of farming. According to M.S.Swaminathan (2002), visionary striving for food revolution in India pointed out three major dimensions for food security – availability of food, access to food and absorption of food into the body. He asserted that Agriculture is not just a food producing machine but is the backbone of the livelihood security system. A.P.J. Abdul Kalam and Y.S.Rajan (1998) have examined the strengths and weaknesses of India and offered have a vision of how India can be among the world’s first five economic powers in the next twenty years.

1.3. Food for all – threats ahead

Today, a total of 792 million people in developing countries remain chronically hungry. Around three-quarters live in rural areas, many come from countries where there is conflict and more than 60 per cent are women. There are more chronically hungry people in Asia, but 18 of the 23 countries facing the most severe problems are African. Seventy per cent of Africans work in agriculture in some capacity. Aid to African agriculture has fallen by 40 per cent since 1980. One per cent increase in crop yields reduces the number of people living on less than $1 a day by between 0.6 percent and 1.2 per cent (FAO, 2000).
The world's arable farm land is close to maximum use. Just 11% of the world's soils can be farmed without treatment (FAO, 2000). The planet is rapidly exhausting its supply of tillable soil posing a threat to agriculture. Loss of fertility is a less visible but equally serious problem. Sometimes it is caused by intensive modern agriculture using high yield varieties in monocultures, machinery, and the indiscriminate application of agrochemicals. “These can be held responsible at least in part for the yield plateaus and declines now observed in farmers' fields where high-input agriculture had been previously successful”. Restoring and maintaining soil fertility is crucial for food output. But soil conservation practices “are often difficult to demonstrate and validate and they are often labour-intensive, and their impact is less visible as they result merely in maintaining or slowly improving yields and therefore they tend to be neglected by the farmer for more immediate economic returns”. Thus it is clear that conventional production through the land resources are decreasing due to reduction in arable land, reduction in soil fertility, poor techniques, illiteracy to utilize the advanced methodologies and more through changes in habits and habitats.

1.4. Promising alternate habitats:

In a three-dimensional habitat, aquatic crops are better feed converters than land-based crops (BOSTID, 1979; Raj 1994). Water is approximately 800 times more dense than air. This single physical characteristic has a more profound effect on the nature of aquatic ecosystems than any other. The extreme density of water (compared to air) means that relatively large organisms and particles can float in water with little, if any, energy expended. This has allowed for the development of an entire
community of organisms – plankton. No other community exists like it. The presence of plankton has resulted in the concomitant development of a diverse and abundant array of filter-feeding organisms. This type of feeding mechanism is not found in terrestrial ecosystems. Sessility can occur because the ocean’s waters are perpetually in motion. Filter feeders save energy by staying in one position and catching food as it passes by. A sessile mode of existence is not possible for land animals because a plankton-like community does not exist in air to nourish such an assemblage as it does in the sea. This is an outcome of the ability of water to support (literally) a floating, plankton community.

Approximately 1.5 million different kinds of living organisms currently co-exists on earth (Raven et al., 1992). A large percentage of these live in aquatic environments, although the bulk of living species are represented by terrestrial insects. Amongst aquatic (freshwater/marine) living species, micro and macro plant forms have a photosynthetic machine. Apart from edible macroalgae, Unicellular / multi-cellular are noteworthy for their bio diversity in south Tamil Nadu.

1.5 Micro Algae

Algae have evolved and survived on earth for three and a half billion years. They create 90 percent of our oxygen and use up fewer of the planet’s resources than any other living organism. Approximately 40,000 identified species of more than algae exist on earth (Raven et al., 1992). These range from single-celled organisms to multi cellular seaweed, plankton, and kelp. New species are being identified at a rate of about one per week. However, unlike the bacteria (ca. 2500 known species) or the fungi (ca. 77,000 known species), algae have
been virtually unexplored with respect to the production of useful products.

Intense efforts have been made in the developing countries to final alternate, new and unconventional protein sources. The idea of utilizing microbial proteins from bacteria, yeasts, fungi and algae was considered as a distinct possibility for meeting atleast partially the protein shortages. Envisaging the increasing world population it can be expected that the population it can be expected that the food needs in the coming decades cannot be covered by conventional agriculture.

