Chapter 1

Influence of Soilless Culture Substrate on Improvement of Yield and Produce Quality of Horticultural Crops

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/59708

1. Introduction

Soilless culture is the modern cultivation system of plants that use either inert organic or inorganic substrate through nutrient solution nourishment. Possibly it is the most intensive culture system utilizing all the resources efficiently for maximizing yield of crops and the most intense form of agricultural enterprises for commercial production of greenhouse vegetables [1-3]. Several studies suggested soilless culture in the greenhouse as an alternative to traditional field production for high-value vegetable crops [4-7]. This protected cultivation system can control the growing environment through management of weather factors, amount and composition of nutrient solution and also the growing medium. Therefore, quality of horticultural crops grown through soilless culture improves significantly compared to conventional soil culture [8,9]. This artificial growing system provides plants with mechanical support, water and mineral nutrient for higher growth and development. Over the years, hydroponics has been used sporadically throughout the world as a commercial means of growing both food and ornamental plants. Now at days, it has also been used as the standard methodology for plant biological researches in different disciplines [10]. Various modification of pure solution culture has been taken place over time throughout the world. Primarily, gravel or sand was used in soilless culture system to provide plant support and retain mineral nutrient and water. Afterward, several substrates have been evolved due to their unique properties for holding moisture, aeration, leaching or capillary action, and reuse potentiality. Soilless growing media are easier to handle and it may provide better growing environment (in terms of one or more aspects of plant growth) compared to soil culture [11,12]. Organic substrates includes sawdust, coco peat, peat moss, woodchips, fleece, marc, bark etc. whereas, inorganic substrate of natural origin are perlite, vermiculite, zeolite, gravel, rockwool, sand, glass wool, pumice, sepiolite, expanded clay, volcanic tuff and synthetically produced substrates are hydrogel, foam mates (polyurethane), oasis (plastic foam) etc. [13-18]. Various raw materials have been used to produce growing media for vegetable production throughout the world. Capabilities of compost for use in soilless culture of horticultural crops have also been confirmed in a number of studies [19,20]. Oil palm frond compost has a great potential to be utilized for the improvement of soilless culture system. It is successfully used to control plant diseases [21-24]. In addition, plant nutrients from oil palm frond compost are released slowly over a long period of time and are less likely to leach out of the media.

Although successful cultivation of different vegetables and ornamentals crops in soulless culture with bark source have been reported [25-27], phytotoxicity from phenolic compounds may be extracted from the substrate [28,29]. Therefore, it is evident that at present, utilization, standardization of nature of raw materials used for soilless growing media is diverse in origin [30]. Each substrate has its specific properties and usually differs from others. These differences between growing media have to be considered for successful soilless cultivation of horticultural crops. In this instance Gruda *et al*. [31] suggested the activity of microorganisms must be evaluated in comparing peat and its substitutes, such as bark, wood fiber substrate, paper and straw substrates. In order to build up own body protein components, these microorganisms need mineral nitrogen, which they gain from the available nitrogen content in the substrate. Therefore, nitrogen would not be readily available for the plants in soilless substrate which in turns may lead to potential quality losses of the produce [31].

In recent years, the use of soilless culture has increased significantly throughout the world [2, 32]. More than 60% of the vegetable greenhouses in the Netherlands cultivated using rockwool media but it is costly and difficult to dispose because it is not biodegradable and environmental friendly [26,33]. Perlite which is less expensive than rockwool has been used as soilless culture substrate around the world for successful production of vegetables, fruits, and cut flowers in the greenhouse [2,34]. Similarly, zeolite has also the potentiality as soilless media for its unique properties. Zeolite crystal alumina silicates have negative charges, which is balanced by one or two valence of positively charged cations [35]. It has high water absorption, retention and releasing capability, high cation exchange capacity, and high buffering ability of pH change [36]. It has been found that due to its higher cation exchange capacity, water and nutrient holding ability; yield and fruit quality of tomato increased greatly [37]. Soilless culture of gerbera produced higher yield in perlite/zeolite (1:1) substrate than other mixtures, due to its improved aeration and water retention ability [38]. Another substrate is coconut coir has a great demand by the ornamental industries especially in The Netherlands and Canada [39], and more recently, the product has been marketed as a substitute for rockwool in the greenhouse vegetable industry. There are many indigenous and locally available soilless culture substrates used by different countries and similarly produced synthetic substrate suitable for growing system of specific crops. Use of different locally available and inexpensive soilless substrates with no pollution limitations but with adequate physical and chemical properties has been suggested worldwide. Mixture of different substrates also been used for higher growth and yield of several crops around the world [40-43]. Soilless culture in bags, pots or trays with light weight medium is the simplest, easiest and economical way of growing crops. The most common types of growing media in container based system are peat-lite, a mixture of bark and wood chips [44]

