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REVIEW OF LITERATURE

This chapter comprises the general description of two essential oil bearing medicinal plants namely, Japanese mint (*Mentha arvensis* L.) and lemongrass [*Cymbopogon flexuosus* (Steud.) Wats]. In addition, a brief description of marine polysaccharides which showed plant growth promoting activity in their depolymerised form is also presented. Furthermore, the effect of irradiated polysaccharides including sodium alginate on various aspects of plant processes has been reviewed. Lastly, various strategies that applied by different researchers to enhance the essential oil of aforesaid plants are also summerised in this chapter.

2.1 General description: A general account of *Mentha arvensis* and *Cymbopogon flexuosus* is presented below.

2.1.1 *Mentha arvensis*

*Mentha arvensis* (commonly known as menthol mint, corn mint or Japanese mint) is a species of mint family (Lamiaceae) and native to the temperate regions of Europe and Western and Central Asia, Eastern Himalaya and Siberia (Fig. 4).

It is herbaceous perennial plant growing to height of 60-75 cm. Mints are propagated readily by vegetative means through underground parts called suckers. These suckers grow underground at a depth of 15 cm and spread in all directions. Six-month-old plants attain a height of about one metre or less. The stem is rigid, pubescent and highly branched. The leaves are lanceolate to oblong in shape, 2.0–6.5 cm long and 1–2 cm broad, in opposite pairs, simple, hairy, and with a coarsely serrated margin. The leaf lamina size may vary from 5 to 8 cm in length. The leaf surfaces, on both sides, appear hairy and have glandular trichomes. There are more trichomes on the ventral surface as compared to the dorsal. The petiole is small, about 5 mm in size. The inflorescence is verticillate known as cyme. The flowers are pale purple (occasionally white or pink), in clusters on the stem, each flower 3–4 mm long. The plants blossom profusely but rarely set seed. The roots are shallow and creeping.

2.1.2 Systematic position of *Mentha arvensis*

According to the system of classification of Arthur Cronquist (1919-1992), Japanese mint occupies the following systematic position.
Figure 4. *Mentha arvensis* L.
2.1.3 Use of *Mentha arvensis*

*Mentha arvensis* is widely used in the food, flavourings and cosmetic industries. It is a stimulant, tonic, vermifuge, antispasmodic, diaphoretic, stomachic, carminative, antiviral, antifungal, antibacterial and choleretic agent. Mint oil has wide application in pharmaceutical, agrochemical and flavouring industry all over the world.

2.1.4 *Cymbopogon flexuosus*

*Cymbopogon flexuosus* (commonly known as East Indian lemongrass, Malabar or Cochin grass) is a member of aromatic tall sedge (family: Poaceae) which grows in many parts of tropical and sub-tropical areas (Fig. 5). *Cymbopogon flexuosus* is native to India, Sri Lanka, Burma and Thailand. It was introduced in India about a century back and now it is commercially cultivated along Western Ghats (Maharashtra, Kerala), Karnataka and Tamil Nadu states besides foothills of Arunchal Pradesh and Sikkim. The species are today cultivated throughout tropical Asia. Lemongrass is tall, perennial sedge throwing up dense fascicles of leaves from a short rhizome. The culm is stout, erect, up to 1.8 metre high. Leaves are long, glaucous, green, linear tapering upwards and along the margins; ligule very short; sheaths terete, those of the barren shoots widened and tightly clasping at the base, others narrow and separating. It is a short day plant and produces profuse flowering in South India. The inflorescence is a long spike about one metre in length. Flowers borne on decompound spatheate; panicles 30 to over 60 cm long.
Figure 5. *Cymbopogon flexuosus* (Steud.) Wats.
2.1.5 Systematic position of *Cymbopogon flexuosus*

According to system of classification of Arthur Cronquist (1919-1992), lemongrass occupies the following systematic position.

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<td>Class</td>
<td>Liliopsida</td>
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<td>Order</td>
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<td>Family</td>
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2.1.6 Use of *Cymbopogon flexuosus*

The oil is distilled from leaves and flowering tops of lemongrass. The oil has strong lemon-like odour due to high percentage of citral in the oil. The characteristic smell of oil makes its use in scenting of soaps, detergents, insect repellent preparations. However, the major use of oil is as a source of citral, which goes in perfumery, cosmetics, beverages and is a starting material for manufacture of ionones, which produces vitamin-A. The citral rich oil has germicidal, medicinal and flavouring properties.

2.2 Marine polysaccharides

Marine polysaccharides include chitin, chitosan, alginate, agar and carrageenans. They are highly reactive chemically and are peculiar for thermo-reversible gel formation. Chitosan is a cationic carbohydrate biopolymer derived from chitin, the second most abundant polysaccharides present in nature after cellulose. The main sources of chitin are the shell wastes of shrimps, lobsters and crabs. For its characteristics, chitosan founds particular application as non-viral vector in gene delivery. Films from chitosan are very tough and long lasting. Carrageenans are linear polysaccharides from red seaweeds. Alginates are derived from seaweed extracts (Pheophyceae), and are mainly used in drug delivery and as hydrogels for immobilizing cells and enzymes, due to the mild conditions of cross-linking through bivalent cations (Ca$^{2+}$). The possibility of chemical modification, blending and addition of biodegradable additives allows
tailoring the final properties of polysaccharides and opens the doors to wider applications, particularly in pharmaceutical area. This issue is intended to explore any new potentiality of marine polysaccharides, as those above mentioned, deriving from chemical or chemical-physical modifications, and the scaling-up of their pharmaceutical applications.

2.2.1 Sodium Alginate

Brown macroalgae is the main source of sodium alginate as a major structural component of cell wall and intercellular matrix. Commercial varieties of alginate are extracted from seaweed, including the giant kelp *Macrocystis pyrifera, Ascophyllum nodosum, Sargassum sinicola*, and various types of Laminaria. The chemical compound, sodium alginate is the sodium salt of alginic acid. Its empirical formula is \( \text{NaCs}_\text{H}_\text{vO}_\text{e} \). It ranges from white to yellowish-brown, and available in filamentous, granular and powdered forms. It absorbs water quickly and it is capable of absorbing 200-300 times its own weight in water. Basically sodium alginate is a polysaccharide and is composed of \((1 \rightarrow 4)\) linked \(\beta\)-D-mannuronic acid and \(\alpha\)-L-guluronic acid. Monomers are arranged in three types of block structure. These blocks may be homopolymeric block (M block, G block) or heteropolymeric block (MG block). MG blocks are known due to most flexible chain formation while M block for its strong immuno-stimulating property. Gel formation property of sodium alginate is due to G block which form stiff chains and cross linked by divalent cations. The source of alginate determines the relative amount of block type. The monomers composition and its sequence govern the functional properties of sodium alginate. Gel and film forming properties and dietary function of alginate made it the most demanding marine material in food and pharmaceutical industries. It is also produced by two bacterial genera *Pseudomonas* and *Azotobacter*, which played a major role in the unravelling of its biosynthesis pathway. Bacterial alginates are useful for the production of micro- or nanostructures suitable for medical applications.

2.2.2 Radiation-induced degradation

Radiation induced degradation can be carried out by the method of Nagasawa *et al.* (2000). The solid material of sodium alginate seals in a glass tube with air atmosphere. The 1 or 4% aqueous solution of alginate in an open glass container irradiates in air or
with N₂ or O₂ gas bubbling through the solution. The irradiation carries out using gamma rays from Co-60 sources with a dose rate of 10 kGy/h.

2.3 Effect of depolymerised polysaccharides on various aspect of plant processes

Tomoda et al. (1994) reported the effect of sodium alginate depolymerized by treating with alginate lyase on barley root elongation. They found that depolymerised alginate (alginate lyase lysate) has growth promoting effect on the elongation of barley root, and especially that of the radicle. They observed that effective concentration of alginate lyase lysate for elongation of roots being 100-300 µg/mL, with no inhibition at the highest concentration. When a radicle was brought into contact with alginate lyase lysate responded by initiating elongation within 2 to 4 hours. They noted that elongation rate increased from 2.9 mm/h to 5.3 mm/h. They also observed 2-3 fold increase in the alcohol dehydrogenase activity in treated plants under hypoxic conditions.

Naotsugu et al. (1998) carried out analyses of UV and ESR spectra and measurement of molecular weight of irradiated alginate. They observed that degradation of alginate being mainly occurred at glycosidic linkage by irradiation for all irradiation conditions. They found that 90 kGy irradiated alginate concentration of 150 ppm is most effective as plant-growth promoter for barley.

