Sustainable initiative of using cyanobacteria as a liquid fertilizer for hydroponic cultivation: A waste to wealth utilization

Sharon Maria Jacob, *R. Ranjith Kumar

Department of Botany, Madras Christian College (Autonomous), Chennai, Tamil Nadu, India, Pin-600 059.

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**Corresponding author.*
E-mail address: ranjithkumar@mcc.edu.in

Abstract

Modern cultivation of vegetables and crops are profoundly dependent on the fertilizers for a higher yield, but currently the high usage of chemically synthesized based fertilizers and inorganic chemicals could cause several threats to human health including the environment. Therefore, applied science researchers turn to concentrate more, on the exploitation of microorganisms like algae, fungi, bacteria, thus can be a more simple, fast and eco-friendly sustainable approach in the field of vegetable and crop cultivation. Among them, cyanobacteria (blue green algae (BGA)), is an interesting group of microorganisms that also have numerous application in advanced biotechnology potential for current crop cultivation methods, through enhancement of nutrient availability, maintaining the organic carbon and can live in association with higher plants, because generally microbes are a biotechnological tool box. Currently, the application of cyanobacteria biomass production and its use as a liquid fertilizer for hydroponic cultivation is a feasible option, thus, empower basically the plant growth and more yields. This cyanobacteria liquid fertilizer allows and stimulates the microbiota in liquid fertilizer medium, which could enhance the nitrogen fixation. Apart from this, cyanobacteria and other group of algae basically produce various bioactive compounds, especially the crop related chemicals, such as growth hormones, enzymes, polysaccharides and antibiotic agents, in liquid fertilizer/soil. However, the hurdles mainly to develop commercialized biofertilizers needs to be addressed in the field of large-scale investigations, along with minimizing the cost of production in an effective manner, thus, could be a win-win situation in the field of algal liquid fertilizer production as an important sustainable eco-friendly resource. This review article focuses on the research achievements on eco-friendly, sustainable microalgae and cyanobacteria-based plant biofertilizers and bio-stimulants, in the hydroponic vegetable (*Mentha*) cultivation.

Keywords: Cyanobacteria; *Spirulina*; Liquid fertilizer; Hydroponics; Crop cultivation; *Mentha.*

Abbreviations: /, Or; BGA, Blue Green Algae; c., Circa; EPS, Exopolysaccharides; FAO, Food and Agriculture Organization; GA_3, Gibberellic acid; GDP, Gross Domestic Product; GLA, Gamma-Linolenic Acid; GRAS, Generally Recognized As Safe; i.e., That is; IAA, Indole-3-acetic acid; $m^{-2}s^{-1}$, Square meter per second; MLFINM, Microalgae Liquid Fertilizer Integrated Nutrient Management; MT, Metric tonne(s); NADPH, Nicotinamide Adenine Dinucleotide Phosphate Hydrogen; NFT, Nutrient Film Technique; nm, Nanometre(s); PAR, Photosynthetic active radiation; PO, Peppermint Oil; PUFAs, Polyunsaturated fatty acids; t/ha^{-1}, Tonne per hectare; WHO, World Health Organization; wt/wt, Weight by weight

1. Introduction

The present era farmers are concentrating more on using chemical fertilizers to increase the yield of the plants and to keep the pests away. This causes a serious threat to the health of the appliers (farmers), consumers (us), quality of the soil and degradation of environment *inter alia*. Hence, alternative ways have to be adopted by using chemical free biofertilizers, which are not hazardous to the environment, for a sustainable and eco-friendly approach. These biofertilizers contain microorganisms such as fungi, microalgae etc., which can have a symbiotic relationship with the host plants that helps to increase the size of the plants and leaves, soil fertility, water holding capacity, protection from pests and also provides the essential nutrients to the plants (Setboonsarng and Gilman, 1998; Richardson, 2001; Parr et al., 2002; Vessey, 2003; Kanimozhi and Panneerselvam, 2010; Carvajal-Muñoz and Carmona-Garcia, 2012; Reddy and Saravanan, 2013; Bhattacharjee and Dey, 2014; Srivastava and Mishra, 2014)

Microalgae are microscopic organisms that are present in all types of environment such as drought, salt, oil and metal contaminated sites and possess the ability to grow even under stress conditions (Nigam and Singh, 2011; Rizwan et al., 2018). They are present in abundance and diverse quantity, hence, they are an unexploited source for several important products, which are used in pharmaceuticals, food, pigments, feed, biofertilizer and cosmetic industries (Lee, 1997; Spolaore et al., 2006; Mobin and Alam, 2017). Microalgae are also used to assess the environment and the amount of pollution in it. It is also used in cleaning the environment by usage in phycoremediation, i.e. it helps to degrade oil and petroleum. Therefore, this helps to recover the fertility of sites which are oil and petroleum contaminated (Apt and Behrens, 1999; Olguín, 2003; Prajapati et al., 2013).

The very basic and major requirement for the growth of the microalgae are water, sunlight and carbon (Christenson and Sims, 2011; Nigam and Singh, 2011). They absorb carbon dioxide (CO_2) from the air and by using the solar energy they produce organic compounds (Richmond, 2004; Prasanna et al., 2012; Esteves-Ferreira et al., 2017). In general, the production of 1 kg of microalgal biomass requires 1.8 kg of CO_2 (Slade and Bauen, 2013; Adamczyk et al., 2016). During photosynthesis, these microalgae release oxygen which makes up about 50% of the atmospheric oxygen (Singh et al., 2011). Microalgae also produce polyunsaturated fatty acids (PUFAs) which helps to cure chronic inflammatory diseases, hence is very essential in human health and nutrition (Robertson et al., 2015; Wang et al., 2015a; Chew et al., 2017). Microalgae does not compete with food crops for land and hence, is very useful for the extraction of high value products (Baicha et al., 2016; Renuka et al., 2018). Many studies have reported that microalgae can be used as biofertilizers and soil conditioners due to their promising values (Priyadarshani and Rath, 2012; Sharma et al., 2012).

Microalgae can be cultivated, in all types of medium and environment, such as agricultural, industrial, sewage, municipal wastewater (Woertz et al., 2009; Ajayan et al., 2011; Rawat et al., 2011; Abou-Shanab et al., 2012; Wu et al., 2012). They help in reclaiming and recovering the water and the nutrients in the water for later application. During the treatment of waste water, some byproducts are formed. It can be used as algal biofertilizers, which makes them a renewable source. They also help in the reduction of greenhouse gases (Wang et al., 2015b; Win et al., 2018).

Cyanobacteria are effectively used as biofertilizers due to their ability to fix nitrogen and release oxygen, short reproduction time, water holding capacity, contain plant growth hormones, secondary metabolites, grow in all types of environment etc. (Chaturvedi and Kumar, 2016; Singh et al., 2016; Kheirfam et al., 2017) (Fig. 1). Biofertilizers not only help in achieving higher yields, maintaining soil health and crop productivity but also help in maintaining a clean and green environment (Pathak and Kumar, 2016).

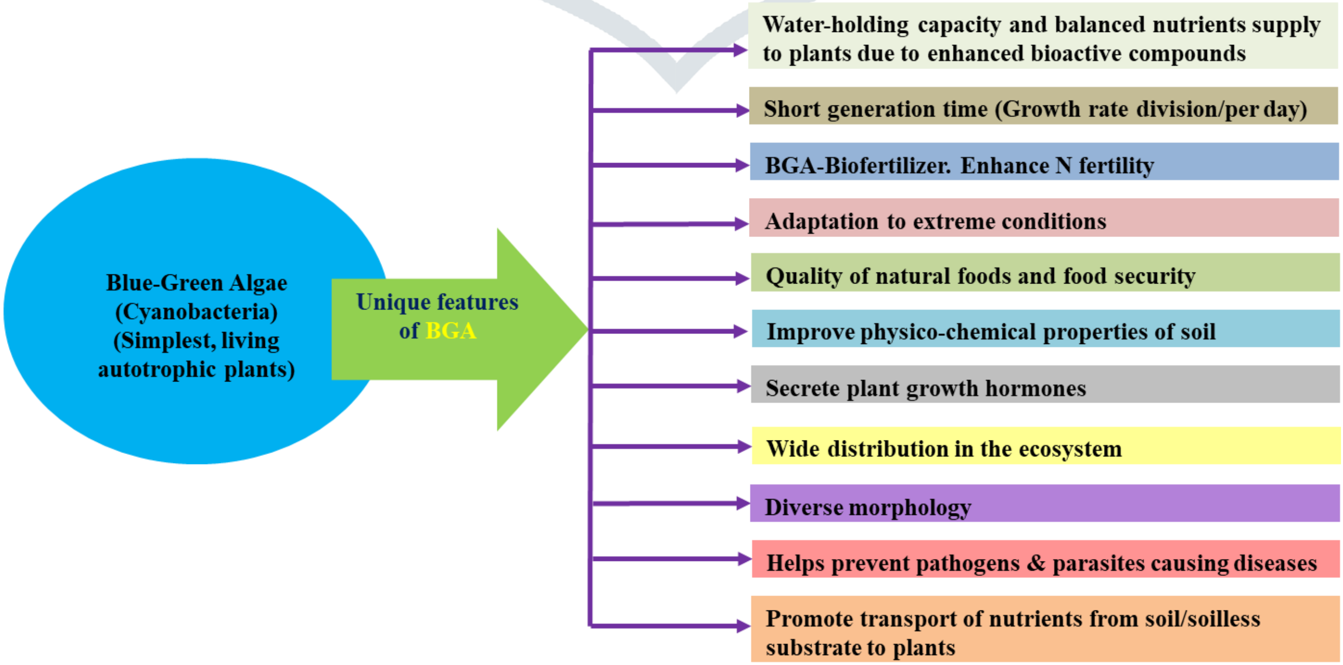

Fig. 1. Unique features of Blue green algae (BGA) used as a biofertilizer. Huge potential of some of the blue green algae; morphologically they are free living, unicellular, filamentous and multicellular organisms that have the capacity to fix atmospheric nitrogen, enhance soil fertility and retain moisture, along with multiplying useful microbiota which improves soil fertility and also prevents pathogens including nematodes etc. Therefore, there is an urge to utilize BGA in the agriculture industry as a biofertilizer for the cultivation of rice and other field crops inter alia.