The problems in agricultural land use such as soil exhaustion, pest infestation or chemical interference are increasing greatly due to intensive cropping, injudicious application of pesticides or continuous monoculture [45-49]. In this regard, soilless culture can avoid problems with monoculture of plants in the same land for years [50]. It can provide several major advantages in the management of both plant nutrition and plant protection. The main reason of need for soil to soilless culture for horticultural crops is the problem related to proliferation of soil borne pathogen in the soil cultivation. Research studies reported that commercial production of greenhouse vegetables with soilless media adopted to reduce economic losses caused by soil-borne pathogens [51-53]. While other researchers reported that soilless culture can provide more efficient use of water and fertilizers [54,55], reduce root diseases [56], and facilitate cultivation of crops in areas where normal cultivation is not possible [57]. Thus, soil has been replacing by many organic and inorganic substrates, since they are disease and pest free inert material capable of holding required sufficient moisture and can be reused year after year. The physical and hydraulic properties of soilless culture substrate is better that those of soil medium. In soil culture plant root get higher water availability just after irrigation which cause lower oxygen content to be used by plant root and micro flora but in substrates optimum aeration is possible due to its leaching or pulling capacity by capillary action. Water application is several times higher in tomato (4 times) and lettuce (5 times) under conventional cultivation system compared to hydroponics [58]. Root development and nutrient absorption is less in plants grown in soil but soilless substrates especially inorganic origin can hold adequate moisture, nutrient through their surface charge and also allow profuse root hair formation for efficient absorption. However, root volume is restricted in container based substrate culture. This limitation has several beneficial effects such as limited supply of nutrient is possible in soilless substrate culture [59, 60] and also increases the root to root competition since there are more roots per unit volume of medium.

Substrate culture under protective agriculture has minimized the discharge of fertilizer and pesticide residues into the natural environment such as freshwater reservoir. However, there are several observations to be considered for successful crop grown in soilless substrate culture. The limited volume of substrate and water availability can cause rapid decrease in water and mineral nutrient status. Therefore, changes in amount of solution, its electrical conductivity (EC), and pH should be monitored regularly for efficient use of water and nutrients. In soilless substrate mineral nutrient usually supplied as ionic form and thus when plant exposed to low relative humidity, it lose water by transpiration leading to evaporation of water from the medium and plant tissue. This transpiration and evaporation can lead to salt build-up in the substrate due to improper management.

Suitability of different substrates in successful vegetable establishment and their effect on growth, yield and produce quality have been extensively investigated by many researchers around the world. However, only few researches have been conducted for improvement of horticultural crop quality in different substrates. Recent reviews suggested that changes in quality parameters of horticultural crops influenced by the use of growing substrate [152] and present a comprehensive overview of the effect mineral soil, inorganic and organic growing media on the growth, development, yield and quality of vegetable crops grown under greenhouse condition [13]. This chapter aims mainly to describe the importance of soilless culture for enhancing quality production of horticultural crops, improving produce quality beneficial to human health, economics of reutilization of once used substrates and also the prospect of soilless culture in improving and maximizing crop yield.

2. Improvement of horticultural produce quality through soilless hydroponics

Horticultural produce from soilless culture have better qualities than those from conventional soil-based cultivation [8,61-63]. Although the exact differences between qualities of vegetables grown in soil or hydroponics are difficult to determine [64] but soilless culture in greenhouse may be an alternative to soil culture for high-value vegetables crops including tomatoes, peppers, cucumbers, lettuce etc. In a study, Massantini *et al.* [9] found better taste, uniformity, color, texture and higher nutritional value in fruits grown in soilless culture than in soil cultivation methods. Similarly, it was also found that tomatoes produced in the nutrient film technique system were firmer and richer in vitamin C than those grown from soil-based plants. It also contained more sugar, acid and sodium, resulting in a distinct taste. Vegetables from organic substrate culture in greenhouse and poly tunnels are in high demand. Thus, in order to increase the qualities of horticultural produce appropriate fertilizer application, especially nitrogen and phosphorus along with growing substrate prepared from organic materials are suggested [65]. Several studies showed that in general plants harvested from soilless culture had a lower dry weight and leaf area, however, significantly higher productivity were observed at the end of harvest [66]. In this culture system, high concentration of nitrogenous fertilizer enhance the vigorous growth, which reduce the penetration of light intensity to the whole canopy due to huge foliage and thus reduce the accumulation of ascorbic acid in shaded parts. Enhanced growth of plants due to nitrogenous fertilizer may also have a relative dilution effect in plant tissue. Therefore, excess use of nitrogenous fertilizer increases the concentration of nitrate in plant tissue and simultaneously decreases that of ascorbic acid, it may have double negative effect on the quality of plant foods [67].