Akimoto et al. (1999) studied the effects of alginate on the physiological activities of plant cells. They tested various concentrations of alginate oligomer (AO), chitosan oligomer (CO) and oligogalacturonic acid (OGA) on the physiological activities, membrane permeability and protoplast formation of Catharanthus roseus L. or Wasabia japonica cells and found that AO and OGA showed similar physiological effects, which were quite different from those of CO. Since alginate appeared to have similar effects to galacturonic acid, they concluded that alginate acts as an endogenous elicitor. Both alginate and galacturonic acid are uronic acids, and they considered their structural similarity. They also studied the effects of esterification of the carboxylic groups of alginate by propylene oxide. Furthermore, they noted that the secretion of 5'-phosphodiesterase decreased with increasing the degree of esterification.

Iwasaki and Matsubara (2000) studied the effect of alginate oligosaccharides on the growth promotion of lettuce. They degraded the sodium alginate by alginate lyase from Corynebacterium spp. and product was purified by an ultrafiltration membrane.
They obtained a mixture of di- to octasaccharides of sodium alginate that had promoting activity towards lettuce root elongation in the concentration range of 200-3000 µg/mL. They also examined the effect of the degree of polymerization on growth promoting activity of sodium alginate by using each oligosaccharide fractionated by gel chromatography. They observed that tri-, tetra-, penta-, and hexasaccharides were each found to have growth promoting activity in a lettuce bioassay.

Hien et al. (2000) investigated the effect of the irradiated alginate with a molecular weight less than 10^4 on the growth-promotion of rice and peanut. Alginate was degraded by gamma-rays irradiation from a Co-60 source in liquid state (powder form). Low concentration of degraded alginate from 4% solution irradiated at 100 kGy is effective for the growth-promotion of plants and the suitable concentrations are ca 50 ppm for rice and ca 100 ppm for peanut. They observed that degraded alginate obtained from higher dose (upto 200 kGy irradiated in liquid state) showed a strong effect on the increase of dry matter of rice seedlings. They observed similar effect for alginate powder irradiated at 500 kGy. In case of peanut, they found 60% more dry matter of peanut shoot than that of control. They also conducted field experiment on tea, carrot and cabbage to find out the effect of foliar spraying of degraded alginate. They observed significantly increase in productivity of ca 15-40% for above crops treated with 20-100 ppm concentration of degraded alginate.

Tham et al. (2001) investigated the role of irradiated chitosan to reduce adverse effect of vanadium toxicity in soybean, rice, wheat and barley. They observed that wheat and barley were sensitive to vanadium than rice and soybean but all seedlings of these plants were damaged at 2.5 µg/mL vanadium (in VCl₃). These damages were reduced by application of radiation-degraded chitosan. The recovery of growth and reduction of vanadium levels in seedlings were obtained by the treatments with 10-100 µg/mL chitosan irradiated at 70-200 kGy of gamma rays in 1% solution. The reductions of vanadium and Fe contents in plants were due to the ability of chitosan to form chelate complexes with metals in solution. They concluded that chitosan irradiated at suitable doses (ca. 100 kGy) is effective as plant growth promoters and heavy metal eliminators in crop production. They also found that unirradiated chitosan induced the various levels of chlorosis in the shoots of seedlings. The chlorosis was decreased at 50 kGy and
disappeared at 100 kGy. The promotion effect of chitosan on growth of rice without chlorosis was observed at higher doses of 70-200 kGy. The promotion effect was observed at the concentrations of 10-200 μg/g of irradiated chitosan.

Luan et al. (2001) studied the effect of irradiated chitosan on growth performance of flower plants namely Limonium latifolium, Eustoma grandiflorum and Chrysanthemum morifolium in tissue culture. They reduced viscosity molecular weight ($M_w$) of chitosan with 80% degree of deacetylation to $1.5 \times 10^5$ by irradiation of 50 kGy in solid phase. They further irradiated the solution of 10% chitosan at a dose of 10-250 kGy and the products were supplied into culture media. They observed that irradiated chitosan showed a strong growth-promotion effect on the increase of the lengths of shoot and root as well as fresh biomass for flower the above plants in tissue culture. The growth-promotion effect was obtained by the treatments with 50 ppm of chitosan irradiated at the doses of 75-100 kGy in 10% solution. The suitable concentrations of chitosan irradiated at 100 kGy are ca. 100 ppm for C. morifolium, 30 ppm for E. grandiflorum and 40 ppm for L. latifolium. In addition, their study also indicated that the survival ratio of transferred flower plantlets treated with irradiated chitosan was improved after acclimatizing for 30 days in the greenhouse. Accordingly, they concluded that degraded chitosan obtained by radiation degradation technique is effective as a plant growth promoter.

Kume et al. (2002) studied the process of upgrading and utilization of carbohydrates such as chitosan, sodium alginate, carrageenan, and cellulose, pectin for recycling these bio-resources and reducing the environmental pollution. These carbohydrates were easily degraded by irradiation and induced various kinds of biological activities such as anti-microbial activity, promotion of plant growth, suppression of heavy metal stress, phytoalexins induction, etc. They tested plant growth promotion activity of degraded carbohydrates under hydroponic condition. Degraded alginate in 4% alginate solution irradiated at 100 kGy or from powder irradiated at 500 kGy had a remarkable effect on growth promotion of rice.

Aoyagi et al. (2002) investigated the distribution of alginate oligomers (AO) which are endogenous elicitor-like substances, in cultured plant cells by using AO conjugated with monopotassium 7-amino-1, 3-naphthalenedisulfonate (ANDS). When
AO-ANDS was added at 0.5 g L\(^{-1}\) to the *Catharanthus roseus* cell culture, it adhered to the cells as observed by fluorescence microscopy. Using protoplasts of *C. roseus*, AO-ANDS was found not only in the cell walls but also in the cell membrane and cytoplasm. When *C. roseus* was cultivated in a medium containing oligo-galacturonic acids, as an endogenous elicitor, this was also found in the cell wall, cell membrane and cytoplasm of *C. roseus* cells. Similar results were also obtained with *Wasabia japonica* cells.

Hafeez *et al.* (2003) studied the effect of irradiated chitosan on growth performance of Chinese Kale (*Brassica oleracea* var. *alboglabra*) and observed that chitosan irradiated at 200 kGy showed significant increase on the growth rate of Chinese Kale. They used 10, 50, and 100 ppm concentration of irradiated chitosan in hydroponic culture. They concluded that irradiated chitosan at suitable radiation rate can be applied in modern commercial farming as it can shorten the harvesting period of certain plants and help in reducing the dependency to insecticide and chemical fertilizers.

Lam and Diep (2003) tested various samples of chitosan irradiated at doses ranging from 20 to 200 kGy on the growth performance of fungi. They reported that degree of deacetylation of chitosan clearly affects its antifungal activity, the higher the deacetylation of chitosan, stronger antifungal activity can be observed. Radiation treatment at doses higher than 20 kGy increased clearly the antifungal activity of chitosan. In addition, dose of 60-75 kGy where the viscosity average molecular weight reduced to 110,000, expressed the highest activity.

Luan *et al.* (2003) studied the effect of irradiated alginate on flower plants in tissue culture. They irradiated alginate [molecular mass (*M*\(_w\)) of approx. 9.04×10\(^5\) Da] at 10–200 kGy in 4% (w/v) aqueous solution. The degraded alginate product was used to study its effectiveness as a growth promoter for plants in tissue culture. They reported that alginate irradiated at 75 kGy with an *M*\(_w\) of approx. 1.43×10\(^4\) Da had the highest positive effect in the growth of flower plants, namely limonium, lisianthus and chrysanthemum. Treatment of plants with irradiated alginate at concentrations of 30–200 mg/L increased the shoot multiplication rate from 17.5 to 40.5% compared with control. In plantlet culture, 100 mg/L irradiated alginate supplementation enhanced shoot height (9.7–23.2%), root length (9.7–39.4%) and fresh biomass (8.1–19.4%) of flower plants.
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The survival ratios of the transferred flower plantlets treated with irradiated alginate were almost the same as the control value under greenhouse conditions. However, better growth was attained for the treated plantlets.