Hydroponics is a science of soilless cultivation. This cultivation can be done in places with less space. It is a pesticide free cultivation and hence is organic. Application into this system does not require much knowledge on agriculture. Minimal water is used and the nutrient water can be reused. Most types of fruits, vegetables and grains such as strawberries, melons, carrots, tomatoes, eggplants, beans, lettuce, parsley, leeks, celery etc., can be grown in this cultivation. As the water availability is becoming scarcer every day with the increasing population, hydroponics is the best system for both home and commercial cultivation (Soilless Gardening - India Magazine, 2013).

In India, due to the high population rate, at least 20% of the whole population, especially the people residing in the villages are starving due to lack of food. States of Andhra Pradesh, Punjab, Delhi, Rajasthan and West Bengal are hydroponically active. Hydroponics in India was brought in during the year 1946 by the then government of Bengal who brought James Sholto Douglas, a British researcher into the country. Douglas's main aim was to develop hydroponics in India and to present it to the people in a cost-effective and simple method of soilless cultivation of crops. An experimental farm was set up in the Darjeeling district where crates were filled with rock chips from nearby hills. This helped to prove that the vegetables can be grown even in harsh conditions without soil and that the materials used as containers do not affect the growth of the plants. Douglas concluded that, materials which do not cling tightly around the roots of the plants, hence, giving them proper aeration, space and retains moisture can be used as a medium. The first modern hydroponic system in the world was built by Douglas which is still prevailing in India (Soilless Gardening - India Magazine, 2013).

Mentha belongs to the family Lamiaceae whose plants are aromatic in nature. The family consists of plants growing up to 100 cm in height. Specific plants of this family are of great economic importance due to the aromatic compounds and essential oils present in them due to which they are cultivated in enormous quantity throughout the world. *Mentha* commonly called as mint is one of the most commonly used flavours after vanilla and citrus (Straumite et al., 2015). The essential oils have the presence of antimicrobial, antioxidant properties and hence is being used to cure many diseases. The leaves are often directly consumed as food. Currently more than 80% of the world population including Europe, Middle East and other advanced countries are using herbal and traditional plants as food and to cure ailments (Straumite et al., 2015; Loolaie et al., 2017).

The aim of this research review article, is to be a part of solution provider in the field of hydroponic cultivation, using blue green algae as a liquid fertilizer in terms of, hydroponic application of cyanobacteria, microalgae utilization, nitrogen fixation of cyanobacteria, sustainable energy from microalgae, reclamation of degraded habitats, importance of *Spirulina* as a food and its other valued products, dual role of waste water treatment and cyanobacteria (BGA) biomass production for biofertilizer preparation (liquid), impact of cyanobacteria in crop cultivation, merits of cyanobacteria liquid fertilizer for hydroponic cultivation, current status of hydroponic cultivation in India and other countries, *Mentha* (oil) production in the world market value as well as the application on *Mentha* oil, biological benefits, *Mentha* in hydroponic cultivation are discussed in detail.

2. Cyanobacteria

One of the oldest and successful form, i.e. cyanobacteria, help in initiating the primary succession of a new area, as they are usually the first phototrophic colonizing organisms (Elster and Svoboda, 1995; Kvíderová et al., 2019). Cyanobacteria can be small or large sized and they are unicellular, filamentous or colonial. Cyanobacteria are known to be over 3.5 billion years old and are considered very important (Pagels et al., 2019). Cyanobacteria are present in all kinds of environmental conditions, ranging from the polar region to the thermal springs. Their photoautotrophic way of life helps them to adapt and colonize in different habitats. They grow best in alkaline pH ranging from 6.8-8 (Solheim et al., 1996; Thajuddin and Subramanian, 2005; Singh et al., 2014; Chakraborty et al., 2019). They require a limited amount of nutrients for their growth, which includes calcium, potassium, phosphorus, magnesium etc. (Rippka et al., 1979; Christenson and Sims, 2011; Nigam and Singh, 2011). For commercial and large scale production, cultivation of cyanobacteria in raceway ponds gives higher yield due to their higher efficiency, low capital investment and low power consumption potentials (Becker, 2007; Christenson and Sims, 2011; Prajapati et al., 2013; Chakraborty et al., 2019). This harvested biomass can be used as feed, biofertilizer etc. (Satpal and Khambete, 2016; Win et al., 2018).

2.1. Oxygen producing and Nitrogen fixing properties of cyanobacteria

Cyanobacteria are one of the major producers of oxygen and it fixes atmospheric nitrogen on the earth (Field et al., 1998; Kumar et al., 2019). Cyanobacteria are photoautotrophic and prokaryotic algae. Due to their high oxygen evolution rate, they contribute almost 30%-40% of the total atmospheric oxygen, hence, they help in making the earth oxygenic (Berman-Frank et al., 2003; Thajuddin and Subramanian, 2005; Stal, 2009; Singh et al., 2019). Thus, cyanobacteria are key primary producers and play a major role in influencing the energy flow and nutrient cycling of the earth. As they can fix atmospheric nitrogen, they are a major part of the microbial community (Jordan et al., 1978; Davey and Marchant, 1983; Lennihan et al., 1994; Solheim et al., 1996; Elster, 2002). Cyanobacteria generate, the reducing power and energy by trapping the 400 nm to 700 nm photosynthetic active radiation (PAR) and fix CO_2 (Field et al., 1998; Esteves-Ferreira et al., 2017).

2.2. Energy from cyanobacteria

Cyanobacteria are unique in nature, as they are the only prokaryotes that have the ability to split the water molecules into hydrogen, by using photons (energy from the sunlight) and produce molecular oxygen and NADPH (Gonçalves et al., 2019). Cyanobacteria harvest a spectrum of light through photosystem I and II and they also contain phycobilisomes. Phycobilisomes are water dissolving coloured protein complexes. They are the primary light absorbers and then transfer light to the two photosystems. Cyanobacteria contain high amount of proteins, carbohydrates, amino acids, lipids and pigments (Pignolet et al., 2013; Ursu et al., 2014). Phycobilisomes are made up of 50% of proteins. These phycobilisomes are chromophores which are capable of capturing light (Bryant et al., 1979; MacColl, 1998; Hirata et al., 2000; Pagels et al., 2019). Cyanobacteria, produce phycobiliproteins, which helps to harvest light energy during photosynthesis, which is then passed onto the chlorophyll. These proteins are used as fluorophores and also in pharmaceutical industries as they contain antioxidant and anticancer activities (Gantt and Conti, 1966; Rijgersberg and Amesz, 1980; Belford et al., 1983; Kuddus et al., 2013; Yaakob et al., 2014; Khanra et al., 2018).

Phycobiliproteins are usually extracted from cyanobacteria by freezing them at -20°C for several hours, and thawing them at room temperature (Calcott and MacLeod, 1975; Li et al., 2019). Out of all the cyanobacteria, *Spirulina* has the highest amount of proteins (60-70%) and hence, is highly recommended (Boiko et al., 1963; Habib and Parvin, 2008; Wells et al., 2016; Khanra et al., 2018). The so-called phycobilisomes extracted from *Spirulina*, are said to have a balanced amino acid composition (Cepoi, 2019; Li et al., 2019). As cyanobacteria have a small genome size, they are easier to manipulate to produce various compounds, to be used in different fields such as food, feed, pharmaceuticals, cosmetics and biofertilizers (Lee, 1997; Spolaore et al., 2006; Mobin and Alam, 2017; Sun et al., 2018; Gonçalves et al., 2019).

3. Algal biofertilizer: Applications

Biofertilizers are eco-friendly and are available in low cost. They help in recycling of nutrients in the soil, as well as in mobilization and mineralization. Cyanobacteria are the most commonly used biofertilizers and soil conditioners (Chaudhary, 2010; Renuka et al., 2018). Cyanobacteria based biofilms as biofertilizers, are a design thinking on basic applied concept because cyanobacteria have the presence of specialized vegetative cells called heterocyst, which helps to fix the atmospheric nitrogen (Wolk et al., 1994; Mariscal et al., 2007; Kumar et al., 2010). Cyanobacterial biofilms, helps in nitrogen fixation, improves nutrition uptake, improves soil structure and fertility, gives higher yields not only in rice crops but also in vegetables, legumes, wheat, cotton, maize etc. (Karthikeyan et al., 2007; Uddin et al., 2014). They also help in enriching the soil with micro and macro nutrients and their translocation inside plants. This shows that, cyanobacteria can work wonders in any habitat ranging from flooded to terrestrial conditions (Mandal et al., 1999; Karthikeyan et al., 2007; Uddin et al., 2014).

The shelf life of the cyanobacterial biofertilizer can be increased by using paddy straw, as a carrier and packing them in translucent material (Jha and Prasad, 2006). Hori et al. (2013) reported that phytoextracts tobacco (*Nicotiana tabacum*), when used to control cyanobacterial diseases, showed higher disease prevention, when compared to neem. For high germination rate, cyanobacteria are wet dried or air dried in an oven at 35-40°C in 24 hours dark condition (Silva et al., 2007). Biofilms matrix produced by these algae contain polysaccharides which helps in the attachment of the microbes and hence, provide an ideal base for colonization by supplying photosynthates and fixed nitrogen. Due to the presence of this matrix, it can also colonize on rice and wheat roots in hydroponic systems (Wolk et al., 1994; Karthikeyan et al., 2007; Swarnalakshmi et al., 2013). The usage of cyanobacterial biofertilizers can reduce the use of chemical fertilizers, as it prevents the leaching of nutrients, provide better soil fertility and organic carbon, which cannot be achieved by the use of chemical fertilizers.

According to several studies, there are some limitations for the commercial utilization of cyanobacterial biofertilizers in the fields (Win et al., 2018). Chaturvedi and Kumar (2016) stated that, factors such as climate, soil, carrier for algae, biotic and abiotic stress, limits the use of these biofertilizers. Also, areas contaminated with heavy metals, herbicides, pesticides, high salinity, can inhibit the algal effects on crops (He et al., 2013; Yadav et al., 2016). Thus, this sustainable approach helps to maintain the soil fertility and curb the loss of nutrients (Chaudhary, 2010; Swarnalakshmi et al., 2013; Renuka et al., 2018).