In a study it was found that, potassium concentration in plant parts may vary for growing seasons (spring or autumn) and also growing systems [68]. It was reported that tomato plant grown in aeroponics gave higher concentrations of P, K and Mg and lower concentrations of Ca than nutrient film techniques [69]. Substrate culture found to be affected greatly increasing mineral contents in plants especially due to luxurious nutrient uptake during vegetative growth [70]. Fruit quality of tomato is greatly influenced by potassium mineral nutrition. It positively affects the contents of soluble sugars, vitamin E, carotenoids in fruits but its luxurious absorption may also negatively affect the uptake of magnesium, calcium, and boron from nutrient solution [71-73]. This antagonistic interaction of potassium with calcium leads to decrease in concentration of calcium in the medium. As a result, a typical symptom generally appears known as blossom-end rot disease on tomato fruit which lower the quality greatly [74]. Despite application on the same medium, various substrates like sand, mine material of volcanic origin, rockwool, wood fiber, peat and coir showed significant differentiation in the nutrient content [75-78].

Soilless culture has been extensively used in tomato cultivation both in commercial and experimental basis. Many researchers has compared, standardized and otherwise applied various substrates in tomato culture in soilless hydroponics. In general soilless culture reported to increase the tomato fruits quality greatly around the world. It has been found that organic growing media produced higher yield and number of fruit than conventional growing system in greenhouse tomato production [13,79]. Many studies also suggested that tomato fruits grown in organic substrates had higher dry matter, vitamin C, and nitrogen compared to rockwool [80,81]. Similarly, these properties were improved in rape straw substrate along with peat and pine bark compared to rockwool [82]. The quality and quantity of tomato fruit in organic media found better than inorganic media [83] and when it grown in different substrates the highest amount of total yield and number of fruits were harvested from perlite + rice hull while fruits with highest total soluble solids were from coco-peat substrate [84]. Tomato plants grown in perlite and zeolite mixture substrate (2:1) produced greater fruit size, total soluble solid, sensorial qualities and also highest dry matter of fruit [85] and it was also reported that cucumber plants grown in nutrient film technique gave higher fruit quality than plants grown in perlite culture [86]. Fruit qualities such as fruit weight, fruit firmness, total soluble solids, titratable acidity, ascorbic acid and carotenoids were found to be influenced by the soilless substrate used, while they had not any effect on EC, pH and dry matter content.

Utilization of rockwool and perlite in soilless hydroponic culture results in higher yield compared to other inert materials [84]. However, it also reported that tomato grown in substrate prepared from cutting pieces of rye and wheat straw [17] or slabs made of shredded rye straw [88] yielded higher than that from rockwool cultivation. The tomato plants that grown in perlite and zeolite with 2:1 ratio had best distribution of fruit size, total soluble solid and sensorial quality and highest dry matter of fruit was found in perlite substrate [85]. Research results also suggested that addition of maize to perlite and pumice could improve properties of inorganic substrates for tomato soilless culture, leading to higher yields and better quality fruit [87]. Most of the sensory characteristics such as redness of surface skin, firmness, crispness, sourness, sweetness, tomato aroma and overall impression after chewing were varied greatly due to differences in variety, followed by maturity, harvest time and EC but type of growing medium either soil or rockwool had no or little effect. However, for the characteristics related to texture (crispness and firmness), the ranking was harvest time, EC, growth medium, maturity and variety, with soil-grown tomatoes being slightly but significantly softer than the rockwool grown tomatoes [89]. Higher EC values in the growing medium may cause decrease in fruit yield but on the other hand, it improves the taste by increasing dry matter, soluble solids, and titratable acidity [90]. It has been found that salinity of the water improves the quality of tomato [91]. In soilless culture, increase the EC value of irrigation water or that of nutrient solution increase the acidity [92], the soluble sugars [93,94], and dry matter percentages of fruits [92,95] while decrease the size of fruits in cherry tomato [96].