Hu et al. (2004) studied the influence of alginate-derived oligosaccharide (ADO) on the maize seed germination at different concentrations. They reported the effect of ADO concentration on $\alpha$- and $\beta$-amylase activities in different germination stages. Variation in $\alpha$- and $\beta$-amylase activities of day 0 seeds showed the identical tendency, both amylase activities reached at peaks response at 0.75% ADO. Compared with the control, root growth on days 3 and 7 showed increases of 34% and 18%, respectively, and shoot growth on day 7 an increase of 46%. In the case of protease activity, treatments with both 0.75% and 1.50% alginate-derived oligosaccharide gave higher activities than the control. Protease activities in 7 day old sets were remarkably higher than those in 0- and 3-day-old sets. These results indicate that the rate of seed germination was enhanced by increasing the activities of several enzymes beneficial for germination.

Hu et al. (2005) studied the antibacterial activity of lyase depolymerised alginate against 19 bacterial strains. They obtained a series of mannuronic acid (M-block) and guluronic acid (G-block) fraction by lyase depolymerization of alginate. They observed that fraction of mannuronic acid (M-block) and guluronic acid (G-block) showed antibacterial activity against certain tested bacteria, whereas M-block fraction showed broader spectra and more potent inhibition than G-block fractions. Among these fractions, the fraction has molecular weight 4.235 kDa exhibited the broadest spectrum of inhibition and high inhibitory activity against *Escherichia coli*, *Staphylococcus aureus* and *Bacillus subtilis*.

Luan et al. (2005) studied the effect of irradiated chitosan on plants in vitro condition. They reported that chitosan with an 80% degree of deacetylation and a weight-average molecular mass ($M_w$) of approx. 48 kDa was irradiated with $\gamma$-rays at doses up to 200 kGy in a 10% (w/v) solution. The $M_w$ of chitosan was reduced from 48 to 9.1 kDa by irradiation. They observed that supplementation with irradiated chitosan increased the fresh biomass of shoot clusters (7.2–17.0%) as well as the shoot
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multiplication rate (17.9-69.0%) for *Chrysanthemum morifolium* (florist’s chrysanthemum), *Limonium latifolium* (limonium or sea-lavender), *Eustoma grandiflorum* (lisianthus, tulip gentian or Texas bluebell) and *Fragaria ananassa* (modern garden strawberry). The optimum concentrations of irradiated chitosan were found to be approx. 70-100 mg/L for chrysanthemum, 50-100 mg/L for lisianthus and 30-100 mg/L for limonium. For the plantlet culture, the optimum concentrations were found to be approx. 100 mg/L for chrysanthemum, 30 mg/L for lisianthus, 40 mg/L for limonium and 50 mg/L for strawberry. Supplementation with optimum concentrations of irradiated chitosan resulted in a significant increase in the fresh biomass (68.1% for chrysanthemum, 48.5% for lisianthus, 53.6% for limonium and 26.4% for strawberry), shoot height (19.4% for chrysanthemum, 16.5% for lisianthus, 33.9% for limonium and 25.9% for strawberry) and root length (40.6% for chrysanthemum, 66.9% for lisianthus, 23.4% for limonium and 22.6% for strawberry). In addition, treatment with irradiated chitosan enhanced the activity of chitosanase in treated plants and also improved the survival ratio and growth of the transferred plantlets acclimatized for 10-30 days under greenhouse conditions.

El-Rehim (2006) investigated gel content and the swelling behavior of crosslinked copolymers of the polyacrylamide/sodium alginate (PAAm/Na-alginate) prepared by using electron beam irradiation. The addition of PAAm/Na-alginate copolymer in small quantities to sandy soil increased its ability to retain water. The growth and other responses of the faba bean plant cultivated in a soil treated with PAAm and PAAm/Na-alginate copolymer were investigated. The growth of the bean plant cultivated in a soil containing PAAm/Na-alginate was better than that cultivated in soil treated with PAAm. The most significant difference between the PAAm and its alginate copolymer is that the latter partially undergoes radiolytic and enzymatic degradation to produce oligo-alginate, which acts as a plant growth promoter. The increase in faba bean plant performance by using PAAm/Na-alginate copolymer suggested its possible use in the agriculture field as a soil conditioner, providing the plant with water as well as oligo-alginate growth promoter.

Quang *et al.* (2006) conducted an experiment to study the effect of irradiated chitosan on the growth performance of barley and soybean. They used chitosan
irradiated at 25-200 kGy in 10% solution and observed positive effect on the growth of barley, however, the unirradiated chitosan inhibited the growth of this plant. They also observed that plants that received the 100 kGy irradiated chitosan product with average molecular weight (Mw) approx. 16 kDa showed the highest response. They separated the degraded samples using ultrafiltration membranes and found that the fraction F2 with Mw in range of 1-3 kDa not only showed a remarkable effect on the growth of barley and soybean, but also significantly increased the activity of phytoalexin enzymes, namely phenylalanine ammonia lyase (87%) and chitinase (186%). Further, they observed that fraction with Mw in range of 1-3 kDa increased 15.8% seed yield of soybean after three month cultivation. Their results suggested that the irradiated chitosan fraction F2 with Mw in range of 1-3 kDa was a trigger for plant growth activity.

Aoyagi et al. (2006) observed that combination of *Alteromonas macleodii* (as exogenous elicitor) and 0.1% (w/v) alginate oligomers (AO: acting as both endogenous elicitor and scavenger of active oxygen species) minimized the cell growth inhibition but enhanced PDase (5′-phosphodiesterase) production (0.474 U/mL) about 20 times higher than the control (no addition). The method for the preparation of mixed alginate elicitors with high activities containing exogenous elicitor (autoclaved *A. macleodii*), endogenous elicitor (AO), and trans-4, 5-dihydroxy-2-cyclopenten-1-one was developed. The mixed alginate elicitors significantly promoted PDase production (2.67 U/mL) by *Catharanthus roseus*, and the productivity was increased 120-fold compared to the control without cell growth inhibition.

Chmielewskia et al. (2007) studied the method of degradation of natural amino polysaccharides to obtain a product applicable as biospecimen in protection and stimulation of the plants growth. They depolymerized the chitosan by chemical degradation combined with irradiation method. The efficiency of these methods was verified by viscometric analysis. They obtained the product with lower crystalline phase content from initial one what was proved by X-ray diffraction studies. They performed preliminary agricultural tests on spring rape seeds. They showed that the biggest growth was observed for chitosan (molecular weight 47,000 Da) in concentration of 0.1 g/kg of seeds. The higher concentration did not affect plant's growth. The average growth over-
ground plant parts was about 16–22%, diameter of roots was about 11–13%, and mass of roots was about 51–65% higher in comparison to the control.

Wisniewska-Wrona et al. (2007) studied the biological properties of chitosan degraded product. They used microcrystalline chitosan to obtain oligoaminosacharides by the enzymatic degradation. They estimated the biological properties of microcrystalline chitosan and the products of its degradation on the basis of the influence of these preparations on the germination ability of radish seeds, and the retardation ability to bacteria and mycotic diseases of plants, as well as of plant viruses. They performed weight-pan method, with the use of filter paper discs saturated with a suspension of chitosan and oligomers of pre-determined concentration of 0.1%, 0.01%, and 0.001% to estimate the germination ability of radish seeds. The influence of the preparations on the germination ability was estimated after 48 hours, on the basis of the number of germinated seeds, the green mass and the length of the germs in relation to the control test with use of water. Their results showed that all tested chitosan forms stimulate germination of radish seeds, but the chitosan oligomers with concentration of 0.01% were characterised by the most advantageous action, the length increase of the germs was by about 55% and that of the mass by about 26% in relation to control tests. The partially degraded chitosan (MCCh 2) and the initial chitosan (MCCh 1) slightly less effective stimulated the seeds germination. The chitosan oligomers stimulated the germination of the radish test seeds at a lower preparation dose in comparison with microcrystalline chitosan.