3.1. Improving the soil structure: Reclamation of degraded habitats

In a country like India, usar soil are widespread, which is either saline or alkaline in condition (Anand et al., 2015). These kinds of soils are hard and unproductive due to the presence of undesirable salts; hence it cannot support the growth of plants. Desert soil and semiarid soil can be reclaimed by using cyanobacteria as a biofertilizer, as they produce exopolysaccharides (EPS). These EPS help in binding of the soil particles, improve the moisture content and promote the formation of microbial associations, hence making the soil productive (Singh and Singh, 1987; Flaibani et al., 1989; Anand et al., 2015). For example, there was an investigation by Trabelsi et al. (2009) on *Arthrospira platensis*, for the enhanced production of EPS, which found temperatures less than 30°C and continuous light intensities higher than 180 µmol photons m^{-2} s^{-1} enhances the EPS production.

Cyanobacteria are usually deployed for the cultivation of rice as well as other crops including vegetables, legumes, maize, wheat and cotton. These BGA help in enriching the soil fertility, retaining the moisture, slowly releasing macro and micro nutrients and also fix nitrogen in the soil *inter alia*. This renewable role helps in maintaining sustainable yields. These cyanobacterial biofertilizers also promote the translocation of phytohormones to shoot, which in turn leads to the higher growth of the plants (Karthikeyan et al., 2007; Chaudhary, 2010; Srivastava et al., 2014). However, further studies can be carried out, to concentrate more on the physiological role of phytohormones in plants, in a systematic approach.

The usage of cyanobacteria in the rice fields to promote the growth and health of the plant, is very commonly reported, as it fixes atmospheric nitrogen and carbon. It also provides phytohormones and polysaccharides. Their biomass contains 40-60% carbon, 1-4% phosphorous, 50-70% proteins and other essential elements. They are used as bioinoculants, to increase the yield, soil structure and fertility. Due to the colonization of cyanobacteria in the roots, the plants also get protection from plant pathogens, such as fungi, bacteria and nematodes, due to the production of hydrolytic enzymes and biocidal compounds. These enzymes and compounds stop the synthesis of proteins, by disrupting the cytoplasmic membrane, hence killing the pathogen. Commonly used cyanobacteria for biofertilizer production are *Anabaena* spp., *Nostoc* spp., *Spirulina* spp. (Prasanna et al., 2012; Priya et al., 2014).

4. Cyanobacteria: *Spirulina*

Spirulina food was rediscovered by a European scientific mission in ‘Chad’ and is traditionally known as ‘dihe’ (Habib and Parvin, 2008). *Spirulina*, belongs to the family cyanobacteria, also called as blue green microalgae, is filamentous in nature and has high nutritional value and is being used as a food supplement. Being one of the most nutritious food known to man, it is grown all around the world. *Spirulina* spp. has large amount (>50% of the dry weight) of starch and glycogen, which are used as raw materials for ethanol production (Chen et al., 2009; John et al., 2011). *Spirulina* spp. is also known to contain high amounts of vitamins, especially vitamin B12 (Cyanocobalamin) and b-carotene, polyunsaturated fatty acids, proteins and pigments (Jespersen et al., 2005; Nagaoka et al., 2005; Sekar and Chandramohan, 2007).

The pigment phycocyanin, a blue photosynthetic pigment, is extracted commonly from *Spirulina* spp. and is used for cosmetics, provitamins and pigmentation. Phycocyanin has low stability to heat and light (photolytic character), yet it is used instead of gardenia and indigo dye in colouring of jelly, gum, chocolates, ice-creams, fermented milk, soft drinks, milkshakes and cosmetics. It was also reported that phycocyanin from *Spirulina* spp. has inhibitory effect on the growth of human leukemia K562 cells, influenced serum cholesterol concentrations and also acted as a hepatoprotective & anti-inflammatory agent (Liu et al., 2000; Santos et al., 2004; Jespersen et al., 2005; Nagaoka et al., 2005; Sekar and Chandramohan, 2007). *Spirulina* spp. are also available in the form of capsules, tablets and powder. *Spirulina* spp. can be cultivated not only in low-cost culturing systems but also in extreme conditions. Thus, it is easy to cultivate. *Spirulina* spp. can be grown in lakes, ponds, raceway ponds, tubular photobioreactor, flat plate photobioreactor, vertical column photobioreactor etc. According to the World Health Organization (WHO), *Spirulina* is considered as a "super food" because of its high nutritional value.

Spirulina spp. contains 42-63% of protein, 8-14% of carbohydrates and 4-11% lipids (Table 1) (Um and Kim, 2009; Parry Nutraceuticals, 2010; Sydney et al., 2010; Priyadarshani and Rath, 2012). Rafiqul et al. (2005) found that, the optimum temperature, pH and light intensity were 32ºC, pH 9.0, 2500 lux, for growing *Spirulina platensis*, under laboratory conditions. Food and Agriculture Organization (FAO) since 2008, qualifies *Spirulina* as “Generally recognized as safe” (GRAS) for human consumption, since it contains high amount of proteins (c. 60%), iron, vitamins, beta-carotene and fatty acids such as gamma-linolenic acid (GLA). Further it states that *Spirulina* is an ideal food and dietary supplement for the 21st century (Pelizer et al., 2003; GRAS, 2011). Nowadays, *Spirulina* spp. are widely being used as a biofertilizer in various developing and developed nations, due to its nitrogen fixation potential through photosynthesis that makes it one of the excellent biofertilizers. Moreover, *Spirulina* are the world-famous food supplement, which was declared by WHO in the year 1992 and currently, *Spirulina* cultivation is one of the leading thrust area for commercial production in natural ways. The production of bulk quantity of *Spirulina* biofertilizer is under process, to replace minerals in soil as well as adding more necessary minerals in soilless crop cultivation. Hence, the use of various chemical fertilizers needs to be curbed, and we need to find an appropriate combination of nutrient enriched liquid/biofertilizers,which could be a suggestable practise in hydroponic cultivation in the near future. So, increasing the organic crop cultivation and replacing chemical fertilizer, cost of the organic fertilizers needs to be attended more efficiently.

Table 1: Various proximate bioactive chemical compositions of *Spirulina platensis*, adapted and modified from Parry Nutraceuticals (2010).

Essential amino acids (EAA) with three letter code	**g/100g**
Lysine (LYS)	3.0 - 6.0
Leucine (LEU)	3.0 - 5.0
Isoleucine (ILE)	3.0 - 4.0
Phenyl Alanine (PHE)	2.5 - 3.5
Threonine (THR)	1.5 - 3.0
Methionine (MET)	1.0 - 6.0
Valine (VAL)	1.0 - 3.5
Tryptophan (TRP)	1.0 - 2.0
Total EAA	16.0 - 33.0
Non-essential amino acids (NEAA) with three letter code	**g/100g**
Glutamic acid (GLU)	6.0 - 9.0
Alanine (ALA)	4.0 - 5.0
Arginine (ARG)	3.0 - 5.0
Serine (SER)	3.0 - 4.5
Glycine (GLY)	2.0 - 4.0
Proline (PRO)	2.0 - 3.0
Aspartic acid (ASP)	1.5 - 3.0
Tyrosine (TYR)	1.0 - 3.0

Histidine (HIS)	0.5 - 1.5
Cysteine (CYS)	0.5 - 0.75
Total NEAA	23.5 - 38.75
Vitamins	**mg/100g**
Vitamin B1 (Thiamine)	0.1.5 - 0.30
Vitamin B2 (Riboflavin)	4.0 - 7.0
Vitamin B3 (Niacin)	10.0 - 25.0
Vitamin B6 (Pyridoxine)	0.5 - 1.5
Vitamin B12 (Cobalamin)	0.10 - 0.30
Folic acid	0.05 - 0.30
Inositol	70 - 90
Vitamin K	0.90 - 1.05
Minerals	**mg/100g**
Calcium	60 - 110
Phosphorus	700 - 1000
Magnesium	200 - 300
Iron	25 - 40
Sodium	700 - 1000
Potassium	1000 -1500
Zinc	1.0 - 3.0
Copper	0.2 - 0.4
Manganese	1.0 - 3.0
Chromium	0.1 - 0.3
Selenium	0.003 - 0.010
Physical properties	
Appearance	Fine, uniform powder
Colour	Blue green to green
Odour & Taste	Mild
Bulk density	0.62 - 0.85 g/cc
Particle size	100% 60 mesh
General composition	**%**
Protein	60% - 69%
Carbohydrates	16% - 20%
Lipids	5% - 7%
Minerals	6% - 9%
Moisture	2.5% - 6.0%
Phytopigments	**mg/100g**
Total Carotenoids	400 - 650
Beta Carotene	150 - 250
Xanthophylls	250 - 470
Zeaxanthin	125 - 200
Chlorophyll	1300 - 1700
Phycocyanin	15000 - 19000
Fatty acids	**g/100g**
Myristic acid	0.01 - 0.03
Palmitic acid	2.0 - 2.5
Stearic acid	0.01 - 0.05
Oleic acid	0.10 - 0.20
Linoleic acid	0.75 - 1.2
Gamma-Linolenic acid	1.00 - 1.50

4.1. Biomass production and waste water treatment: A waste to wealth utilization

For waste water treatment, *Spirulina* is one of the most widely studied microalgae (Tanticharoen et al., 1993; Phang et al., 2000). Chuntapa et al. (2002) reported that *Spirulina platensis* provides excellent water quality for shrimp cultivation, by reducing the inorganic nitrogen present in the water. This helped to increase the density of shrimp. *Spirulina* has been used in the process of phycoremediation due to many of its advantages namely, 1) it is the only microalgae with the highest protein content (60-70%) and hence, is used as a food supplement, 2) it also contains PUFA (polyunsaturated fatty acids) which helps to cure chronic inflammatory diseases in humans, 3) its cheap and easy modes of cultivation and harvesting, as it grows in high pH there is less contamination with other microorganisms, 4) used as feed for terrestrial and aquatic animals, 5) certain spp. can grow both in heterotrophic and mixotrophic conditions and 6) it absorbs heavy metals from the waste water due to the presence of polysaccharides (Hernández and Olguín, 2002; Olguín et al., 2003; Olguín, 2012). *Arthrospira maxima* was cultivated in the laboratory, outdoor raceway ponds and in tropical and subtropical conditions using piggery wastewater. This integrated system was found to do the process of phycoremediation (treating the piggery wastewater) and also produce high yields of biomass, of *Arthrospira maxima* along with biogas. This biomass is used as a source of feed for fish larvae and also used to extract essential compounds in various industries (Olguín et al., 1994; Olguín et al., 1997; Olguín et al., 2003; Chaiklahan et al., 2010).