Maize stems having light weight and less costly can be used as substrate in soilless culture which contains readily available organic matters [97]. In another study, tomato fruit quality characteristics such as mean fruit weight, fruit firmness, total soluble sugars, titratable acid, carotenoids, and ascorbic acid were affected differently by the use of maize shredded stems, perlite and pumice substrates and among them maize shredded stem substrate resulted in greater fruit firmness compared to perlite, pumice substrate [98]. Customer tests indicated that firmness and flavor are important criteria for high quality tomato, where typical tomato flavor depends on the ratio between sugar and acid [99]. Higher sugar and organic acid content improves the quality of tomato fruits [100]. Amount of citric acidity in tomato fruits was found as higher or similar in tuff or sand substrate compared to soil medium [101]. In another study with lettuce, Siomos *et al.* [102] found that soilless culture results in higher citric acid percentage compared to soil culture. However, fruit size and quality characteristics also showed no significant difference within substrate of coco-peat, rockwool and masato [103]. Harvesting time of tomatoes had influence on the quality parameters as in September harvest produced higher dry matter and carotenoids content than that of June harvested fruits. However, June harvested fruits were characterized by a higher total sugars content, pH of juice and soluble solids content [104]. In this regards, it is mentionable that tomatoes sensory quality mainly determined by sugar content which represent the major components of soluble solids [105].

After tomato lots of research works have been conducted on soilless substrate for its influence on improvement of growth, yield and quality of pepper. Growing media composed of soil, peat, perlite, sand and pumice significantly affect the yield, fruit weight, ascorbic acid values and total soluble solids of pepper cultivars [106]. The highest early yield was obtained in pepper plants grown on the peat medium compared to perlite, pumice, sand and soil [106]. Schnitzler *et al.* [107] observed better plant growth, fruit yield and quality in bell pepper (*Capsicum annuum* L.) grown in wood fiber substrate. Recent studies showed that plants grown on peat media had higher ascorbic acid content, total soluble solids, fruit number per plant and yield than its mixture with perlite or sand [108]. Peat contains higher potassium than its mixture substrates [108] and it has been reported that growing media with high potassium could increase the vitamin C content in plants [109]. Green peppers were grown in mixture of substrates such as vermiculite + sand, peat + perlite and rockwool showed that peat + perlite had most influence on its growing traits and yield [110]. However, when perlite compared with rice husk substrates it was found that plants grown in rice husk had higher growth and yield in the later [111]. In another study, differential response of growing substrates were reported and they showed significant effect on plant height, number of leaves, chlorophyll index and total yield per plant [112].

In strawberry better growth has been reported in coir than that in perlite substrate [113]. In another study, the influence of different substrates on the growth of strawberry was reported as peat, finpeat or finpeat + perlite in Camaros and Fern cultivars [114]. Jafarnia *et al.* [115] reported total soluble solid were influenced by substrate and cultivars and fruit qualities such as vitamin C and titratable acidity were highest in rice husk substrate. Caso *et al.* [116] used rice husks and pumice with different ratios in column system for the production of strawberry and they recommended that 100% rice husks substrate influence majority of measured traits.

It also found that content of phenolic compounds, especially anthocyanin depend on substrate pH [117] while Lopes da Silva *et al.* [118] reported total anthocyanin would range between 200 and 600 mg kg^{-1} fresh weight. From research results it is evident that soilless culture substrate affect the quality of strawberry and desirable fruit production is greatly depends on suitable choice of substrate and cultivars [119]. They found that highest total anthocyanin content and titratable acidity in Camarosa cultivar in vermiculite + perlite + coco-peat; the highest antioxidant in Camarosa and Mrak cultivars in substrate of Sycamore pruning waste and coco-peat + perlite; and the highest total soluble solids in Selva cultivar in vermiculite + perlite + coco-peat substrate. Strawberries grown in greenhouses with different soilless growing media also showed their impact on phytochemical and nutritional composition [120]. Agricultural cropping systems greatly influence the productivity and yield of crops. It has been reported similar [121,122] or even higher [123] yield for organic corps than conventional soil cultivation. Minerals such as calcium and magnesium concentrations were observed higher in organic and low input soil system but soilless growing system produced fruits with higher firmness in the green stage which is related to higher flesh thickness of fruits [124].