Mollah et al. (2009) reported the effect of sodium alginate irradiated by gammaradiation (Co-60) of various doses (12.5-50.0 kGy) on the growth performance of on the vegetable red amaranth (Amaramhus cruentus L.). They observed that the irradiated sodium alginate of 37.5 kGy at 150 ppm solution showed the best performance. Dry matter of red amaranth significantly increased at 37.5 kGy of irradiated alginate treatment which was about 50% higher than that of the untreated samples. The effect of sodium alginate on red amaranth significantly increased plant height (17.8%), root length (12.7%), number of leaves (5.4%) and maximum leaf area (2%) compared to that of the control vegetative plant production.
Hewajulige et al. (2009) studied potential use of gamma irradiated chitosan for control of the anthracnose disease causing organism, *Colletotrichum gloeosporioides*, and extension of storage life of papaya varieties ‘Ratna’ and ‘Red Lady’. They used chitosan in powder form irradiated with different doses viz. 5, 10, 25, 50, 75, 100 and 150 kGy of Co-60 gamma rays-in order to enhance antifungal activity. They observed complete inhibition of growth in both fungal strains on PDA plates incorporated with 1% chitosan solution at all irradiated doses compared with that of the control (distilled water). The plates incorporated with nonirradiated chitosan (0 kGy) and inoculated with the fungus isolated from ‘Red Lady’ papaya showed slight mycelial growth while ‘Ratna’ isolate showed complete inhibition of growth with this treatment. However, irradiated chitosan powder was found to be less effective in inhibiting *in vitro* growth of both fungal strains, 1% chitosan solution (in 10% acetic acid) irradiated at the lowest dose (5 kGy) was selected for *in vivo* experiments on storage life extension of papaya fruits. 80% marketable quality fruits were observed in ‘Ratna’ papaya while 70% marketable quality fruits were observed in ‘Red Lady’ subjected to irradiated chitosan treatment and stored at 13.5°C, 95% RH for 14 days followed by 2 days at ambient temperature (28°C ± 2).

Sarfaraz et al. (2010) conducted a pot experiment to study the effect of gamma-rays degraded sodium alginate on the performance of growth and yield of fennel. They took two controls for this experiment. They observed that foliar spraying of radiation degraded alginate improved the growth (shoot and root lengths, number of leaves, fresh and dry weights), biochemical attributes (total chlorophyll content, carotenoids content and proline content) and yield (umbels per plant, umbellets per umbel, hundred seed weight and seed yield) of fennel (*Foeniculum vulgare*). Among the different concentrations of radiation degraded alginate, 80 ppm concentration (IR80) had clear effect on all the parameters studied. They concluded that radiation degraded alginate can act as plant growth promoter for fennel (*Foeniculum vulgare*). The results also showed that the best concentration of radiation degraded alginate (radiated at 520 kGy) to enhance the growth and yield of fennel (*Foeniculum vulgare*) was 80ppm. Number of umbels, umbellets, 100-seed weight and seed yield were significantly increased by 80ppm and gave 68.0, 70.4, 33.1 and 62.3% higher values for these parameters over the control.
Khan et al. (2010) conducted a pot experiment to study the effect of foliar sprays of irradiated sodium alginate on the performance of poppy (*Papaver somniferum* L.) in terms of growth characteristic, yield parameter and alkaloids production. They observed that the effect of unirradiated sodium alginate (UN) was found not significant for most parameters in comparison to control. They observed that treatment IR-120 ppm showed highest response and gave 37.5, 63.5, 59.8, and 47.6% higher values for shoot length, root length, fresh and dry weight of plant respectively. They also found higher values for physiological parameter in plants treated with IR-120. Parameter like chlorophyll a, chlorophyll b, total chlorophyll, total carotenoid contents and leaf nitrogen content registered 20.5, 33.9, 43.1, 31.4 and 23.0% higher values in plants treated with IR-120 ppm than that of control. She also studied nitrate reductase activity and carbonic anhydrase activity in treated plants and 31.7 and 28.2% higher values noted in plants treated with IR-120 ppm. Yield parameters like capsule dry weight, seed yield, and crude opium were also higher in treated plants. They also performed the HPLC analysis of crude opium and found that irradiated sodium alginate did not increase the morphine content, however codeine content was doubled and thebaine content and noscapine contents increased significantly in plants treated with IR-120 ppm.

Idrees et al. (2010a) conducted a pot experiment to study the effect of gamma irradiated sodium alginate on growth, photosynthesis, physiological activities and alkaloid production of *Catharanthus roseus* L. variety ‘Rosea’. Sodium alginate was irradiated at 520 Kilo Gray using Co-60 gamma rays and the degraded alginate product was used to study for its effectiveness as a plant growth promoter for *Catharanthus roseus* L. The plants sprayed with Control (deionised water sprayed plants ($T_0$), 20 ppm irradiated sodium alginate ($T_1$), 40 ppm irradiated sodium alginate ($T_2$), 60 ppm irradiated sodium alginate ($T_3$), 80 ppm irradiated sodium alginate ($T_4$) and 100 ppm irradiated sodium alginate ($T_5$). They observed that irradiated sodium alginate showed promotive effect on the growth and alkaloids production of *Catharanthus roseus* L. Further, they reported that irradiated sodium alginate at 80 ppm concentration significantly enhances the growth, photosynthesis physiological activities and alkaloids production of the plant.
2.4 Various strategies that applied to enhance the essential oil of *Mentha* and *Cymbopogon*

The essential oil, a product obtained from these plants is located in the leaves of the mint and lemongrass. Till date, there was no reference found related to irradiated sodium alginate on these particular plants, however, various strategies had applied to enhance the essential oil of these plants including the application of nutrients, fertilizer and plant growth regulators. Some of the work carried out in this regard on different species of genus *Mentha* and *Cymbopogon* is mentioned below.

### 2.4.1 *Mentha arvensis*

Farooqi and Sharma (1988) conducted field experiments with Japanese mint using different growth retardants. They observed that chlormequat chloride (2-chloroethyltrimethylammonium chloride) increased the oil content significantly and inhibited growth to some extent only whilst ethephon (2-chloroethyl phosphonic acid) at 0.06% concentration significantly decreased growth but had no significant effect on oil production. Among the two oil components studied, menthone content only was significantly increased by 0.06% ethephon whereas the other growth retardants proved ineffective. Correlation studies indicated a strong negative relationship of leaf/stem ratio with plant height and herb yield while a strong positive relationship was obtained between the latter two characters. The oil content of the plant was negatively correlated with herb yield and plant height but it was related positively with leaf/stem ratio.

Subrahmanyam *et al.* (1992) conducted a field experiments to investigate the influence of soil and foliar applied Fe on yield and Fe status of MAS-1 and Hybrid-77 Japanese mint. They noted significant oil yield increase with two applications of Fe-EDTA (Iron-ethilenediaminetetracetic acid complex), and FeSO₄ in mixtures with ammonium sulphate and mint compost (mint distillation waste) and four split applications of FeSO₄ (total Fe of 12 kg ha⁻¹) between sprouting and 30 days after first harvest compared to the control. The highest oil yields from two harvests (180 kg ha⁻¹) were consistently obtained with the Fe-EDTA treatment. Soil application by FeSO₄ at sprouting stage and first harvest proved ineffective compared to Fe-EDTA application. Foliar application of 30 kg ha⁻¹ of Fe-EDTA resulted in oil yields equal to the yields
obtained with soil application of 140 kg ha\(^{-1}\) of Fe-EDTA. Fe applications increased the concentration and the total uptake of Fe by the crop. Foliar application of Fe-EDTA at two weeks interval alleviates Fe-chlorosis in Japanese mint.

Patra et al. (1993) conducted field experiment to study the influence of organic mulches viz. paddy straw and citronella (Cymbopogon winterianus Jowitt) distillation waste on herb and essential oil yield and fertilizer N use efficiency in Japanese mint (Mentha arvensis L.) for two years. They observed that herb yield (dry weight) increased by 17 and 31\% with paddy straw and citronella distillation waste, respectively over the use of no mulch. Essential oil yield also significantly increased due to mulching. A significant response to N was observed with 200 kg N ha\(^{-1}\) in unmulched plots as against 150 kg N ha\(^{-1}\) in mulched plots. Mulched soils have been observed to contain 2 to 4\% higher moisture as compared to unmulched soils. Nitrogen uptake increased by 18 and 25\% over no mulch with using paddy straw and citronella distillation waste, respectively.

Chattopadhyay et al. (1993) compared the efficiency of mint-residue, composted alone and amended with starter nutrients, microbial culture and soil suspension (hereafter termed amended compost) with farmyard manure and inorganic fertilizer on the yield of Japanese mint (Mentha arvensis L.) and improvement of soil fertility. They observed that herbage, essential oil yield, nutrient uptake of Japanese mint and soil available nutrients were significantly enhanced due to application of amended compost as compared to non-amended compost, farmyard manure and inorganic fertilizer. Organic fertilized soils maintained significantly higher available nutrients throughout the crop growth period as compared to inorganic fertilized soils. No additional improvement in yields and soil fertility was recorded with combined application of compost and inorganic fertilizer in 1:1 ratio as against addition of compost alone. Advantage of such combinations was recorded in case of farmyard manure. They suggested possibilities for nutrient recycling through composted mint-residue for supplementing the fertilizers requirement of Japanese mint.

