Journal of Elementology ISSN 1644-2296

Ul Haq, Z., Ahmad, R., Sial, J., Saad, A. and Ali Khan, A. (2024)
'Effectivity of different media carriers on tomato production in greenhouse conditions',
Journal of Elementology, 29(4), 911-929,
available: https://doi.org/10.5601/jelem.2024.29.1.3309

RECEIVED: 8 March 2024
ACCEPTED: 27 October 2024

ORIGINAL PAPER

Effectivity of different media carriers on tomato production in greenhouse conditions*

Zia-Ul-Haq, Rai Niaz Ahmad, Jehangir Khan Sial, Abu Saad, Aksar Ali Khan

Department of Farm Machinery and Precision Engineering
PMAS-Arid Agriculture University Rawalpindi, Pakistan

Abstract

Hydroponic agriculture is the science of growing plants in inert media such as coco cake/powder, gravel, sand, peat, vermiculite, pumice, or sawdust, rather than in soil. Essential nutrients for normal growth of plant are provided through irrigation. Conventionally, growing media (coco cake) imported from Sri Lanka are used in Pakistan for off-season vegetable production in greenhouse conditions. Unavailability of an indigenous media carrier at the farm level has forced researchers to developed new media carriers. Keeping in view the above problem, an experiment was conducted on developing and testing the feasibility of different types of media carriers for tomato production at the Institute of Hydroponic Agriculture Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan. The experiment was run for two growing seasons and included three different treatments (media carrier) viz. T_1 (bottle), T_2 (slab), and T_3 (pipe). The comparison of these media carriers was made on the basis of plant height, stem diameter, number of flower trusses, number of clusters, nodal distance, total number of fruits, and total yields of the plant. The experimental results show that the media carriers have a significant (P<0.05) effect on the tomato plant and its yield. It was concluded from the experiment that treatment T_2 with slabs as media carrier had the best performance in terms of all the above parameters for the tomato growth under greenhouse conditions in both years.

Keywords: hydroponics, greenhouse, media carrier, tomato plant, yield

Zia-Ul-Haq, PhD, Department of Farm Machinery and Precision Engineering, Faculty of Agricultural Engineering and Technology, PMAS-Arid Agriculture University Rawalpindi, Pakistan, e-mail: zia.ch@uaar.edu.pk

* The work was supported by the Institute of Hydroponic Agriculture, PMAS-Arid Agriculture University Rawalpindi.

INTRODUCTION

Hydroponic agriculture is an innovative method of crop production in urban environments with limited land and water resources. The technique of growing plants in a system without soil is referred to as “soilless agriculture”. In this crop production system, various soilless growing media are used. They are typically referred to as potting media, substrate, aggregate systems, and growing media (Gruda 2009).

The amount of medium available for root growth depends on the container’s size but crop performance is not always dependent on the root volume in a pot. Although decreasing root volumes resulted in a smaller root ball, yields of broccoli or cauliflower were unaffected. At the time of field planting, tomato and pepper transplants grown in small-volume containers were smaller and had lower early yields, but total yields were unaffected. However, when the size of a container increased, the yield of eggplant increased, too. Cauliflower and celery transplants did not respond to container shape (square, round, or pyramid), while lettuce and leek seedlings produced higher branches and dry weights as cultivated in pyramid-shaped pots (Arancon et al. 2004).

Although the volume of the media carrier was not specified, tomato seedlings perform better in sowing trays with square root cells than those grown in round cells. Horticulturists, plant biologists, and substrate physicists have been fascinated for at least 200 years by how roots react to mechanical impedance, but our understanding of how roots grow in a container under the impact of many factors is still far from comprehensive. Spencer-Lemaire Industries made an effort to develop a dish/container that would incorporate the additional advantages of existing methods. The benefits of this method, which include the ability to produce better quality seedlings in containers, reduce root malformation, facilitate transplanting, and control mineral nutrition, have been enhanced by the design of containers (Caso et al. 2009).

A media carrier with a predominately horizontal axis offers the benefit of higher water retention than an identical substrate filling. Numerous studies on the geometry of lettuce-holding containers, from tall and narrow to wide and short, have shown that the shape had no bearing on yield when the containers had the same capacity. However, if a plant is kept in a container for a long time, the depth of the container affects the size of the plant’s main root and thereby the plant’s capacity to endure under constrained conditions. Many container shapes, including those that are round, rectangular, hexagonal, or square and tapered from top to bottom, have been tested for the cultivations of horticultural, ornamental, and even forest plants Numerous factors, including the substrate, fertigation, and pollination of a culture container, can influence the root growth and consequently the plant’s balanced growth. Numerous studies have shown that the size, volume, shape, depth, colour and even texture of a container’s inside walls have an impact on the plant's growth characteristics, particularly the strength of its root system (Yano et al. 2018).