5. Modes of application of cyanobacterial biofertilizer

Cyanobacteria can be applied in the form of dry biomass, suspended liquid, foliar sprays, biofilms, seed dressings, seed treatment, seed inoculation, seedling root dip and direct field application. Foliar spraying is reported to induce the stomatal operations and improve the water use efficiency in plants. These are found to increase the growth and yield of plants as well as increases the seed germination rate, especially in vegetable crops (Li et al., 2014; Singh and Kumar, 2015; Bushong et al., 2016; Coppens et al., 2016; Renuka et al., 2018). A study by Grzesik et al. (2017) revealed that, when *Salix* sp. monocultures were treated with foliar algal biofertilizer, it helped in increasing the yield of the plants. Foliar application of *Acutodesmus dimorphus* in the form of dry biomass and cellular extract, has a positive effect on the growth of the plants, seed germination and floral production in Ramo variety of tomato (Stirk and Van Staden, 1997; Garcia-Gonzalez and Sommerfeld, 2015). Hegazi et al. (2010) found that, the application of dried and fresh cyanobacterial biofertilizer, helped to increase the height and number of leaves and leaf area of beans. According to Krishna et al. (2012) cyanopith and cyanospray applications of cyanobacterial biofertilizer, increased the leaf width of *Aloe barbadensis.* Recently, Asmamaw et al. (2019) reported that, when kale, pepper and maize plants were treated with dried and liquid cyanobacterial biofertilizer, it helped in increasing the fertility, nitrogen, carbon and other nutrients in the soil. However, microalgae liquid fertilizer integrated nutrient management (MLFINM), could be a better replacement of chemical fertilizer for hydroponic cultivation in the near future (Fig. 2).

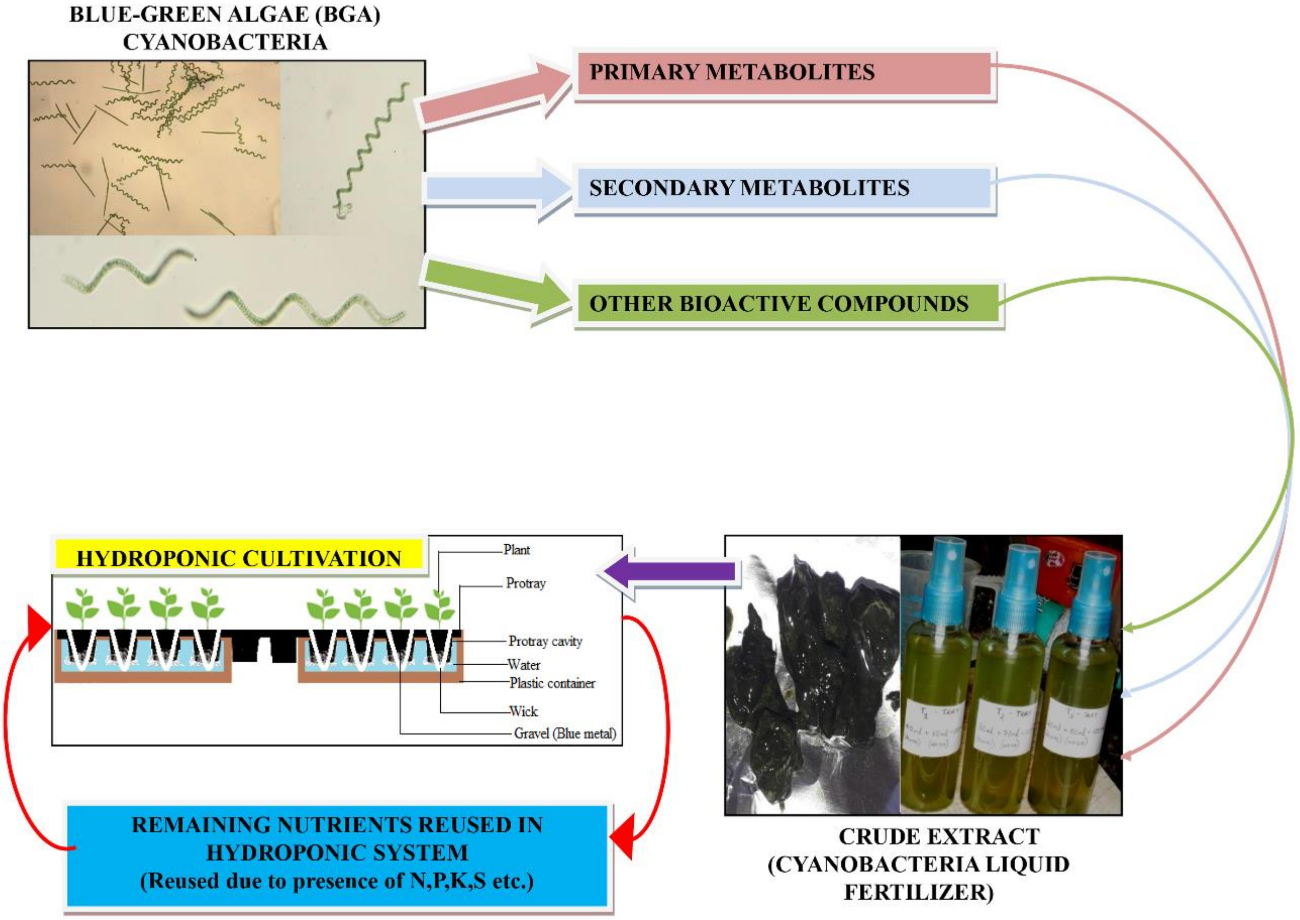

Fig. 2. Microalgae liquid fertilizer integrated nutrient management (MLFINM). The application of cyanobacterial liquid fertilizer in the hydroponic system helps to enhance the quantity, quality and production of high value products such as protein, carbohydrate, lipids and secondary metabolites in the plants because cyanobacteria produce a wide range of metabolites and bioactive compounds that are uptaken and continuously reused throughout the whole hydroponic system, the primary medium being water.

6. Case studies: Interaction of cyanobacteria with the crops

A study by Krings et al. (2008), showed that cyanobacteria form loops and coils, which enables them to colonize in the parenchyma cells, intercellular spaces and substomatal zones, as they have the ability to enter the plant through the stomata. The effect of the cyanobacterial biofertilizers may vary from plant to plant (Srivastava et al., 2014). Shariatmadari et al. (2015) reported cyanobacteria produce a wide range of bioactive molecules and secondary metabolites in plants, including essential oils in *Mentha* x *piperita*. Prasanna et al. (2016) demonstrated that when *Chrysanthemum morifolium* Ramat - ‘Golden Ball’ and ‘White Star’, planted in soilless media composed of a mixture cocopeat, vermiculite and perlite (3:1:1, w/w), treated with *Anabaena* sp. and *Trichoderma* sp. biofilm, showed highest plant height in variety ‘Golden Ball’ which ranged from 63-72 cm. The plant height of variety ‘White Star’ ranged from 67.8-69.9cm. It was also observed that there was 30%-50% increase in the nutrient availability (N, P and C) in the variety of ‘Golden Ball’ after cyanobacterial fertilizer treatment. Bidyarani et al. (2016) observed that, when chickpea plants were inoculated with cyanobacterial bio-filmed biofertilizers, it helped in enhancing the crop productivity, by increasing the uptake of nitrogen, which has a positive correlation on the phosphorous level and microbial associations.

Swarnalakshmi et al. (2013) stated that, when the biofilm of *Anabaena torulosa* when used in wheat crop, helps to improve the metabolic activity, plant growth and survival of the microbes. *Anabaena pseudomonas* was found to fix the highest amount of atmospheric nitrogen. Cesário et al. (2018) reported, marine microalgae are also used as a source of biofertilizers. The cell wall of the cyanobacteria breaks apart releasing proteins, hence producing foam on the wave edges. A study by Yilmaz and Sönmez (2017) showed, that the soil treated with algal biofertilizer has higher concentrations of carbon. These algae also helped in increasing the macro and micro nutrients, stabilizing and mineralizing the soil. Hussain and Hasnain (2011) revealed that, higher concentrations of cyanobacterial hormones, auxin and cytokinin have a positive response to the plant growth, including the weight of the seeds and shoot, spike and root length. Victor and Reuben (2001) observed the decrease of the mosquito rate and increase in grain yield in the rice fields due to the inoculation with cyanobacterial biofertilizer.

In the year 2017, Chittapun et al. used *Nostoc carneum* and *Nostoc commune* as cyanobacterial biofertilizers for cultivating rice plants. He found that these cyanobacterial biofertilizers helped in increasing the root length, plant growth, yield and grain quality. According to Xue et al. (2016) lettuce crops showed highest plant yield, when treated with cyanobacterial biofertilizers containing *Anabaena cylindrica* and *Nostoc* sp.. Maurya et al. (2016) found that, when maize crops were treated with lipid extracted from algae biomass as a biofertilizer, it helped in increasing the yield of the plants. Cyanobacteria have a great diversity of species and are present in multiple niches which helps them to be explored and be used in various applications (Luan and Lu, 2018). The application of the cyanobacterial biofertilizers can help in the development of sustainable agriculture, as it is an environmental-friendly approach (Chaudhary, 2010; Swarnalakshmi et al., 2013; Renuka et al., 2018).

Anabaena laxa biofilms when used to grow chickpea showed 50% higher grain yield than the control (Prasanna et al., 2014). Velu et al. (2015) revealed that, with less utilization of nitrogen and water, bioproducts were produced by *Tolypothrix* sp. in the tropical regions. Valiente et al. (2000) stated that, when cyanobacteria and nitrogen based chemical fertilizers were added to the plants, the results showed the plants inoculated with cyanobacteria, showed higher accumulation of nitrogen in them. This cyanobacteria based biofertilizer helped to increase the yield of the rice plants due to its high nitrogen fixing ability. Tantawy and Atef (2010) studied that, when seeds of *Lupinus termis* were treated with plant growth hormones produced by cyanobacteria, it showed higher seed germination compared to seeds treated with plant growth hormones IAA, GA3, and cytokinin. Rice seeds treated with four species of *Anabaena* strains resulted in higher seed germination rate when compared with control (Saadatnia and Riahi, 2009). Under salt stress conditions, *Anabaena oryzae* was found to release PO_4^{-3}, which can be potentially used as a biofertilizer in high alkaline and saline soils (Singh et al., 2006). Singh and Datta (2007) observed that, *Anabaena variabilis* mutant strains helped to increase the growth of rice plants in flooded soils. This strain was also found to be resistant to herbicides. According to Sinha and Häder (2006) cyanobacteria has photoprotective mechanism against UV-B radiation. This property can help cyanobacteria to be used as biofertilizers in agricultural fields for the growth of crops.