Ram et al. (1995) conducted a field experiment at the Central Institute of Medicinal and Aromatic Plants, Lucknow, India during 1988 and 1989 to evaluate the relative performance of pyrethrum flower waste and Dicyandiamide (DCD) as
nitrification inhibitors applied with prilled urea (PU) to Japanese mint (*Mentha arvensis* L.). They found that application of the nitrification inhibitors with prilled urea significantly increased the herb and essential oil yield of the crop compared to that of prilled urea alone. They also observed that addition of Dicyandiamide and pyrethrum flower waste gave 30 and 23% higher herb yield than prilled urea alone, the corresponding increase in oil yield being 27 and 22%, respectively. Application of nitrogen at 200 kg ha$^{-1}$ in dicayndiamide or pyrethrum flower waste treated soil significantly enhanced the herb and essential oil yields and N-uptake by the crop to more than that for 300 kg N ha$^{-1}$ with prilled urea. Both the materials improved the N use efficiency by one and half time as compared to that with PU at 100 kg N ha$^{-1}$. Their results indicated that pyrethrum flower waste can be effectively used as a potential nitrification inhibitor.

Patra (1997) conducted laboratory incubation and greenhouse experiments with two soils having contrasting physico-chemical characteristics to evaluate nitrogen (N) mineralization, immobilization in soil microbial biomass, and accumulation in Japanese mint (*Mentha arvensis* L.) using labelled ($^{15}$NH$_4$)$_2$SO$_4$, applied at 0, 50, and 100 mgkg$^{-1}$ soil. Rate of mineralization in soils varied from 0.08 to 2.21 μg g$^{-1}$ day$^{-1}$. They observed that fertilizer application increased the mineralization of native soil N and about 22 to 60% of the applied $^{15}$N was recovered in the soil microbial biomass during the growth period of mint (January-June). Relative contribution of fertilizer $^{15}$N towards total N uptake by mint at maturity was 42-54% in soil I and 35 to 55% in soil II. Contribution of soil N towards total N accumulation increased with the doses of $^{15}$N application.

Ram and Kumar (1997) carried out field experiments during winter-summer seasons to study the effects of organic wastes and/or manures on the regenerated and transplanted mint crops as well as rescheduling of the harvest time in the sucker-planted crop. The treatments studied were of citronella (*Cymbopogon winterianus*) distillation waste and pea (*Pisum sativum*) straw mulches at 7 t ha$^{-1}$, farmyard manure (FYM) at 20 t ha$^{-1}$ at planting, FYM at 20 t ha$^{-1}$ after the first harvest and a control (no application of mulch and FYM), supplementary to the inorganic N fertilisation at 0, 80, 160 and 240 kg N ha$^{-1}$. They observed that the use of citronella distillation waste as mulch and FYM were most effective in enhancing the total herb and essential oil yields (planted +
regenerated harvests) when the planted crop was harvested at 110 days after planting. The yield of regenerated crop improved significantly in the plots that had received citronella mulch or FYM during the planted-crop period, as compared with that of the control; citronella-waste mulch treatment proved better than FYM treatment. Application of 160 kg N ha\(^{-1}\) in the form of inorganic fertilizer and citronella distillation waste mulch at 7 t ha\(^{-1}\) met the N requirements of the transplanted mint crop. Mulch applications improved the efficiency of utilization of inorganic N by about 10%. Application of mulch had no effect on the quality of the oil obtained in the first harvest of the sucker-planted crop and in the transplanted crop. They recommended that under subtropical conditions, citronella distillation waste mulch should be applied after the sprouting of suckers during the planted crop period to obtain higher yields of herb and essential oil from the planted as well as the regenerated crop harvests. In order to get the maximum yield advantages from both the harvests, the planted crop should be harvested at 110 days after planting. The use of citronella-waste mulch with 160 kg N ha\(^{-1}\) minimised the cost of transplanted mint production by a factor equivalent to one third.

Rao (1999) conducted field experiment to study the influence of planting commint (Mentha arvensis L. f. piperascens Malinvaud ex Holmes) in different months on its biomass and essential oil yields. He observed that crops planted in the month of August (rainy), November (autumn), and December (winter) produced significantly superior total biomass and essential oil yields compared to September and January planted commint. He also indicated the feasibility of intercropping corn mint with tomato (6.3 t/ha) during the first harvest period. The quality of the essential oil with 73.0% menthol, 9.6% menthone, 4.0% isomenthone, and 4.0% menthyl acetate was found to be good and readily accepted in the market. This investigation in a farmer’s field with 42.5–63.5 t/ha total biomass yield and 196.3–271.5 kg/ha total essential oil yield, clearly demonstrated the economic feasibility of cultivating corn mint in semi-arid tropical climate.

Farooqi et al. (1999) conducted an experiment on mentha species to study the effect of different photoperiodic regimes on growth, flowering and essential oil. They planted the subterranean suckers (runners) of these plants in earthen pots and allowed to establish and resume growth as plantlets for 15 days under natural day-night light – dark
conditions during the month of January. Subsequently, they categorized randomly pots containing plantlets of each species into three sets for exposure to three different photoperiods: these being normal days (ND), long days (LD) and short days (SD) for 60 cycles. They observed that photoperiodic treatments showed clear effect on the overall performance of mentha. They also observed that three *Mentha* species (*M. arvensis*, *M. citrata*, and *M. cardiaca*) are long day plants, exhibited substantially higher vegetative proliferation under long-day conditions, however, shorter day conditions resulted in slower growth. The leaf/stem ratio observations showed that reduced leafy plant canopy under short day conditions enhanced the ratio, as compared to those observed with normal and long-day conditions. They also observed that the oil concentration and biogenesis was maximal in short-day plants. The photoperiodic treatment also affected the oil composition.

Patra *et al.* (2000) conducted field experiments for 2 years at two different locations (i.e. Lucknow and Pantnagar) in Uttar Pradesh, India to assess the herb and essential oil yields of Japanese mint (*Mentha arvensis* cv. Hy 77), and its nutrient accumulation under single and combined application of organic manures and inorganic fertilizers (NPK). They also determined changes in physical and chemical characteristics of the soils (Fluvisols, Mollisols). They compared eight treatments comprising different combinations of NPK through inorganic fertilizers and farmyard manure (FYM). They recycled the distilled waste of mint after extraction of essential oil to soils in the plots to supplement the nutritional requirement of the succeeding mustard crop (*Brassica juncea* cv. Pusa Bold). They found significantly higher herb and essential oil yield of mint with combined application of organic and inorganic sources of nutrients as compared to single application. They observed that accumulation of N and P was at par under full inorganic and combined supply, whereas, K accumulation was higher with the former. Soil organic C and pH after harvest of mint did not significantly differ among the treatments, but the level of mineralizable N, Olsen-P and NH₄OH extractable K were higher in soil with integrated supply of nutrients. They found significant increase in soil water stable aggregates, organic C, available NPK and microbial biomass, and decrease in soil bulk density with waste recycling over fertilizer application. This study indicated that combined application of inorganic fertilizers with organics helps in increasing the availability of nutrients and crop yield and provides a significant effect to the
succeeding crop. Similarly, recycling crop residues reduced the need for fossil fuel based fertilizer, and helped in sustaining and restoring soil fertility in terms of available nutrients and major physical and chemical characteristics of the soil.

Srivastava et al. (2002) studied the characteristics of menthol mint *Mentha arvensis* cultivated in the Indo-Gangetic plains. They reported considerable variation in the yield and quality of oil obtained from the crops of menthol mint varieties Himalaya and Kosi taken in the area. They also studied the soils sampled from the fields for variability in reaction, salinity, organic carbon content, the contents of the macro nutrients nitrogen, phosphorous and potassium and micro-nutrients manganese, iron, copper and zinc and crops of mint on the concerned fields that characterized for the herb, essential oil and menthol yields. They collected data from 69 farmer’s fields and found variation in soil characteristics, as well as herb, essential oil and menthol yields from the crops taken on them. However, they noted no difference in oil content of herbs harvested from different fields. They observed imbalance in N, P and K supplements to the different fields.