As a freshwater food source, algae have been used by man for thousands of years. Ancient Chinese herbalists recommended taking the organism to fight vitamin deficiencies. Algae were also harvested and consumed in some European communities, by the Mayans and Aztecs in the New World, and, to this day, by the Kanembu natives living near Lake Johann in Chad, Africa, who eat algal cakes to supplement their daily protein intake (Shelef & Soeder, 1980).

The characteristics of microalgae as an efficient photosynthetic machine for converting solar energy into biomass have proclaimed it as a new weapon to fight the world-wide deficiency for proteinaceous matter (Plate 1a). This is mainly because of their high reproduction rates, adaptability to various environmental conditions and their omnipresence in any aquatic environment where nutrients, carbon source and irradiance are sufficiently present together with the proper range of temperatures.

In recent years, the technological developments in the large scale production of algae all over the world have been very significant. The setbacks have been primarily in the transfer of technology from the capital and energy intensive systems of
developed countries to a low-level technology appropriate for the developing countries.

1.6 Search for native microalgae resources

The native study area Kanyakumari District, is the smallest in the State (with an area of 1684 km\(^2\)). The district lies between 77.0\(^0\) and 77.36\(^0\) of the eastern longitude and 8.03\(^0\) and 8.35\(^0\) of the northern latitude having the best tropical climate. The district has a favourable agroclimatic condition, which favours the growth of number of food crops. Both the south-west monsoon and the north-east monsoon greatly influence the climate of the region with an average rainfall of 1465mm per year, according to the agricultural statistics (1988). The district has 2748 freshwater ponds along with total irrigated area exceeding 55,000 hectares of land.

This area looks like a piece of sponge at the end of peninsular India. The innumerable tanks and the water drenched fields favour the growth of interesting algae. Based on the topography and rainfall, the district is divided into two agro-ecological situations i.e. Hills and plains. The hilly region of Kanyakumari district lies 20 to 35 km away from the town and spreads from the east to the west. The topography, climatic conditions of soil and crops in the region are different from those occurring in the plains of this district. The topography is undulating and the region consists of plateau, hills hillocks and low lying areas. The low lying lands remain flooded from May June to February - March and are fit for the cultivation of Paddy only. The plain extend from the coast to about 20 km in the western side and 35 km in the eastern side.
In the plains the following types of fresh water bodies are encountered (1) Lakes (2) Reservoirs (3) Ponds (4) Rainwater puddles (5) Open well (6) Rock pools (7) Paddy Field (8) Temple tanks (9) Streams (10) River (11) Wet lands and (12) Swamps. Some of them many be permanent and others temporary.

With a total 2748 existing ponds in this area, ranging from 0.002 – 250 ha, 1640 are rain-fed, 987 channel-fed and 301 spring-fed. Raj (1989) has classified the fresh water ponds into 7 types on the basis of utility, purity of water and period of availability. They were village, drainage, sewage, irrigation, ephemeral, percolation and temple ponds. Raj and Kitto (1990) surveyed the microalgae for biomonitoring indicators in the fresh water ponds of South Tamilnadu.

Kavitha (2000) characterised 138 genera of microalgae of which 51 were Chlorophycean, 26 Cyanophycean and 35 Bacillariophycean. She also reported a protein content of 650 µg/gm fresh weight in Chlorella.

Characterization of the different phytoplanktons from the fresh water bodies of Kanyakumari District with respect to SCP candidates was felt wanting.

1.7 What is PUFA/Carotenoid nutrition?

Gamma-linolenic acid (GLA) is an essential fatty acid that comes primarily from plant-based oils. Linoleic acid, an omega-6 fatty acid, which is found in cooking oils and processed foods, is converted into GLA in the body. GLA is then broken down to arachidonic acid (AA) and/or another substance called dihomo gamma-linolenic acid (DGLA). AA can also be consumed directly from meat. GLA supplements are available in the form of evening primrose oil, black
currant seed oil, and borage oil, which also provide linoleic acid. Fungal oils, human milk contain GLA. Microalgae do contain GLA in sufficient quantities. Gamma-linolenic acid (GLA) is an essential fatty acid (EFA) in the omega-6 family that is found primarily in plant-based oils. EFAs are essential to human health but cannot be made in the body. For this reason, they must be obtained from food. EFAs are needed for normal brain function, growth and development, bone health, stimulation of skin and hair growth, regulation of metabolism, and maintenance of reproductive processes. People who have diabetes are less able than healthy individuals to convert linoleic acid to GLA.