Bhuvaneshwari et al. (2011) reported, the inoculation of *Helianthus annuus* with cyanobacterial biofertilizer, increased the number of leaves and leaf area. Kalpana et al. (2011) demonstrated that when a combination of *Rhizobium+Azotobacter+Lactobacillus+Spirulina* was used as a biofertilizer for green gram plants, the plants showed greater height of shoot and root length, higher amount of nitrogen, chlorophyll and proteins. Even though the different applications of cyanobacteria are known, they are very less explored and exploited. They are used in a wide range of applications, hence there is a necessity for continuous improvement of different cultivation technologies (Chaillan et al., 2006; Abed et al., 2009; Hays and Ducat, 2015; Lau et al., 2015; Singh et al., 2016).

7. Advantages of cyanobacterial liquid biofertilizers

There are many advantages of cyanobacterial liquid biofertilizer over chemical fertilizers namely 1) due to their liquid state, they have a longer shelf life of up to 12-24 months, 2) as these cyanobacteria used as a biofertilizer grows in very high pH and temperature, there are less chances of contamination, 3) has great potential against bacteria, fungi, insect and pest causing diseases, 4) their application is safe to the plants, 5) when applied they help to increase the yield, seed germination, soil fertility and many other properties, 6) can be used by the farmers easily, 7) has high export potential and 8) provides high commercial revenue returns (Singh and Kumar, 2015).

8. Hydroponics

The term hydroponics was derived from the Greek words ‘hydro’ refers to water and ‘ponos’ refers to labour (Douglas, 1977; Sardare and Admane, 2013; Soilless Gardening - India Magazine, 2013). Hydroponics is the process in which plants are grown in a soilless aqueous medium with bare roots. The nutrients are provided to the plants through water, which offers the ability to grow plants and also the water could be reused along with the nutrients. There are liquid system, aggregated system, wick system (Fig. 3), drip system, aeroponics system available. In liquid hydroponic system, floating rafts and nutrient film techniques (NFT) are being used, while in aggregated hydroponic system, media such as peat, sawdust, clay, gravel are being used. The wick system is considered the simplest hydroponic system, as it is based just on the capillary force. One end of the wick is placed into the water and the other is placed near the root of the plants. Hence, the water reaches the roots from the containers below through the wick. Drip system is the most popular hydroponic system in which the pump is operated using a timer which pumps the water through pipes and drips at the root of each plant. In aeroponics system, the plants are placed on the top of a container with their roots in the air. The container has sprayers that are activated by the timers (Fu et al., 1999; ATTRA, 2006; Soilless Gardening - India Magazine, 2013; Borges and Dal'Sotto, 2016; Son et al., 2016).

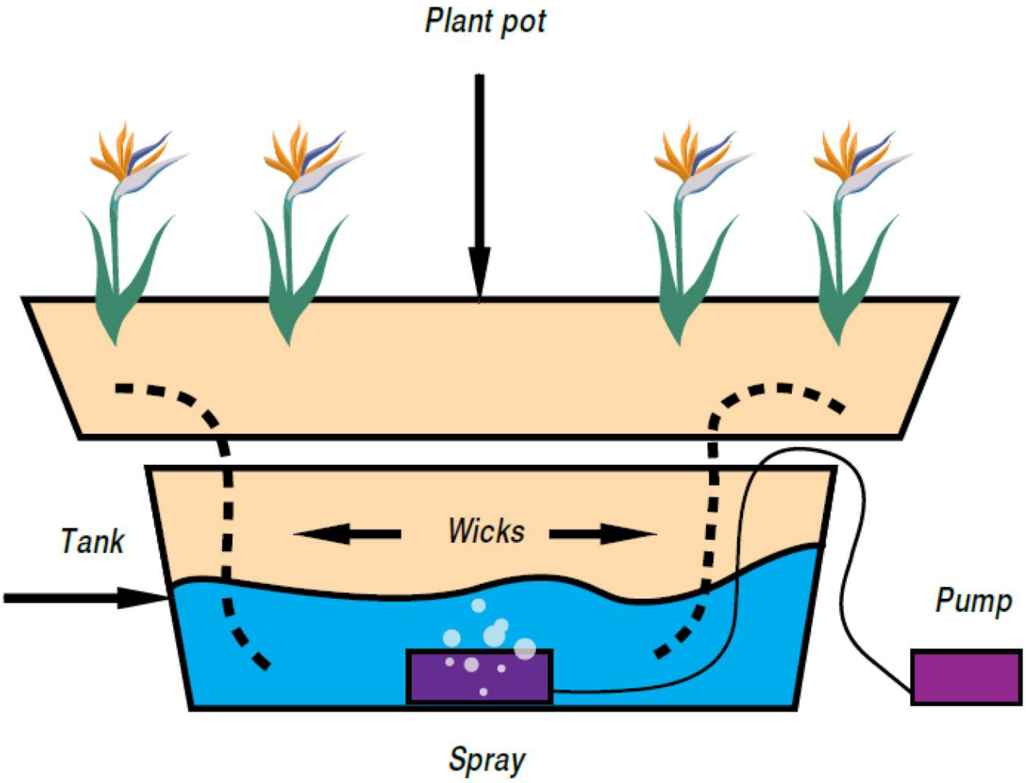

Fig. 3. Wick system, adapted from Soilless Gardening - India Magazine (2013). The water from the tanks reach the plant roots through a wick which works purely based on the action of capillary force, hence is considered the simplest hydroponic system. This innovative method, may help to reduce the freshwater usage from higher amount to lower amount and also this system will control the utilization of water in the future.

In a hydroponic system, plants are grown in greenhouses, using mineral nutrient solutions like water as a medium without soil. The controlled delivery of water, nutrients and environmental alterations within the greenhouse, is one of the major reasons why hydroponics is so successful. It is considered as a constructive method which uses only 10% of the water used in conventional methods and hence, is a sustainable and an eco-friendly approach (Rakocy, 2012; Alshrouf, 2017; Souza et al., 2019). A hydroponic system usually provides the plant with a risk free and pathogen free nutrient medium to grow, and as there is no soil, it prevents the outbreak and spread of diseases. One of the advantages of this system is that, the root as well as the shoot (leaves, stem) can be harvested individually, when required (Zhang et al., 2009; Nguyen et al., 2016; Wang et al., 2019). According to the WHO (2003), at least 400g of vegetables have to be consumed in a day by an individual for proper health.

Crops grown in a hydroponic system are healthier and is under high demand as no chemical fertilizers and pesticides are used and hence, is increasingly cultivated. It provides higher returns than conventional cultivation. Commercially for cultivation of vegetables, nutrient film technique (NFT) and deep flow technique (DFT) are commonly employed with recirculated nutrient solutions (Fu et al., 1999; Borges and Dal'Sotto, 2016; Son et al., 2016). Many plants are being cultivated in the hydroponic system including leafy vegetables such mint (*Mentha* x *piperita*), lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea* var. *capitate*), spinach (*Spinacia oleracea*), basil (*Ocimum basilicum*), beetroot (*Beta vulgaris*) and other vegetables such as tomato (*Solanum lycopersicum*) and cucumber (*Cucumis sativus*) (Lennard and Leonard, 2006; Roosta and Sajjadinia, 2010; Roosta and Hamidpour, 2011; Liang and Chien, 2013; Hu et al., 2015; Hussain et al., 2015; Filep et al., 2016; Shete et al., 2016; Knaus and Palm, 2017). Hydroponic vegetable production (soilless culture) in India was reported by Sardare and Admane (2013) (Fig. 4).