Bekiaroglou and Karataglis (2002) cultivated the clones of *Mentha spicata* in nutrient solution, to which lead and zinc were added in soluble form. The plants remained in a controlled environment for 2 weeks in this solution. They measured the root length of the plants and the chlorophyll content of the upper and lower leaves and also determined the lead and zinc contents of the plant tissue. They found that the increased concentration of metals resulted in a decrease in root growth and chlorophyll content. The relation that connects the concentration of the heavy metal to the decrease in root growth is logarithmic. They also observed that more lead than zinc entered the plant tissues, but unlike zinc did not reach the leaves.

Gupta et al. (2002) conducted field experiments to study the effect of inoculation with vesicular-arbuscular mycorrhizal (VAM) fungus *Glomus fasciculatum* on the root colonization, growth, essential oil yield and nutrient acquisition of three cultivars of menthol mint (*Mentha arvensis*); Kalka, Shivalik and Gomti. They observed that the VAM inoculation significantly increased the root colonization, plant height, fresh herbage and dry matter yield, oil content and oil yield as compared to non-inoculated cultivars. The effect of VAM inoculation on the root colonization, growth and yield of
mint was more pronounced with the cv Shivalik than the cvs Kalka and Gomati, indicating Shivalik as a highly mycorrhizal dependent genotype. VAM inoculation significantly increased the uptake of N, P and K by shoot tissues of mint, but most markedly increased the uptake of P. The VAM-inoculated mint plants depleted the available N, P and K in the rhizosphere soil as compared to non-inoculated control, however, the extent of nutrient depletion was greater for P than N and K. They concluded that the VAM inoculation could significantly increase the root colonization, growth, essential oil yield and nutrient acquisition of mint for obtaining economic production under field conditions.

Patra et al. (2003) studied the growth response of mint (*Mentha spicata*) to light and shade condition. They observed that shaded plants showed a decrease in biomass production, even though leaf number and area increased. They found more total chlorophyll but lower the chlorophyll a/b ratio in plants grown under shade than in those grown in light. They also found higher leaf area index and specific leaf weight in sunlight plants, whereas leaf area ratio and specific leaf area higher in shade plants. They suggested that *Mentha spicata* can be well adapted to high light intensities; although capable of growing under shade, its biomass production was higher under full normal light condition.

Kiran and Patra (2003) conducted field experiment to evaluate the relative performance of *Mentha spicata* and *Artemisia annua* oils and dementholized oil (DMO) as natural nitrification inhibitors in regulation of soil mineral nitrogen (N) and yield and N accumulation in Japanese mint (*Mentha arvensis* cv. Hy-77). They used dicyandiamide (DCD), a chemical nitrification inhibitor for comparative study and coated urea with the essential oils and DMO at the rate of 0.50% (w/w) of prilled urea. Results revealed that urea coated with these natural nitrification inhibitors significantly increased the herb and essential oil yields of the crop compared to DCD coated and uncoated urea. They observed that during the field experimentation in 1997, among the three nitrification inhibitors at 100 kg N ha⁻¹ rate of fertilizer application, the highest increase in oil yield (36.5%) was with *M. spicata* oil followed by the *A. annua* oil (21.6%) and DCD (16.5%) compared to uncoated urea while corresponding increases during 1998 with the *M. spicata* oil and DCD were 12.0 and 11.2%, respectively, while
it was the highest (16.2%) with DMO. With 200 kg N ha\(^{-1}\) application, increase in oil yield during 1997 with Artemisia oil was 46.7%, followed by \textit{M. spicata} oil (43.2%) and DCD (23.7%), while during 1998 corresponding increase with the \textit{M. spicata} oil and DCD were 14.5 and 10.3%, respectively. They suggested that higher yield of herb and essential oil may be attributed to better utilization of N by the crop due to retarded losses of N by these nitrification inhibitors. They concluded that these essential oil bearing plants can be used as potential nitrification inhibitors to reduce mineral N loss through different mechanisms thereby reducing the load of nitrogenous gases in the atmosphere and nitrate in the ground water.

Prasad \textit{et al.} (2003) conducted a pot experiment to compare the response of four mint and four cultivars of Japanese mint to the soil sodicity condition. They observed the significant inhibition in sprouting of all cultivars of Japanese mint by soil sodicity. The extent of inhibition in sprouting was greater in the cultivars Kalka and Himalaya than in the Shivalik and Koshi. They also observed a severe shoot injury symptom in \textit{M. citrata}, \textit{M. cardiaca}, and \textit{M. arvensis} after 50 days of transplanting at the soil ESP (Exchangeable sodium percentage) level 54.0 and in \textit{M. piperita} after 50 and 70 days of transplanting at the soils ESP levels 25.0 and 54.0, respectively. They noted that \textit{Mentha piperita}, grown on soils ESP of 25.0 and above, failed to survive after developing the shoot injury symptoms. Soil sodicity significantly restricted the herb yield of mint genotypes. At the ESP level of 54.0, the decrease in herb yield was 83.1, 92.2, 89.6, and 98.2\% over control in \textit{M. citrata}, \textit{M. cardiaca}, \textit{M. arvensis}, and \textit{M. piperita}, respectively. The reduction in the yield of Japanese mint at the soil ESP level of 45.0 was 53.8, 81.4, 53.2, and 71.4 \% over control in the cultivars Shivalik, Kalka, Himalaya, and Koshi, respectively. The oil yield of mint species was not significantly affected with increases in soil ESP level from 1.5 (control) to 25.0. Increases in soil sodicity enhanced the concentration of sodium (Na) and decreased that of potassium (K), calcium (Ca), and magnesium (Mg) in shoot tissues of mint genotypes as compared with control. The Na induced Ca nutrition imbalance had a greater impact on growth inhibition and shoot injury in \textit{M. piperita} than K and Mg nutrition imbalance. Decreases in K/Na, and Ca/Na ratios in shoot tissues of Japanese mint were significantly and positively correlated with decrease in herb yield. The relatively lower increase in Na and the capacity to maintain
high K/Na, Ca/Na and Mg/Na ratios in the cultivars Shivalik and Himalaya showed their greater tolerance to sodicity than that of Kalka and Koshi.

Hashmi (2004) conducted six experiments on Japanese mint (*Mentha arvensis* L.) in pots to study the effect of two nutrient (nitrogen and phosphorus) and two plant growth regulators (gibberellic acid and kinetin) on the growth, physiological and yield characteristics of the crop. She found that 90 kg N/ha and 30 kg P/ha proved best for most of the parameter studied. She also found that GA$_3$ at $10^{-4}$ M and kinetin at $10^{-5}$ M concentration proved very effective for the growth, physiological and yield characteristics.

Priti *et al.* (2005) conducted an experiment to compared response of five cultivars of Japanese mint (*Mentha arvensis* L. var. Piperascens Mal.) to water stress and ameliorative effect of chlormequat chloride. They found decrease in relative water content, water potential, herbage and oil yield under water stress, while abscisic acid, sugar content, peroxidase activity, oil and menthol content increased significantly. They observed that ameliorative effect of chlormequat chloride in stressed plants of different varieties. RWC, herbage and oil concentration increased and ABA and peroxidase activity decreased in chlormequat chloride treated stressed plants, as compared with untreated stressed plants. Observations suggested that chlormequat chloride can partially alleviate the detrimental effect of water stress in Japanese mint.

Singh and Singh (2006) studied the effects of phosphorus deficiency on carbohydrate fractions of *Mentha arvensis* L. var. Piperascens. They observed that phosphorus deficiency brought about a definite increase in all sugar fractions in leaves and root whereas a reduction was noticed in stem. The stem appeared to be the principal storage organ throughout the growth. Maximum sugar concentration was recorded at the age of 70 days, which represents the full maturity stage, and coincided with maximum essential oil accumulation.

Pande *et al.* (2007) conducted a pot experiment under glasshouse conditions to evaluate the response of *Mentha arvensis* (cv. Kushal), an essential oil bearing plant, to different concentrations of zinc (Zn) and iron (Fe) supply with respect to their influence on biomass, oil yield, and oil quality. They planted the suckers of Japanese mint with
four graded levels each of Fe and Zn (viz. 0, 5.0, 10.0, 25.0 mg Fe kg\(^{-1}\) and 0, 2.5, 5.0, 15.0 mg Zn kg\(^{-1}\)) and a combination of both the elements. The results indicated that fresh weight, oil content, and chlorophyll content increased significantly with increase in Fe supply, the optimum level was recorded as 10 mg Fe kg\(^{-1}\). Iron uptake increased significantly with increases in its supply. Zinc, when applied singly, showed enhancement in growth parameters, but the effects were nonsignificant. The optimal level of supply for Zn and Fe in *M. arvensis* was evaluated to be 5 mg Zn kg\(^{-1}\) and 10 mg Fe kg\(^{-1}\), respectively.