Rockwool substrate can be used to produce melons hydroponically [125,126] but costs would be higher than other substrate materials and its disposal is very difficult [127,128]. Recently, Rodriguez *et al.* [129] investigated different combinations of media (coarse and medium perlite) and containers (polyethylene bags and plastic pots) for hydroponic production of 'Galia' muskmelons (*Cucumis melo* L.) and found that fruit yield and quality were not affected by any combination of media and containers. In recent studies it was found that sweeter cantaloupes or rock melon fruits harvested in plants grown in empty fruit branch media than coconut dust as soilless media [130]. Effect of different substrates has been studied on growth, yield and quality of watermelon in soilless culture [131]. Quality and quantity of watermelon fruit had not any significant difference between different substrates evaluated [131]. Influence of peat substrate and its mixture with perlite or zeolite on the quality of cucumber seedlings and photosynthesis parameter has investigated [132]. It has been suggested that the highest yield of cucumber fruit obtained from cocopeat substrate than other substrates like perlite-cocopeat (50-50, v/v), perlite-cocopeat-peatmoss (50-20-30 and 50-30-20, v/v) and other growth indices such as stem diameter, biomass, fruit's number, fruit size and fruit diameter were greater in cocopeat [133]. In another study, it was showed that total soluble solids along with growth indices such as yield, biomass weight, shoot diameter, plant height, root weight, and leaf area index of cucumber plant were significantly higher in date-palm substrate than soil media but generally had no significantly difference as compared with perlite substrate [134].

In a recent study, carrots were grown successfully in hydroponics using perlite substrate [135]. It was found that carrot plants grown in 0.6 mm perlite supplied with 100% nutrient solution produced significantly higher root yield compared to larger perlite particles and higher concentrations of nutrient solution. Carrots grown in 0.3 mm perlites produced shorter roots, wider near the proximal end and whitish in the distal end due to excessive water content causing oxygen deficiency. It was found that seedlings grown in peat substrate are higher, have bigger leaf area than seedlings grown in peat-perlite, peat-zeolite substrate, but in leaves and roots dry matter accumulation was less. Higher tuber yield in potato grown in hydroponics compared to conventional system was reported [136]. This higher tuber yield was attributed by the uninterrupted and optimal nutrient and water supply in hydroponic culture.

Soilless culture has predominant influence on the floriculture industries and can provide means of best quality flowers production throughout the year. In roses industry, higher yield and best quality of stems are entirely depends on physico-chemical properties of growing substrates. It was found that incorporation of rice hulls and press mud in traditional substrate found to be improved the growth and quality indices and increased flower yield of *Rosa hybrids* L. cvs. 'Kardinal', 'Anjlique' and 'Gold Medal' [137]. Fascella and Zizzo [138] studied that soilless cultivation of roses in perlite or coconut coir dust increased yield and stem quality. This might be related to the higher water holding capacity and cation exchange capacity of coconut coir, suggesting this organic substrate is one of the alternatives to peat for hydroponic culture. The highest quality of cut flowers of gypsophila in terms of stem length and number of branches per flower were obtained from plants grown in sawdust growing medium under soilless hydroponics with bag culture [139]. High quality cut flowers of oriental hybrid lily were obtained in solid medium hydroponics when compared to mist culture system [140]. It was also observed that broken chaff substrate induced higher quality lily cut flowers as compared with chaff, hydro-ball or carbonized chaff substrate. Hsu *et al.* [141] grew *Oncidium* orchids in rockwool, sphagnum peat moss and mixed medium containing crushed stone, bark and charcoal. They found that pseudo bulbs mass, root activity, cut flower qualities in terms of flower length, floret number and number of shoots were higher in rockwool compared to other media. However, little difference in yield and quality could be attributed due to types of soilless medium used under adequate management practice and environmental conditions [126,142]. The amount of nutrients in both organic and inorganic substrates changes during active vegetative growth of plants and its indication may be appeared in the leaves. Thus frequent analysis of substrate, at least once a moth is important for successful cultivation under soilless cultivation [76,78,143].