Aging also appears to reduce conversion of linoleic acid to GLA. Rheumatoid arthritis. GLA may reduce inflammation. Diabetes. GLA supplementation assists nerve function and helps prevent nerve damage caused by diabetes. In cancer, GLA may help suppress tumor growth and spread of cancer, particularly in colon cancer, breast cancer, and melanoma. In heart disease, GLA may also help prevent heart disease by inhibiting plaque formation, dilating blood vessels, and lowering blood pressure. Eyes. GLA is beneficial in Sjögren's syndrome and may be useful in other dry eye conditions. GLA supplements may help the symptoms of many conditions that occur with aging. It can also reduce the symptoms of alcoholism, Atopic Dermatitis, and Osteoporosis. (Tsai \textit{et. al.}, 1998; Fan and Chapkin 1998; Kruger \textit{et.al.}, 1998; Kenny \textit{et.al.}, 2000).

Carotenoids are required for most forms of life, but few organisms are able to synthesize them. Carotenoids have an almost universal distribution occurring in the most primitive bacteria (Archebacteria) and the prokaryotic bluegreen algae (Schizophyceae) up to the highly developed flowering plants
(Angiospermae). The biological function of carotenoids in animals include light perception, vitamin A activity, pigment transfer, Chemo-reception, reduction of Cholesterol, intracellular oxygen supply, calcium transport, cancer prevention, Immune response and wound healing etc. (Latscha, 1990b).

1.8 Can we efficiently cultivate cheap SCP?

Microalgae can be grown in both open-culture systems such as ponds, lakes and raceways, or in highly controlled closed culture systems, similar to those used in commercial fermentation processes. Certain microalgae are very suitable for open system culture where the environmental conditions are very specific, such as high salt or high alkaline ponds lakes or lagoons. The extreme nature of this environment severely limits the growth of competitive species, although other types of organisms may contaminate the culture. The advantages of such system is that they are generally a low investment, very cost-effective and easy to manage. Closed-culture systems, on the other hand, require significantly higher investments and operating costs, but are independent of all variations in agro-climatic conditions and are very closely controlled for optimal performance and quality.

Open-culture systems take advantage of natural sunlight and are totally subject to the vagaries of weather unless some form of shading system is utilized. Highly controlled closed systems use photobioreactors for phototropic culture and conventional fermenters for heterotropic growth. The range of sophistication available for the two systems is very great, as is the associated investment. As an example, photobioreactor can vary from simple, externally-illuminated glass jars to highly engineered fermenters saturated with light transmitting fibre optic filaments to ensure even lighting to all cell and fused with specific gas mixtures to control metabolism and growth.
rates. Certain new photobioreactors incorporate thin tubular designs for greater cost-effectiveness and commercial efficiency.

1.9 Novel Photo-Bioreactors

Two major systems have so far been used for the cultivation of microalgae - cultivation in open systems (outdoor ponds) and cultivation in closed systems (tubes, fences, coils). Outdoor ponds have relatively low construction cost. However it is technically difficult to monitor and control cultural and environmental conditions in an open systems. Mono culture is particularly difficult.

One approach to the solution of these problems is the use of the closed systems, which offers a greater flexibility in the choice of the organisms under study and allows better control of cell physiology and growth, making it more suitable for fundamental study. Most industrial algal reactors are designed with open pond technology. Considerable progress have been made in developing algal biotechnology to maintain stable mono algal culture in large scale closed systems. Tubular photobioreactor (Pirt et al., 1983) and thin panels (Tredici et al., 1991) are the most widely investigated closed system for photosynthetic cell cultivation because they have high surface area to volume ratios. However many economic and technological problem in the scale up of such photobioreactor result from the need to keep the surface area to volume high, limiting tube diameters and panel depths.

Solar light energy is one of the most abundant natural resources on earth and development of technologies for its efficient utilization will go a long way in solving the world's
resource, energy and environmental problems. This will serve as the useful eco-technology in he coming years for microalgal culture.