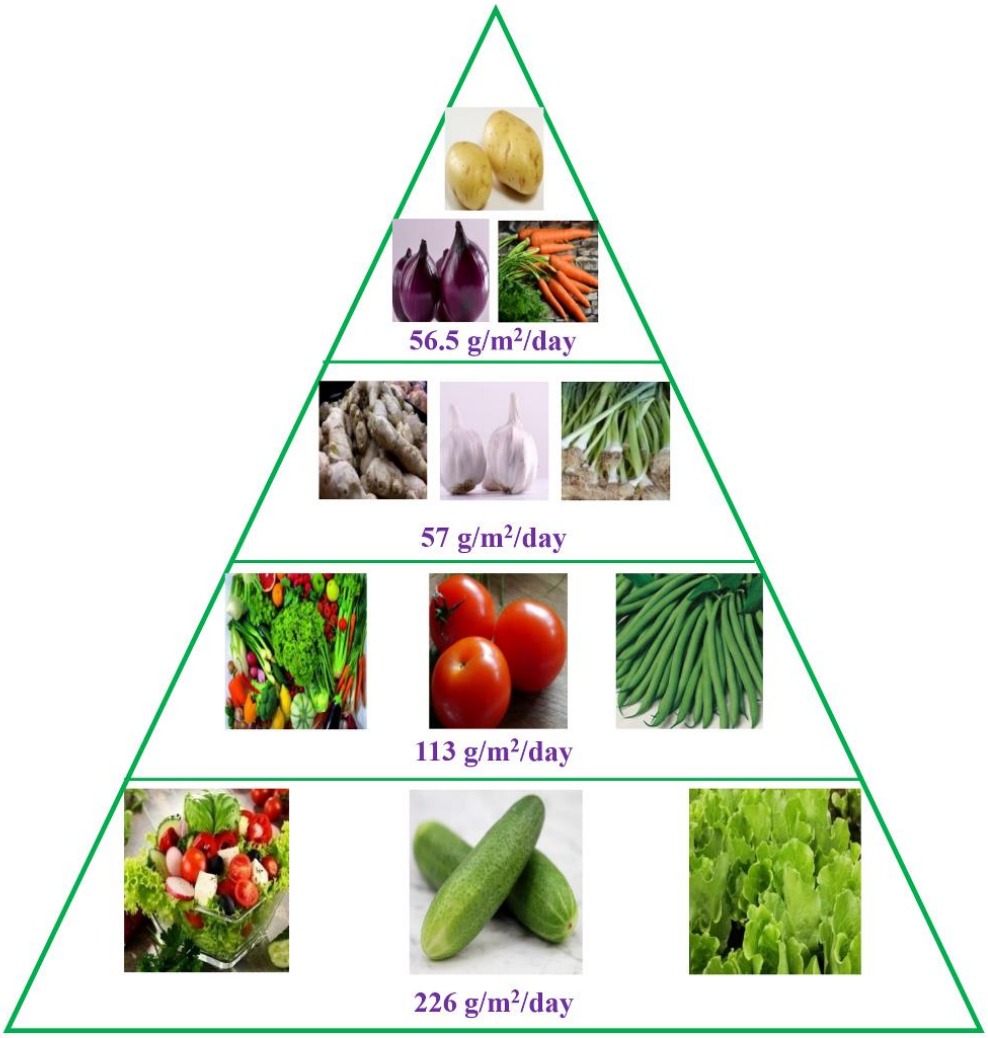

Fig. 4. Production of common vegetables using hydroponic cultivation system in India, adapted and modified from Sardare and Admane (2013). Crops grown in hydroponic systems are of high demand as they are organic. The quantity of vegetables produced per day, per square meter, are potato, onion and carrot 56.5g; ginger, garlic and leek 57g; greens, tomato and green beans 113g; salad greens, cucumber and lettuce 226g respectively.

8.1. Advantages of hydroponic system

Hydroponic system is advantageous, as this is a viable solution to grow plants in limited land area and on lands which cannot be used for cultivation. As it is a soilless cultivation, it helps to reduce the soil-borne pathogens and diseases. The growing conditions can be easily manipulated, hence providing more yield. At present, there is a high demand for organic food, hence, this technique is highly valued due to the non-usage of chemicals or pesticides (Fu et al., 1999; Zhang et al., 2009; FAO, 2014; Borges and Dal'Sotto, 2016; Nguyen et al., 2016; Son et al., 2016; Wang et al., 2019). The main objective is to grow plants without soil by suspending their roots in solutions, which helps the farmers to make better use of their lands. This system can be enclosed in polyhouse-type structures, to reduce the loss of water through evaporation, to protect the plants against the changing weather, as well as climate, and to provide optimum growing conditions. Therefore, hydroponics is an integrated approach between the cultivation of crops with soil and soilless cultivation (Douglas, 1977; Rakocy, 2012; Alshrouf, 2017; Chow et al., 2017; Souza et al., 2019). There was a comparative study by Sardare and Admane (2013) in which, the hydroponic cultivation averages were compared with ordinary soil yields of both monocot & dicot plants as a staple food (Table 2).

Table 2: Comparative study: Hydroponic cultivation averages compared with ordinary soil yields, adapted and modified from Sardare and Admane (2013).

Monocot / Dicot	**Name of the crop**	**Botanical name**	**Family**	**Hydroponic equivalent per acre**	**Agricultural average per acre**
Monocot	Wheat	*Triticum*	Poaceae	5,000 lb.	600 lb.
	Oats	*Avena sativa* L.	Poaceae	3,000 lb.	850 lb.
	Rice	*Oryza sativa* L.	Poaceae	12,000 lb.	750-900 lb.
	Maize	*Zea mays* L.	Poaceae	8,000 lb.	1,500 lb.
Dicot	Soybean	*Glycine max* (L.) Merr.	Fabaceae	1,500 lb.	600 lb.
	Potato	*Solanum tuberosum* L.	Solanaceae	70 tonnes.	8 tonnes.
	Beet root	*Beta vulgaris* L.	Amaranthaceae	20,000 lb.	9,000 lb.
	Cabbage	*Brassica oleracea* var. *capitata* L.	Brassicaceae	18,000 lb.	13,000 lb.
	Peas	*Pisum sativum* L.	Fabaceae	14,000 lb.	2,000 lb.
	Tomato	*Solanum lycopersicum* L.	Solanaceae	180 tonnes.	5-10 tonnes.
	Cauliflower	*Brassica oleracea* var. *botrytis* L.	Brassicaceae	30,000 lb.	10-15,000 lb.
	French beans	*Phaseolus vulgaris* L.	Fabaceae	42,000 lb. of pods for eating.	-
	Lettuce	*Lactuca sativa* L.	Asteraceae	21,000 lb.	9,000 lb.
	Lady’s finger	*Abelmoschus esculentus* (L.) Moench	Malvaceae	19,000 lb.	5-8,000 lb.
	Cucumber	*Cucumis sativus* L.	Cucurbitaceae	28,000 lb.	7,000 lb.

8.2. Hydroponic cultivation in India and abroad

Hydroponics in India was introduced by W.J. Sholto Douglas an English scientist in the year 1946, who also established a laboratory in Kalimpong area, West Bengal. He wrote a book named Hydroponics - The Bengal System. By 1960s and 1970s, commercial hydroponic farms developed initially in countries such as Germany, Russia, Belgium, Japan, Denmark, Italy and Netherlands. By 1990s, hydroponic home kits came into existence (Douglas, 1977; Sardare and Admane, 2013; Soilless Gardening - India Magazine, 2013).

The book Hydroponics - The Bengal System by Douglas (1977) stated that, in the year 1929, there was a successful attempt in growing of tomato vines, up to twenty-five feet in height, in large basins, containing a nutrient solution by Professor W.F. Gericke, University of California. Further, he went onto make little changes in the setup, to adapt to the geographical region and so started the technique of sand and gravel culture, hence, it was first evolved in the middle west. Hydroponic systems are usually carried out in places which has unproductive soil or areas with difficult access to soil. Countries like China, Latin America, Mexico and Brazil are called hydroponic countries (Rodríguez-Delfín, 2012; Croft et al., 2017; Souza et al., 2019).

8.3. Current scenario in hydroponic cultivation

Today, hydroponics is an established branch of agronomical science. Some of the plants can be grown off season in hydroponics. It is said that the vegetables and fruits grown through hydroponics, are more luscious and sweeter than the vegetables and fruits grown in ordinary soil. Advantage of hydroponic cultivation is that, it requires less growing area, minimum labour, low cost, and no hard manual-labour. Hence, this setup can be placed in areas like cities, rooftop gardens, deserts, mountains, barren and sterile areas, which can be made productive at relatively low cost and humans can get fresh fruits and vegetables at their doorstep. Thus, not only is it a profitable undertaking, but one which has proved of great benefit to humanity (Douglas, 1977; Roosta and Sajjadinia, 2010; Rodríguez-Delfín, 2012; Liang and Chien, 2013; Filep et al., 2016; Shete et al., 2016; Croft et al., 2017; Souza et al., 2019). This industry is expected to grow exponentially. In a developing country like India, to ensure food security, we have to adopt soilless culture, to help improve the yield and quality of the produce, as the land is shrinking due the increase in population size every day (Sardare and Admane, 2013; Muller et al. 2017; Gwynn-Jones et al., 2018; Li et al., 2018). According to the report in FAO (2017), as the population is rising at a very high level, by the year 2050 the population size will be 9 billion and to feed this expanding population there should be at least a 70% increase in production of food. Due to the increase in population, the land for cultivation is dwindling, while the land for the accommodation of this huge population including the rural and urban expansion is increasing. Hence, new methods have to be found and adopted to grow crops, by utilizing less resources and less land area, to provide food, for this drastically increasing population (Souza et al., 2019). Gwynn-Jones et al. (2018) stated that “The human life in economically developing countries can become sustainable, only, if minimum resources are utilized to grow crops”.

Due to the increase in population and restricted natural resources and land space available, farmers must find alternative techniques to increase eco-friendly crop production by sustainable methods and in an efficient manner, using the resources which are available, i.e. land, water and energy, by maintaining a balance between the crop production and resources (Treftz and Omaye, 2016; Schwerz et al., 2017). Hydroponics is considered as a reliable, efficient, flexible, innovative, sustainable and eco-friendly method for food production. It also provides food security and social and economic development of the country by helping in providing employment and income. Therefore, this method is being considered as one of the most advanced system for crop production without soil. In a hydroponic system most type of plants can be cultivated, but usually plants such as vegetables are preferred over grains (Carvalho et al., 2014; Muller et al., 2017; Gwynn-Jones et al., 2018; Li et al., 2018).

Hydroponics is a possible solution to address the current environmental climate change concerns (Burt et al., 2019). Chow et al. (2017) reported that, the present investigation, with respect to literature data, could contribute to the nation and scientific communities, in terms of potential improvement of the quality and quantity of food crops, potential reuse of nutrient water from the production of food crops and reduction in the excessive application of agrochemicals (Table 3).

Table 3: Pros and cons of hydroponic system in comparison to soil based culture, adapted and modified from Chow et al. (2017).

Challenges	Hydroponic system	Soil culture	References
Aqueous	- Efficient water usage - Irrigated water can be recycled or reused - No nutrient waste due to water runoff - Irrigation water is supplied directly to root areas - Possible to control water holding ability by using different kinds of medium	- Insufficient water usage - Irrigation water cannot be recycled or reused - Eutrophication of the environment due to surface run-off - Difficult to control the water-holding capacity	Midmore and Deng-Lin (1999)
Usage of land and environmental effect	- Less affect by soil & external factors - Indoor system and ease of nutrient control - Excellent control of temperature, humidity & lighting	- Limited by different soil types - Subjected to different changing environment	Gibeaut et al. (1997); Jones (2004); Noren et al. (2004); Norström et al. (2004)
Nutrients in the form of solution	- Even distribution of nutrient - Efficient use of biofertilizers and cost saving - Ease of pH control	- Uneven distribution of nutrients - Excessive use of fertilizers - Variation of pH with the changing weather and external factors	Rolot and Seutin (1999); Resh (2012)
Yield of crop in both quantity & quality	- Stable and even, amount of crop production in quality & quantity	- Unstable crop production, and subjected to pests/ soilborne pathogens	Cornish (1992); Sarooshi and Cresswell (1994); Rolot and Seutin (1999); Resh (2012)

9. *Mentha*

Mentha x *piperita L.* belongs to the family Lamiaceae is a natural hybrid between spearmint (*Mentha spicata* L.) and water mint (*Mentha aquatica* L.). It is commonly called as peppermint (Spirling and Daniels, 2001; Saller, 2004; Rita and Animesh, 2011; Khalil et al., 2015; Loolaie et al., 2017).