3. Production of specialty crops providing human health benefits through soilless hydroponics

The world's population increased greatly in last few decades. The improvement of living standard in many countries increased with the great demand for high value crops, off season supply and high quality products. Therefore, quality of life (QOL) of people increased considerably. In this regard, protected agriculture which is a labor intensive industry can produce higher amount of food for the increased population of the world. The efficiency and quality of the agricultural produce can be increased through the modifications of the environmental controls, management of culture systems and use of technological innovations. The greatest advantage of soilless culture is that it allows direct control of the nutrient solution, possible to modify composition and concentration to achieve predictable results in relation to dry matter content, nitrate content or other organoleptic and structural features of the crop produce [144]. Thus, physical, chemical and biological characteristics of the substrates must correlate with water and fertilizer supply, climatic conditions and plant demand [145-149]. In addition, production or biosynthesis of bioactive compounds will largely be depending upon the manipulation of these characteristics. Phenolic acids are important bioactive compounds having antioxidant activity. Tomato fruits are the good source of phenolics usually taken by human through their daily diet [150,151]. However, it was found that growing medium (standard mineral wool slabs or coconut fibre slabs) or harvest term (September or June) had no influence on the phenolic acids content in the tomato fruits [104]. Other studies also showed that the qualitative traits of the products obtained from soilless culture appear to be substantially similar to the products coming from conventional cultivation [152,153]. Soilless culture may improve the parameters related to nutritional, organoleptic and hygienic-sanitary characteristics [152,153] but some aspects of vegetable quality reported to be clearly improved, such as phytosanitary residues, enhanced organoleptic characteristics and longer shelf life [154]. Special dietary requirements are also sometime fulfilled e.g., enrichment of and/or increase in selenium [155], iron [156], omega 3 [157], and lowering the nitrate [158], and potassium content [159].

Soilless substrate originated from organic materials would improve the product quality with health promoting substance. Many studies indicated that higher nutritional value and higher content of biologically active compounds in the agricultural products from organic farming [160-162]. However, other studies reported that effect of cultivation method disappears when the results converted to absolutely dry matter [163,164]. In most studies it also found that vitamin C content in organic fruits is higher than that of conventional tomatoes [163-165]. In conventional cultivation methods, tomato plants absorb easily assailable nitrogen from the substrate. A large concentration of this macro element results in increased synthesis of protein components and proteins, which adversely affect the synthesis of carbon-based compounds such as vitamin C. Therefore, plant products from organic farming are higher in vitamin C compared to conventional system [166,167]. Organic growing system also influence the nutritional value and phenolic compound content in tomato [168] and a two years study showed that organic tomato had higher ratio of reducing sugar/organic acids, more total sugars, vitamin C, total flavonoids, 3-quercetin rutinoside, quercetin-3-*O*-glucoside, myricetin, chlorogenic acid and kaempferol content than convention fruits.

Research reports revealed that tomato flavor is related to the balance between total soluble sugars and organic acids in the fruits [169]. It has been found that potassium fertilization had positive effect on fruits sugar and acid content [170], therefore, soilless substrate containing higher amount of potassium will increase the sweet flavor of fruits. Potassium supplied from the growing media also influences the antioxidant content of tomatoes, which is considered as beneficial for human health. On the other hand vitamin C is a health-promoting substance with antioxidant properties, which in turn play efficient role in preventing the conversion of nitrate to nitrite in plant tissue and within the human body [171]. Amount of nitrogen absorbed is an important factor influencing the vegetables quality and the way in which absorbed nitrogen is utilized in plant metabolism either as nitrate or nitrite form in the edible plant tissue [172]. These factors can be better managed in hydroponics through management and supply of nutrient solution composition in the small volume of rooting or culture medium.

Fast growing fruits and leafy vegetables had great potential for enrichment of minerals, bioactive compounds and health promoting substances. Commercial cultivation of these crops for a specific dietary requirement can be possible in order to meet the demand of such type of people. Cultivating leafy vegetables in a floating system is the easiest and cheapest means of production, since this system shows high water and nutrient use efficiency with low environmental impact [173]. This cultivation system produced acceptable yield and good control quality parameters in baby leaf species. Siomos *et al.* [174] found that plants from a soilless culture had higher nitrate, total nitrogen, phosphorus and potassium content compared to plants harvested from soil culture. Fruits and vegetables grown in soil contaminated with environmental toxicant or pollutant from industrial effluent or heavy pesticide application have higher mineral contents along with toxic heavy metals and if accumulated in their tissue will impose potential health risk to human [175-177]. Surface soil act as toxic chemical filters that may absorb and retain toxicants from waste water and other effluents. However, due to continuous accumulation of these pollutants and changes in soil pH, the capacity of soil to retain toxic elements reduces and thus surface soil permit these elements to pass into ground water or available for plant uptake [178]. Micronutrients and heavy metals are a group of non-biodegradable elements with the tendency of bioaccumulation in living systems causing serious health problem [179-182]. Moreover, research results reported that some heavy metals such as Cu, Cr, Ni, Zn, Fe etc. at low doses are essential for plants but at high doses cause metabolic disorders and growth inhibition especially Pb and Ni [183,184].