Arzani *et al.* (2007) conducted field experiments to evaluate the effect of some micronutrient minerals on twelve Iranian mint accessions, three of which belonging to *Mentha longifolia* (Mzin5, Mzin6 and Mzin11) and the remaining were *Mentha spicata* L. species (Mzin1, Mzin2, Mzin3, Mzin4, Mzin7, Mzin8, Mzin9, Mzin10, and Mzin12). They assigned to two essential nutrients, iron (Fe) and magnesium (Mg) concentrations of two mint herbage harvests in 12 mint clones within each of two studied years. They observed significant difference among accessions and a non-significant difference between species for Mg and Fe concentrations. Mean comparisons showed that Mzin2, Mzin12 (both belong to *M. spicata*) and Mzin6 (belongs to *M. longifolia*) possess the highest Fe concentration while Mzins 5, 6 and 11 belong to *M. longifolia* as well as Mzins 2 and 10 belong to *M. spicata* did not significantly differ and all included the first ranking group for Mg concentration. They found average Fe concentration on the first harvest ranged from 134 mg/kg for Mzin4 genotype (belongs to *M. spicata*) to 210 mg/kg to for Mzin5 genotype (belongs to *M. longifolia*), while Fe concentration at the second harvest varied from 315 mg/kg for Mzin1 to 582 mg/kg for Mzin12. At the first harvest, Mg concentration ranged from 748 mg/kg for Mzin1 to 1174 for Mzin5. At the second harvest, Mg concentration varied from 1171 mg/kg for Mzin9 to 1618 mg/kg for Mzin11. They concluded that the magnesium and iron concentrations of *Mentha species* are comparable to those reported for other leafy vegetable crops and evidenced that herb is rich in some essential nutrient minerals, especially Fe and Mg which are essential for human health.

Duriyaprapan and Britten (2009) conducted the experiment to study the effects of solar radiation on growth performance of Japanese Mint (*Mentha arvensis*). They grew
plants of Japanese mint under 100, 64, 49 and 28% conditions of prevailing radiation for 10 weeks, with harvests at 4, 6.8 and 10 weeks. They noted that the stem length and leaf area showed greatest morphological responses to increased shading intensity and little response showed by mean relative growth rate (RGR) or mean net assimilation rate (NAR) while that of mean leaf area ratio (LAR) marked. They found no significant differences in oil yield among different treatments at the final harvest nor there great differences in amounts of menthol and menthone, two important constituents of Japanese mint oil. Their results indicated that within the experimental limits imposed, Japanese mint tended to compensate in growth and oil production for shading effects.

Vimolmangkang et al. (2010) used the deep flow technique (DFT) to determine the differences between spearmint (Mentha spicata L.) and Japanese mint (M. arvensis L. var. piperascens Malinv.) cultivated in either soil or nutrient solution. They measured the differences in terms of harvest period (full bloom period) and quantity and chemical components of volatile oils. The spearmint and Japanese mint were cultivated in four different nutrient formulas: plant standard nutrient, plant standard nutrient with an amino acid mixture, plant standard nutrient with a sulphur compound, and a combination of plant standard nutrient with an amino acid mixture and a sulphur compound. They observed that cultivation of spearmint and Japanese mint in nutrient solution using DFT is an effective method to provide high production of volatile oil, since it results in an earlier harvest period and higher quantity of volatile oil. They determined that for spearmint an amino acid mixture is an appropriate nutrient supplement to enhance production of volatile oil with optimum carvone content. They observed high menthol content in Japanese mint grown in all four nutrient formulas. However, supplementation with a combination of sulphur fertilisation and amino acid mixture yields the highest quantity of volatile oil.

2.4.2 Cymbopogon flexuosus
Rao et al. (1984) conducted two field experiments to compare the efficiency of prilled urea and urea-supergranules in the cultivation of a perennial aromatic grass, citronella (Cymbopogon winterianus Jowitt) in a sandy loam soil. They used two N levels (150 and 300 kg N ha\(^{-1}\) year\(^{-1}\)) and two urea materials, prilled urea and urea-supergranules (USG), and a 'no nitrogen' control. They applied nitrogen in four splits in each year.
Prilled urea was applied in bands made in the ridges by the side of plant rows and the average depth of placement obtained without causing damage to roots and ridges was 2.5-3.0 cm. They observed that nitrogen application significantly increased herb and essential oil yields of citronella except in the fifth harvest and application of 300 kg N ha$^{-1}$ year$^{-1}$ resulted in the highest yields. Urea-supergranules significantly increased the total herb and oil yields over prilled urea at both levels of nitrogen.

Samiullah et al. (1984) conducted two simple randomized field experiments to study the effect of eight levels each of nitrogen (150, 200, 250, 300, 350, 400, 450, 500 kg N/ha) and of phosphorus (0, 25, 50, 75, 100, 125, 150, 175 kg P$_2$O$_5$/ha) was on the leaf N, P and K content of lemongrass (Cymbopogon flexuosus) at three cuts. Applied nitrogen had a significant effect on the concentration only of N at all three cuts and K at first and second cut. The N concentration increased significantly by different levels of N, of which N$_{200}$ at first and third cut and N$_{250}$ at second cut proved optimum. The maximum K concentration was found in treatment N$_{300}$ at first cut and N$_{500}$ at second cut. The effect of applied phosphorus on N, P and K content of leaves was significant at all three cuts. The concentration of these three nutrients was increased appreciably up to P$_{150}$ at first and third cut and up to P$_{125}$ at second cut.

Samiullah et al. (1988) conducted another field experiment with eight levels of basal nitrogen (150, 200, 250, 300, 350, 400, 450, 500 kg N/ha) and three harvest (120, 180 and 240 days after planting) to study the effect on height culms, leaves, fresh and dry weights, herb yield, oil content, oil yield and citral content of Cymbopogon flexuosus. The pooled data of three cuts revealed that the effect of nitrogen application was significant on all characteristic studied. It was inferred that nitrogen application benefited growth, yield and quality of lemongrass. Application of 300 kg N/ha proved best for most parameter including oil and citral contents.

Beech (1990) conducted an experiment on lemongrass (Cymbopogon citratus) grown on a sandy clay loam, to investigate its response to nitrogen (N) applications ranging from 0 to 1200 kg N/ha year$^{-1}$. They observed that urea and ammonium sulphate showed similar trend as nitrogen carriers. They obtained curvilinear response for overall N treatments with a linear response up to 600 kg/ha. They found significant increase in tiller number and leaf area index, while depressing specific leaf area and oil content in
plants that received higher N concentration. Additional nitrogen significantly decreased total dry matter of the unharvested portion of lemongrass (i.e. stools, rhizomes and roots). The amount of N, P and K in the harvested herbage increased manifolds in plants that received 900 kg N/ha year\(^{-1}\) treatments. They also noted considerable seasonal variation within the 6 harvests for all components measured.

Misra and Srivastava (1991) conducted an experiment to study the influence of different foliar applications of the triacontanol based plant growth regulator-'Miraculan', on growth, CO\(_2\) exchange and essential oil accumulation in lemongrass (*Cymbopogon flexuosus* Steud. Wats.) in glass-house conditions. They applied sprays of 'Miraculan' at 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 \(\mu\)g/mL at three growth stages namely tillering, flag leaf and pre-flower emergence. They observed that foliar sprays of 'Miraculan' at increasing concentrations from 0.0 to 0.4 \(\mu\)g/mL, enhanced the overall growth attributes, yield components and biomass production and significantly accelerated the accumulation of essential oil and hence metabolism but inhibited some other components at the highest concentration applied (0.6 \(\mu\)g/mL). All the concentration of PGR application significantly increased plant height, tiller number, total biomass, essential oil and its constituents geraniol, critral-a and citral-b, but not the number of leaves per tiller. They found significantly positive correlation between these characters. They observed a decreasing trend for all these parameters and growth attributes at concentrations, higher than the 0.5 \(\mu\)g mL\(^{-1}\) PGR treatment. The transpiration rate, CER and the total chlorophyll increased significantly up to 0.4\(\mu\)g mL\(^{-1}\) but then decreased at higher concentrations, however, stomatal resistance and chl a/b ratio values were the lowest at this concentration. They observed significantly increase at 0.4 \(\mu\)g mL\(^{-1}\) of 'Miraculan' treatment in the accumulation of essential oil and particularly the components citral-a and citral-b, whereas geraniol content remain unaffected at the different levels of Miraculan applied.