Peppermint is economically very important; hence it is cultivated all over the world (Table 4). The origin of peppermint is from the Mediterranean region. It is very commonly used in folk remedies, including traditional medicine. Due to the presence of fragrant economically valued essential oil, it is also used to flavour chewing gums and after dinner mints apart from being used in cosmetics, medicinal, and pharmaceutical industries. As this plant contains antitumor and antimicrobial properties, it is widely used for the treatment of digestive problems, nausea, lessening of cramps, diarrhoea and for its renal action (Işcan et al., 2002; Dorman et al., 2003; Keifer et al., 2007; Loolaie et al., 2017).

Table 4: Local names for *Mentha* in different countries, adapted and modified from Loolaie et al. (2017).

Economy	Country	Local name	Classification
Developed	USA	Lab Mint, Mint	Kingdom: Plantae Clade: Angiosperms Clade: Eudicots Clade: Asterids Order: Lamiales Family: Lamiaceae Genus: *Mentha* Species: *M.*× *piperita*
	Norway	Peppermynte	
	Poland	Pepparmunta	
	Spain	Mentainglesa	
	France	Menthe	
	Portugal	Hortelana pimentosa	
	Sweden	Pepparmynt	
	Denmark	Pebermynte	
	Germany	Peppermint	
	England	Brandy Mint	
Developing	Iran	Nanafelfeli	
	Brazil	Nortela pimento	
	China	Po Ho	
	India	Urdu, mint, Pudina, Pudyana, Puthina	
	Turkey	Nana	
	Russia	Myata perechnaya	
	Uruguay	Menta	
	Iraq	Nana	
	Mexico	Menta piperita	

10. *Mentha* oil and its major producers worldwide

Mentha x *piperita* is also called as *hierba buena* which means good herb. It is most commonly used to extract the essential oil whose principal component is menthol (Table 5, Fig. 5). This *Mentha* oil can also be extracted from many other species of *Mentha*, but the oil obtained from *Mentha* x *piperita* is said to be of the best quality (Dorman et al., 2003; Rita and Animesh, 2011). According to a data in 2003, India is one of the major sources of *Mentha* oil in the world with around 14,000 metric tonnes production and 3,000 metric tonnes exports annually (Rohloff et al., 2005; Rita and Animesh, 2011; Afridi et al., 2016). Souza et al. (2014) reported that more the maturity of the *Mentha* leaves, higher the amount of essential oils. Essential oil content in young leaves was 0.74 ± 0.02% and in adult leaves was 0.89 ± 0.03%. The FAOSTAT report 2014 on peppermint production states that there in an increase in the production of peppermint throughout the world. In 2014, the production was 92,295 tonnes. Asia contributes 92.23% of total production of peppermint which is followed by America with 7.61% production (Oroian et al., 2017). In India, the state of Uttar Pradesh is the highest *Mentha* producer. Usually eight species of *Mentha* are cultivated out of which three are exported. *Mentha arvensis* commonly called as mint or pudina is the vast grown medicinal plant in India. It is regularly exported which helps in increasing the GDP of the country (Pal et al., 2015; Nadeem et al., 2017). India's 'mint belt' stretches through an area of 1,500 km long and 250 km wide covering the states of Bihar, Uttar Pradesh, Haryana, Uttarakhand, Punjab and Himachal Pradesh in the Himalayan range of the Indo-Gangetic plains. Uttar Pradesh produces more than 80% of *Mentha* and is the highest *Mentha* producing state of the country. This is followed by Uttarakhand, Bihar and Punjab. *Mentha* cultivation is in the Barabanki, Sitapur and Lucknow districts of Uttar Pradesh covering an area of about 1,07,513 ha with 10,752 MT of *Mentha* oil production (Vivek et al., 2009; Kumar et al., 2011; Pal et al., 2015; Nadeem et al., 2017).

Table 5: Components present in *Mentha* x *piperita* L. essential oil, adapted and modified from Afridi et al. (2016).

Chemical constituent	Concentration (%)
Alpha-Phellandrene	0.168
Alpha-Pinene	0.245
Camphene	203
Bicyclo [3.1.0] hexane, 4-methylene-1-(1-methylethyl)	0.569
Beta-Pinene	0.480
o-Cymene	0.835
D-Limonene	5.516
Eucalyptol	1.996
Beta-Linalool	0.283
Borneol	8.865
p-Menthan-3-ol	25.749
p-Cymen-8-ol	0.219
p-menth-1-en-8-ol	0.220
2-Isopropenyl-5-methylhex-4-enal	0.192
p-Mentha-6,8-dien-2-one, (R)-(-)-	46.434
7-Oxabicyclo[4.1.0]heptan-2-one, 6-methyl-3-(1-methylethyl)	2.039
Alpha-Santalol	0.325
Santalol	0.325
2-isopropylidenecyclohexanone	4.838
1H-cycloprop[e]azulen-7-ol,decahydro--1,1,7-trimethy1-4-methylene	0.491
Caryophyllene oxide	0.407
Epiglobulol	0.491

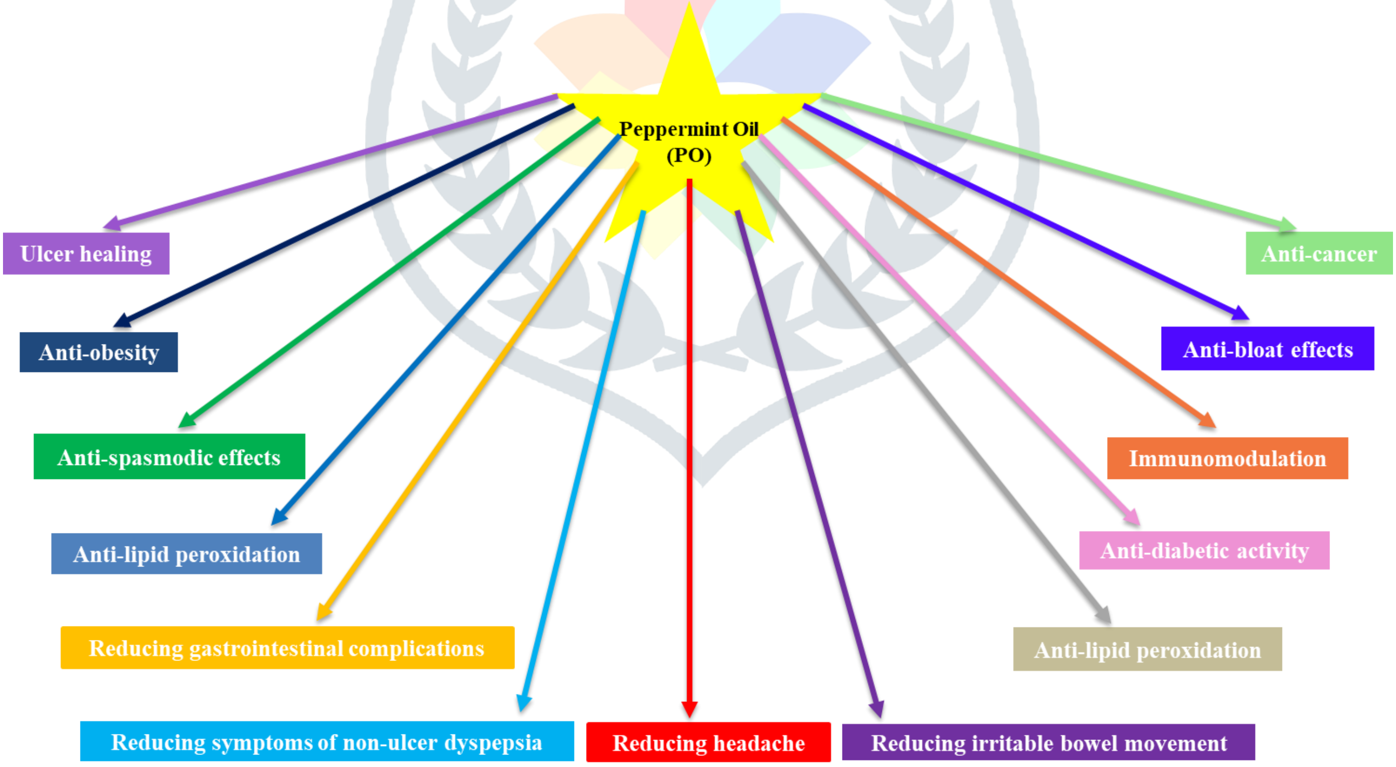

Fig. 5. Valuable health benefits of essential oil from *Mentha*, adapted and modified from Loolaie et al. (2017). The peppermint oil (PO) is a natural, aromatic and volatile secondary metabolite which has strong odour and also a complex composition of various compounds. This PO is also used in medicine for preventing various diseases without any side effects.

India produces more than 38,000 MT (Metric Tonnes) (80%) of *Mentha* oil followed by China (9%), Brazil (7%) and USA (4%) with the productivity of around 1.1 t/ha^{-1}. India tops the *Mentha* oil exporting countries by exporting about 6,000 MT of *Mentha* oil per annum to many countries like China (32%), USA (20%), Brazil (4%), Japan (2%), UK (2%), etc. From of all these exports, India gets more than Rs. 800 million per year. Apart from being the top producer and exporter, India alone consumes 7,500 MT of *Mentha* oil annually, making it the largest consumer of *Mentha* oil. Thus, the *Mentha* oil production in India, the market shows an upward trend from 2 MT to 32,000 MT since 1965 to 2006 (Vivek et al., 2009; Pal et al., 2015; Nadeem et al., 2017).