Industrial effluent often contains considerable quantities of heavy metals and other substance that may be toxic to people but beneficial for horticultural crops. Therefore, it is imperative that before effluent can be used for commercial production of vegetables and fruits, it must be determined whether there is or not accumulation of heavy metals [185]. In a study, application of recycling water in broccoli caused an increased yield but it also resulted in enhanced heavy metals in tissues [186], therefore, when applying recycle water, the amount of heavy metal must be considered and managed to a minimal level. In this regard, Emongor *et al.* [187] reported that applying secondary treated sewage effluent enhanced yield of tomato when compared to the plants irrigated with tap water. Recycle water is the easily available source of nutritional supplement necessary for crop growth and thus it has reported to an increase in agricultural crop productivity [186,188,189]. Although wastewater and sewage effluents had beneficial effect on horticultural crops, it contains a significant amount of trace elements and other toxicant that are harmful to human [190]. Previously, an enhanced amount of minerals with applying recycle water has been reported [191]. Similarly, it has been reported that with application of recycle water in cabbage the amount of mineral caused an increase in tissue and resulted in enhanced yield [192]. Moreover, from the economic viewpoint, recycle water in irrigation of crops under proper agronomic and water management practices may provide higher yields and save additional cost of water and fertilizer [189].

Now a day's expensive pesticides application in controlling pests and diseases is a prerequisite for successful production of horticultural crops. Pesticide residues in the agricultural products often cause health hazards. Therefore, growing demand of high quality of fruits and vegetables with minimal or without pesticide residue is desirable to the local consumer and also for commercialization. In this case, soilless culture is a good alternative method of quality crop production [193]. Therefore, soilless culture techniques could be applied to grow selected and popular local horticultural crops with the application of food safety standards at a reasonable price [194]. In addition, injudicious use of nitrogenous fertilizers lead to the production of green vegetables with higher NO_3^- content, which considered to be cancerous to human health. Apart from soil culture, solution culture also produces vegetables with higher NO_3^- and this hazardous ion could be reduced to a greater extent through eco-organic soilless culture system [195]. In regards to NO_3^- content of fruit, the highest value was found in organically grown green peppers and the lowest values were observed in red peppers regardless of organic, low-input and soilless systems [124].

4. Reuse of soilless culture substrate with an economic view point and environmental issues

Substrate culture is considered to be main soilless technique for commercial scale production of horticultural crops. However, it has disadvantage of disposal of growing substrate after crop cultivation. In general, hydroponics is claimed to involve a high initial capital investment and need of technical knowledge for complicated cultivation procedures. However, these problems could be resolved by using locally available materials in simplified methods and equipments. For example, farmers in Japan built their own hydroponic production system using local material which much cheaper than purchasing [196]. Reviews of several research works on the use of substrate in soilless culture showed differential influences on growth, yield and quality of crops. In addition to cultivars and horticultural management practices, growing media had great influence on the yield and fruit quality of greenhouse grown tomato [197]. It was found that plants grown in perlite produced higher total marketable yield that plants grown in either rockwool or pine bark. However, the initial costs to grow greenhouse tomato in perlite were higher than rockwool and were the lowest in pine bark. Replacing perlite substrate at every growing season of tomato was found costly [197]. Continued culture with perlite substrate without proper reconditioning, desalination and disinfection may cause medium compaction, salt built up and pest infection [198-200]. Thus increased salt concentration can reduce fruit size [201], decrease fruit number [202] or can negatively impact root and shoot growth of tomato plants [203]. Therefore, reuse techniques are necessary for sustainable soilless production with lower inputs. Recent researches suggested that perlite can be recycled and used for many years, thus reduce production cost without any negative impact on crop yield [198,199]. If rockwool substrates can be steam sterilized and reused once and then it must be disposed because of fiber break-down during steam sterilization and handling [204]. Therefore, a significant cost is associated with the disposal of rockwool substrate [205]. Disposal of used substrate create environment hazardous in the 1980s, thereafter several research efforts has been taken on modern horticultural techniques to comply with ecological mandates and bio-stability of soilless substrates [206]. As a result several new organic growing media have been suggested by many researchers around the world based on renewable raw materials.