1.9.1. Key cultivation issues

The major issue in the commercial cultivation of photoautotrophic algae is the sustained trapping of solar energy at as high an efficiency as possible throughout the year; the more efficiently, this can be accomplished, the sounder the economic basis for this promising biotechnology would become. Converting solar irradiance to chemical energy at 2% efficiency on a year-round basis which is definitely theoretically possible (Hall et al., 1987), implies annual net yields averaging between $30-40$ g dry matter m$^{-2}$ d$^{-1}$ or $140$ t dry matter ha$^{-1}$ yr$^{-1}$. From an industrial standpoint, it is very important to achieve significant increase in production rates because, this alone will reduce production costs to an extent.

With increased irradiance, up to light saturation, the rate of photosynthesis increases. But the efficiency by which light is converted into chemical bond increases (Richmond 1992). Viewing micro aquaculture from this angle sharpens the focus on the scientific challenge to develop the species, the culturing devices and the management protocol which would permit maximal exploitation of the super saturating photon flux densities (PFD) existing outdoors for a significant part of the day.

To produce photosynthetic chemical from micro algae at competitive prices, efficient large scale photobioreactor must be designed. Two prototype photobioreactors have been designed and used for the large scale cultivation of photosynthetic cells of *Chlorella* in which easy scale up is the primary design criterion-Bioheliotron and Bioroof photosystems. In most flat plate reactors,
scale-up is more likely to proceed by just increasing the number of reactor units rather than significantly increasing the s/v ratio of the master photostage unit. Free solar irradiance establishes the Bioroof and Bioheliotron as two helioscreen ecotech bioreactors for the future.

1.10 Bioconversion

Micro-organisms such as yeast, bacteria, fungi, or algae are the single-cell proteins used for most bioconversion of useful single cell biomass to make food or feed. According to Waslien et al., 1970, observations made on human subjects fed algae protein (10-500 g / day) gave disagreeable flavour and gastrointestinal discomforts. A crucial question is; What is the nutritional value of the final product of the bioconversion process? The diversity of SCP biomass resource is so vast and complex in terms of size biochemistry and nutrition requirements. It is therefore necessary to evolve procedures for deciding the best type and mode of biomass utilization. Of recent, Gouveia et al., 1999 employed Chlorella vulgaris and Haematococcus pluvialis for animal feed. Chlorella could be easily and efficiently bioconverted into rotifer biomass, the primary livefeed for the aquaculture of fish / shellfish; larviculture of polychaetes (Pereinereis nuntia), Paramecium, Copepods etc.

1.10.1. Algae in animal feeds

Hundley and Ing (1956) demonstrated the feasibility of improving wheat flour and bread by the addition of Chlorella and Scenedesmus. The largest number of feeding trials have been conducted on poultry and it can be assumed that the incorporation of algae into poultry rations offers the most promising prospect for commercial utilization of algae in animal feeding. On the effect of algae in feed on the performance of
laying hens, no difference was found in egg production rate, egg weight and food conversion efficiency between controls and birds receiving up to 12% sewage-grown Chlorella (Lipstein et al., 1980), in contrast to the results obtained with broilers, the algae serve as almost the sole source of protein in layer rations.

1.11. Objectives of the present study

The objectives of the present study are summarised herein:

1. Enumeration of fresh water chlorophycean species in the fresh water bodies of south Tamil Nadu and estimation of total dry protein per unit volume of natural surface waters of ponds.

2. Screening a native microalgal strains for PUFAs; and compare with exotic easily cultivable microalgae and carotenoids.

3. Conduct an extensive review on the photobioreactor technologies advanced round the globe in the last century and establish an ecotech bioreactor.

4. Designing efficient photobioreactor: optimizing the light path and the resulting light dark cycles, aiming for maximal utilization of high light intensity for photosynthetic productivity of photoautotrophic mass.

5. Economic bioconversion applications of fresh water microalgae (Chlorella) for intensive rotifer culture systems in a technically improvised Cyclobiostat cultivar.

6. To review the realistic potential of utilizing the algae as a source of protein in animal / poultry feed rations and indirectly in aquaculture.

7. Possible cheap production of useful bioactive compounds using the novel device.