Singh and Singh (1992) conducted two field experiments for two crop cycles in two successive years on an entisols to study the effect of rate and sources of N application on yield and nutrient uptake of Citronella Java (*Cymbopogon winterianus* Jowitt). They used three sources of nitrogen (N), namely prilled urea, urea supergranules and Neem cake coated urea at five N rates (50, 100, 150, 200 and 250 kg N ha\(^{-1}\)). They
observed significantly influence on fresh herbage and essential oil yields by application of N up to 200 kg ha\(^{-1}\) yr\(^{-1}\), however only 150 kg N ha\(^{-1}\) increased tissue N concentration and N uptake. They also noted that the oil yields with Neem cake coated urea (urea granules coated with Neem cake) and urea super granules were 22 and 9% higher over that with prilled urea and urea supergranules were significantly increased up to 200 kg N ha\(^{-1}\) while with Neem cake coated urea, response was observed only to 150 kg N ha\(^{-1}\). Estimated recovery of N during two years from neem cake coated urea, urea supergranules and prilled urea were 38, 31 and 21%, respectively.

Sangwan et al. (1994) conducted an experiment to study the growth performance and essential oil metabolism of two species lemongrass under mild and moderate water stress. They observed that both the species suffered considerable decreases in plant height as well as in leaf length, dry weight and leaf area, under mild and moderate water stress. However, tillering in the plants remained un-changed. Compared to C. nardus, C. pendulus exhibited more pronounced restrictions to growth rate and leaf expansion under water stress conditions. They observed significant increase in oil content in both the species at ninety days of mild stress, however, the oil content did not increase significantly at 45 days in C. nardus whereas in C. pendulus a significant increase was evident under moderate stress. They also observed that after 90 days of moderate stress the response was species-specific as the oil content decreased significantly over the control in C. nardus, but in C. pendulus it persisted at the same elevated level as under mild stress. Oil yield per plant did not decline in the two species under mild and moderate stress after 45 days except in C. nardus where a decrease of 20% was noticed after moderate stress. But at 90 days, moderate water stress resulted in a significant decline in the oil yield per plant in C. nardus whilst the level was almost the same as the control in C. pendulus. Finally they concluded that plant growth was reduced considerably whilst the level of essential oils was maintained or enhanced. The major oil constituents, geraniol and citral increased substantially in both the species. Activity of geraniol dehydrogenase was also modulated under moisture stress. The responses varied depending upon the level and duration of moisture stress.

Singh (1999) conducted field experiment to study the effect of irrigation and nitrogen on herbage, oil yield and water use of lemongrass under three soil moisture
regimes (0±75, 0±50 and 0±25). They planted rooted slips of lemongrass with a spacing of 60 cm between rows and 30 cm between plants. They observed significant increased in fresh herbage and essential oil yields by irrigation, however effect was not significant for the change from 0±25 to 0±50 IW:CPE ratio at the first two harvests. They obtained similar results for oil yield. They found significant difference for both herbage and oil yields when compared the 0±25 and 0±75 IW:CPE ratios. They obtained low oil yield at 0±25 IW:CPE ratio due to moisture stress, which adversely affected crop growth. Further, they obtained significantly higher fresh herbage and essential oil yields in plants which received 100 kg N ha⁻¹ compared with that from 0 kg N ha⁻¹ (control). However, they observed that N application increased herbage and oil yield but there was found no significant difference between the highest application rate of 150 kg N ha⁻¹ and 100 kg ha⁻¹ when compared. They also studied the interaction effects of irrigation and N rates and found that interaction of irrigation and N rates significantly increased the production of herbage and essential oil yields. Finally they concluded that an application of 100 kg N ha⁻¹ was found to be optimal for crop yield. Oil content and quality of oil were not affected by irrigation and nitrogen rates.

Farooqi et al. (2005) conducted an experiment to study the ameliorative effect of chlormequat chloride and IAA on the growth and essential oil content of Cymbopogon martini and C. winterianus under drought stressed condition. They observed chlormequat chloride decreased plant height significantly in stressed plants of C. martini, however more decrease evident in C. martini for the same. They noted a significant increase in leaf area in general by the application of chlormequat chloride and IAA irrespective of cultivar or species under drought stress, but the increase was greater in C. winterianus than in C. martini. They also found 24–61% increase in tiller number in stressed plants of C. winterianus due to chlormequat chloride application. Their results indicated that the application of chlormequat chloride and IAA significantly increased herbage yield in stressed plants of C. winterianus with the increase being greater in IAA treated plants. Herbage yield increased in stressed plants by 20–42% in C. martini and 33–85% in C. winterianus due to IAA treatment. Relative water content decreased significantly under drought stress in both the species; the decrease was greater with C. winterianus than in C. martini. Oil concentration was higher in stressed plants of C. winterianus ranging from a 30 to 55% increase compared
to control plants. They observed that oil concentration was negatively correlated with RWC. They found that stressed plants of *C. winterianus* showed higher oil concentration by the application of chlormequat chloride and IAA compared to control plants. The amount of oil per plant decreased under drought stress in *C. martinii*. Among the cultivars of *C. martinii* the decrease in amount of oil ranged from 18 to 46% compared to the control plants. Finally they concluded that that chlormequat chloride and IAA can partially alleviate the detrimental effect of drought.

Sharma *et al.* (2009) conducted an experiment on *Cymbopogon martini* to investigate the correlation between the concentration of geranyl acetate (GA) and acetyl CoA: geraniol acetyltransferase (GAAT) activity in palamarosa (*Cymbopogon martini* var. Motia) inflorescence and leaves at their different physiological stages. They selected three parameters to study GA accumulation in the oil of floral spikelets at different maturity stages. They observed highest GAAT activity in unopened spikelets, declining with the maturation status of the spikelet. They obtained a positive correlation coefficient value of 0.79 (at 95% confidence) when regression curves were drawn between GA concentration (mg g Fw⁻¹) and GAAT activity (IU 10⁻³ g Fw⁻¹). They observed that the total oil and geraniol concentrations were highest in unopened spikelets but varied little in partly opened spikelets, and decreased by around 50% (oil) and 36% (geraniol), respectively, in fully opened spikelets. Their results suggested that volatile ester (like geranyl acetate) synthesis in foliage and flowers of the aroma oil plant is controlled by the existent catalytic levels GAAT rather than the availability of geraniol. Their study also indicated that the GAAT to be a good target to over-express for improvement of oil quality in terms of GA linked to fruit-fresh olfactory note of the oil.

Idrees *et al.* (2010b) conducted a pot experiment to study the physiological and biochemical alteration induced by Salicylic acid (SA) in lemongrass (*Cymbopogon flexuosus* Steud. Wats.) under stress conditions. SA application at concentration of (10⁻⁵ M) applied as foliar spray on lemongrass varieties (Neema and Krishna), subjected to drought stress. The treatments were as follows: (i) 100% FC+0 SA; (ii) 75% FC+0 SA; (iii) 50% FC+0 SA; (iv) 75% FC+10⁻⁵ M SA; and (v) 50% FC+10⁻⁵ M SA. SA treatment reduces the damaging action by water deficit on growth and accelerates a restoration of
growth processes. They observed that growth parameters were significantly reduced under the applied water stress levels; however, foliar application of salicylic acid \((10^{-5} \text{ M})\) improved the growth parameters in stress-affected plants. The plants under water stress exhibited a significant increase in activities of nitrate reductase and carbonic anhydrase, and electrolyte leakage, proline content, free amino acid and in PEP carboxylase activity. Content and yield of essential oil also significantly decreased in plants that faced water stress.

2.5 Conclusion
The literature reviewed above indicated that polysaccharides including sodium alginate in depolymerised form have considerable potential to affect on various plant processes. Although, significant work has been done to enhance the essential oil of these plants but no work was has been done the responses of *Mentha arvensis* and *Cymbopogon flexuosus* to the effect of application of foliar sprays of the aqueous sirradiated sodium alginate. Therefore, an effort to study the effect of irradiated sodium alginate on these plants seems considerably reasonable.