11. *Mentha* oil activity

11.1. Antibacterial agent

Işcan et al. (2002) and Vasinauskienë et al. (2006) reported that, *Mentha* x *piperita* oil from India, has stronger antibacterial activity against *Pseudomonas syringae* in beans and tomato and *Xanthomonas campestris* in beans. Menthone and menthol from *Mentha* x *piperita* helps to protect the plant against plant pathogenic bacteria. Kokoskova et al. (2011) found that 1 ml (millilitre) dose of *Mentha arvensis* oil was more effective than streptomycin in inhibiting *Pseudomonas fluorescens*, *Pantoea agglomerans*, *Erwinia amylovora* and *Pantoea dispersa* (Table 6). *Mentha* oil have the presence of phenolic compounds in them. These compounds enter the pathogen (bacteria) and form complexes with enzymes and proteins causing disruption of the plasma membrane which inhibits the growth, eventually leading to the death of the pathogen (Oussalah et al., 2006; Xu et al., 2008; Rhouma et al., 2009).

Table 6: Antibacterial activity of *Mentha* x *piperita* L. essential oil, adapted and modified from Afridi et al. (2016).

Microorganism	**Family**	**Gram positive (+) or negative (-)**	**Zone of inhibition (mm)**	**Zone of inhibition of positive control (mm)**
Bacillus cereus	Bacillaceae	+	15 ± 0.12	19 ± 0.25**
Escherichia coli	Enterobacteriaceae	-	17 ± 0.87	20 ± 0.34*
Enterococcus faecalis	Enterococcaceae	+	16 ± 0.23	19 ± 0.65*
Klebsiella pneumoniae	Enterobacteriaceae	-	13 ± 0.31	17 ± 0.39*
Pseudomonas aeruginosa	Pseudomonadadaceae	-	15 ± 0.53	20 ± 0.81*
Staphylococcus aureus	Staphylococcaceae	+	17 ± 0.61	23 ± 0.37**
Salmonella typhi	Enterobacteriaceae	-	14 ± 0.21	17 ± 0.36*

Data expressed as mean ± standard deviation of three separate experiments.

*Ciprofloxacin

**Azithromycin

11.2. Antifungal Agent

Mimica-Dukić et al. (2003) and Džamić et al. (2010) reported oil extracted from *Mentha longifolia* inhibited the activity of *Aspergillus niger*, *Aspergillus versicolor*, *Cladosporium fulvum*, *Fusarium sporotrichioides*, *Penicillium funiculosum* and *Cladosporium cladosporioides*. Hussain et al. (2010) reported, essential oil from *Mentha* x *piperita*, *Mentha longifolia* and *Mentha spicata* showed antifungal activity against *Alternaria alternata*, *Rhizopus solani* and *Aspergillus niger*. Singh (2010) and Pandey and Tripathi (2011) found the essential oil of *Mentha arvensis* inhibited the growth of *Fusarium* spp. and *Aspergillus* spp. on papaya fruits and pigeon pea seeds. Saharkhiz et al. (2012) reported, *Mentha* x *piperita* oil exhibited fungicidal activity against *Aspergillus* spp. (Table 7). Regnier et al. (2014) reported essential oil from *Mentha spicata* helped to control *Penicillium italicum*, *Penicillium digitatum* and *Geotrichum candidum* var. *citri-aurantii*. *Mentha* oil have the presence of phenols and terpenes in them which could be the reason for their antifungal activity (Griffin et al., 2000).

Table 7: Antifungal activity of *Mentha* x *piperita* L. essential oil, adapted and modified from Afridi et al. (2016).

Microorganism	**Family**	**Zone of inhibition (mm)**	**Zone of inhibition of positive control (mm)**
Candida albicans	Saccharomycetaceae	15 ± 0.52	21 ± 0.19*
Aspergillus niger	Trichocomaceae	16 ± 0.37	19 ± 0.41*
Aspergillus parasiticus	Trichocomaceae	15 ± 0.16	17 ± 0.20*
Aspergillus fumigatus	Trichocomaceae	13 ± 0.32	18 ± 0.18*

Data expressed as mean ± standard deviation of three separate experiments.

* Clotrimazole

11.3. Insect Pest Agent

Kumar et al. (2009) found that, the essential oil from *Mentha* helps to protect the seeds by completely eradicating the oviposition of *Callosobruchus chinensis*. The essential oil penetrates into the eggs of the insects causing surface tension, which leads to the alteration in oxygen within the eggs therefore inhibiting the embryonic development (Abdullahi et al., 2011).

11.4. Chemical characters- Chlorophyll in Mentha leaf

The name chlorophyll is derived from the Greek word 'chloros' meaning green and 'phyllon' meaning leaf. Chlorophyll is a green pigment found in most of the plants. There is presence of a few different forms of chlorophyll namely chlorophyll 'a' (Fig. 6), chlorophyll 'b', chlorophyll 'c' etc. The general formula for chlorophyll is $C_{55}H_{72}MgN_4O_5$. The primary photosynthetic pigment in green plants is chlorophyll 'a'. Plants usually absorb red light at 660 nm and blue light at 430 nm and reflect the green light, hence appear green to human eyes. The chlorophyll and haemoglobin have a very similar structure, except that in haemoglobin the central atom is iron, whereas in chlorophyll it is magnesium (Glimn-Lacy and Kaufman, 2006; Blankenship, 2008; İnanç, 2011).

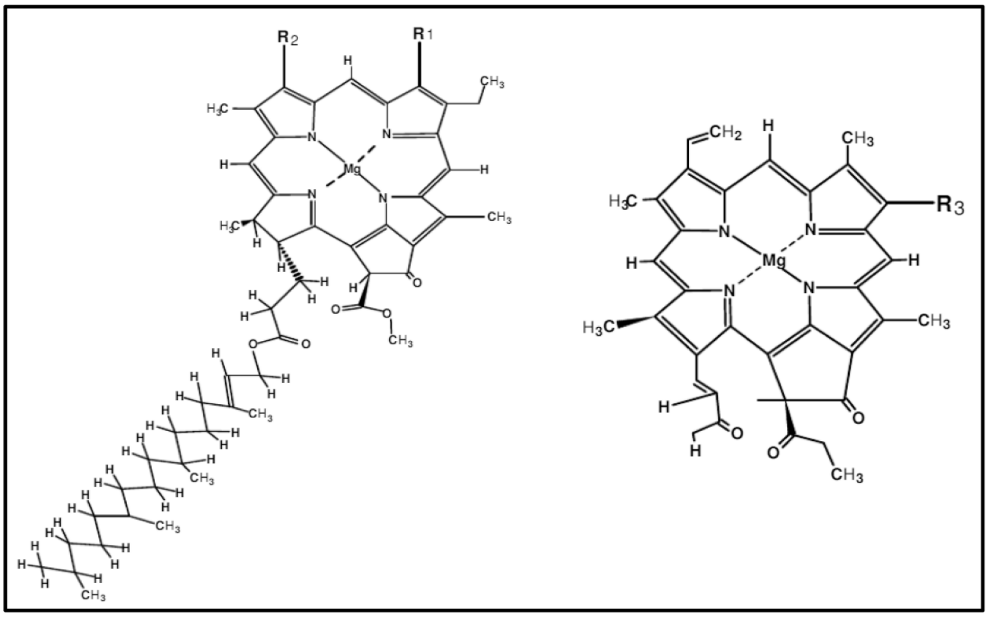

Fig. 6. Structure of chlorophyll 'a', adapted from İnanç (2011). The universal primary photosynthetic pigment in plants is chlorophyll 'a' and this is a green pigment. It enables the plants to appear green as plants reflect green light and absorb red light at 660 nm and blue light at 430 nm.

In 2015, there was a study done by Latvia University of Agriculture, the highest content of chlorophyll 'a', chlorophyll 'b'and total chlorophyll was found in *Mentha* x *piperita*. Chlorophyll 'a' in the stem was 0.107 ± 0.004 mg g^{-1}, in leaves was 0.849 ± 0.020 mg g^{-1}. Chlorophyll 'b' in the stem was 0.157 ± 0.006 mg g^{-1}, in leaves was 0.179 ± 0.008 mg g^{-1}. Total chlorophyll in the stem was 0.264 mg g^{-1}, in leaves was 1.028mg g^{-1} (Straumite et al., 2015). A chlorophyll derivative called chlorophyllin is used as a food additive agent, food colouring agent in desserts, soft drinks, chocolates, sauces, cheese and as an alternative medicine. It is called as "natural green 3" when used as a food colouring agent (İnanç, 2011).

12. Growth of *Mentha* in hydroponics

Daryadar (2015) reported that *Mentha* x *piperita.* grown in different hydroponic methods showed higher dry weight by 1.5-2.7 times when compared to the *Mentha* grown in soil culture. In different hydroponic methods and soil culture conditions, 71-73% of menthol was observed. In the study done by Padmathilake et al. (2007) shows that, the plants grown in hydroponic system have higher concentrations of potassium, nitrogen, phosphorous in shoot & root, higher leaf area, higher number of pods & seeds per plant. *Mentha* grown in hydroponics also yielded twice the fresh weight and oil yields. The yields were 2.12 times higher than that of soil grown plants.

13. Conclusions

The utilization of crushed *Spirulina* spp. biomass as a liquid fertilizer for crop and *Mentha* cultivation, is an undoubtably sustainable and eco-friendly approach. This research review article are findings of current technology, to improve adapted hydroponics system for vegetable cultivation. In a country like India, due to high population growth, which is causing land shrinkage and pollution, the urge is high, to replace and fulfil the demand of vegetable production. The cutting-edge research in the field of hydroponic cultivation using wick, blue metal etc., is getting more awareness, due to the enhancement of yield through hydroponic cultivation, especially, by the use of cyanobacterial liquid fertilizers. Apart from this, these cyanobacterial liquid fertilizers can maintain nutrients in water and also continuously recycle the nutrients for healthy hydroponic cultivation. Thus, the liquid fertilizer footprint has a complete life cycle assessment of *Mentha* and the vegetable production can be regulated in a large extent. Most probably, hydroponic *Mentha* cultivation blueprint, could have a strong future in the world marketing, as at the present scenario, there's a high demand for medicinal and aromatic herbs. It has great health benefits and can be used in the treatment of human ailments. Applied algal researchers around the world, can concentrate more on commercialization of cyanobacterial fertilizers, including liquid fertilizers, which could replace the chemical fertilizer usage for crop production as well as increasing the soil fertility/soilless cultivation. Therefore, one of the vital keys to the future of the world is, cultivation through hydroponics. Thus, further standardization needs to be done, to obtain yield not just in quantity but also in quality and in reduced time through cyanobacterial liquid fertilizer.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests that could have appeared to influence this work.

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