In substrate culture, continuous recirculation of nutrient solution is difficult to maintain. Low sterilization techniques are necessary, thus rockwool slabs with drainage to waste are the most common system especially in the Netherlands [207]. In soilless culture, salt e.g., Na^+ and Cl^- accumulation in the growing media is common which may exert negative effects on salt sensitive crops [208]. Therefore, collection and sterilization technique of drainage nutrient solution are to be developed for reuse [209]. In recent years, a number of investigations have been taken on the water and nutrient balance in greenhouse-grown crops [210]. It has been clearly shown that the large excesses of water and minerals absorption lead to the emissions of N in larger extent and P to a lesser extent to the environment. Therefore, recirculation of once used nutrient solution is imperative for economic crop production hydroponically. In this regards, high EC and nutrient level in the soilless medium are necessary to meet the crop requirements at the high rates obtained under protected cultivation [211] which in turns will enhance product quality grown therein [212]. On the other hand, in soil-bound crops surface water is often used, and since it contains rather high salt concentrations, leaching is necessary to prevent salinity problems [213]. Therefore, the need of leachation, sterilization and reutilization could be the process sustainable crop production through soilless culture system. However, the cost of fertilization was found to be insignificant compared with the total production cost in greenhouse cropping [214]. Crop cultivation in reused substrates revealed both positive and negative responses compared to fresh ones. Some researchers found reduction of crop yield and/or produce quality in re-used substrate [215], while others reported no or minimal differences between new and reused substrate [216-221].

Reuse of substrate is an important option for environmental management of growing media and of soilless culture. It may increase crop profitability, although substrate costs generally constitute a small fraction of the total production costs of greenhouse and nursery crops [222]. However, breakdown of substrate materials can exert detrimental effect on crop for repeated use several years. Physical and chemical modification of both organic and inorganic substrates may also occur after one or two growing cycles, and number of growing cycles of a substrate depends on its nature and the type of crops grown. Research findings showed that generally inorganic substrates tend to last longer for example; polyurethane upto 10 years [223,224], perlite upto 3 years [225], rockwool upto 3 years [226]; and organic substrates have a shorter life upto 2-3 years due to minor biostability [227,228]. Thus, physical stability of the growing medium becomes an important issue in maintaining favorable growing conditions for the whole period [229-231]. It has been suggested that substrate volume could be reducing until 25%, without yield reduction, if irrigation scheduling is adapted to the lower water buffer. Decision on prolonged the use of substrate should be taken using new quick test for assessing the physical, chemical and phytopathological conditions before the start of new cultivation [232]. Among the soilless substrate perlite has good traits for soilless cultivation because of its high water absorption ability, high water efficiency, reuse potentiality and decrease cost of production [233].

5. Future prospects of soilless culture for maximizing yield of horticultural crops

Soilless culture technique has been used successfully in the production of difficult to grown plants. It has great opportunities to explore the inabilities of production constraints involving environmental controls. Modification of culture methods and culture environment can lead to a sustainable crop production desirable for human beings. In this regards, hydroponic production of medicinal and aromatic herbs showed a new insight towards the mass production of these plants leading to high secondary metabolites yields and qualities [234-236]. Soilless culture of medicinal herbs has many valuable advantages such as high yields, clean cultivation, year round production and production of drugs with minimum herbicide and pesticide residues [237,238]. Adequate supply of water and mineral nutrients increase the absorption and subsequently higher dry matter production both in aerial and underground parts of medicinal plants are the main advantages of substrate culture compared to field grown counterparts [237,239-241]. Therefore, successful soilless hydroponics of high value medicinal plant could be promising for pharmaceutical and food industries on meeting their high demands for *Chrysanthemum balsamita* (L.) Baill. raw materials [242].

In Southern Tunisia, the application of geothermal water in soilless culture using sand as substrate found to be much more appropriate than perlite and stone pumice substrates. In sands, plants growth was faster and gave higher marketable yield with improved fruit quality having higher acidity and sugar content [243]. Transpiration influences transport and translocation of calcium in the plant body. It has been found that, nutrient and transpiration are both important in preventing blossom-end rot disease in tomato in soilless culture. Thus, mineral nutrient level i.e., EC value should be maintain for improvement of produce quality. Studies revealed that potassium and EC have positive effects on quality of vegetable crops grown in hydroponics. On the contrary, low EC found to promote quality of cut flower. Further investigation are necessary to determine the prolong reuse of the substrates and their mixtures.

The need for soilless culture arose from plant protection issues with soil-borne pathogens and environmental regulations against groundwater pollution with industrial effluents, nitrate and pesticides. Soilless substrates either having organic or inorganic ingredients have been used as for finding suitable growing media for horticultural crop production. The types of raw material used vary according to their domestic availability in the world. Raw materials variations in different substrate influence the plant growth and development directly and/or indirectly. Thus selection of ideal substrate from various materials is imperative for productivity of each crop [244]. Lots of substrates evolved for horticultural crops production with their cultural guidelines. From them only suitable or adapted cultural guidelines will benefits the grower in successful cultivation for his produce.

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