Experiments were conducted to investigate plants' growth behaviour in different kinds of containers and pots. A meta-analysis of 65 studies was conducted to examine how the pot size affects the plant's responses. The production rose by 43% on average when the pot size was doubled. Another study on the impact of a pot size on the fundamental growth drivers revealed that, contrary to changes in the leaf shape or biomass allocation, smaller pots resulted in less photosynthesis per unit leaf area, which in turn caused a slower growth. The size of plants grown pots naturally dictates the size of pots (Poorter et al. 2012*a*).

The pot size is important for maintaining proper temperature and other resources essential for plant growth. If no protective measures are taken, the temperature of soil at the edge of a pot may rise and the elevated temperature may finally reach the middle of the pot. This is especially true in the case of small pots maintained in experimental gardens and greenhouses. Small pots heat up more quickly because they have larger surface than volume. Slower plant growth in small pots may be due to greater temperature variations. High temperatures in a pot can affect plant growth in various ways, both directly (via root growth and respiration) and indirectly (through increased microbial activity). It is difficult to determine how frequently temperature changes in pots. This temperature variation slows down the growth of plants. The reduction of the growth of plants in hydroponic culture implies that temperature changes alone are perhaps insufficient to justify the entirety of pot effects (Chirino et al. 2008).

An experiment was conducted to assess the overall effects of doubling the pot size on the physiology, morphology, and growth of plants. It can be predicted that certain plants, due to their target size, will be more confined in a tiny pot than in a large one. In other words, seedlings are basically unaffected by the pot size, but as plants mature, the pot size effect becomes more evident, even in medium-sized containers. If an experiment goes on long enough, even a larger pot size may not be sufficient to support an unrestricted growth of a plant (Mascarini et al. 2012).

Experimental results have shown that the impact of a pot size on the plant growth increases with the passage of time. The relative growth rate (RGR), which measures the rate of increase in biomass per unit biomass present, appropriately describes how quickly individual plants accumulate biomass and how this rate varies with the plant size. At the end of the experiment, the differences in biomass are always smaller than the differences in the RGR of plants growing in pots of various sizes (Poorter et al. 2012*b*).

Plant production in containers involves ornamental plants, flowers, and even vegetable plants, which are grown in pots instead of being grown in the ground. This is a type of gardening. Height control is crucial in commercially potted ornamental plants, where it is required to keep plant height and quality at a suitable level. For producers to store their products until they reach end users and for traders to store them for extended periods of time and use well the available space, plants with longer flowering cycles and shorter heights are more valuable. Therefore, one of the most crucial production variables for ornamental potted plants in the horticultural industry is the management of vegetative growth with the ultimate reduction in plant height (Hadizadeh et al. 2010).

An experiment was conducted on a monthly basis to determine the impact of the pot size on plant growth, number of buds, seedlings, and offshoots produced, taking the length of the petiole, width of the leaf, number of leaves, and the number of flowers as plant growth indicators. In this study, rectangular pots with the dimensions of 50 h × 45 w × 22 d cm were found to be better for growth than the other tested pots (round and basket-shaped). This might be because rectangular pots have plants with larger plant-leaf surfaces, shoot biomass, and root biomass than the plants grown in round pots and baskets. Plants in round pots and baskets had the petiole lengths of 53.83 and 46.00 cm, respectively, whereas plants cultivated in rectangular pots had the petiole length of 57.25 cm. The study showed that the size of pots affects flower production. Plants grown in round pots, rectangular pots, and baskets produced an average of 0.50, 13.00, and 1.38 flowers, respectively (Al-Menaie et al. 2012).

The major drawback to using small pots in the research is associated with biological limitations. A small container contains less soil or other substrate, which nearly always results in less water and nutrient availability for the plant. Along with limiting resource availability, small pots typically obstruct the growth of plant roots. Even at a relatively early age, several species can readily generate roots that are longer than 1 m in length, easily outgrowing the size of the majority of commonly used containers. Large plants in small pots may have a significant portion of their roots "pot-bound", which can have a variety of secondary effects (Jackson et al. 1996).

An experiment was conducted to examine the pot size effects over an extensive range of pot volumes, ranging from 5 mL to 1700 L, on herbaceous greenhouse crops and trees growing respectively over a period of several years. Plants grew well apparently in all pot sizes at the start of the experiment, but after four weeks the biomass gain had already decreased in the smaller pots, and by the harvest, none of the pots were large enough to ensure unrestricted growth (Bar-Tal, Pressman 1996).

The size of a pot immediately affects the plant's fresh weight, dry weight, leaf area, root volume, flower diameter, and bloom shape, which in turn directly affects plant height. As a result, a smaller pot volume makes it difficult for the plant to absorb enough nutrients and water, which has an adverse effect on the rate at which the plant absorbs light and on its vegetative growth (Taherpazir, Hashemabadi 2016).

Farmers in Pakistan grow successfully off-season vegetables in high and low tunnels. Tomato, cucumber, strawberry, capsicum, and roses are common in high tunnels, whereas melon, watermelons, okra, pumpkin are often grown in low tunnels. Farmers make large profits through sale on local markets. However, the yield levels are generally low and the quality of vegetables is poorer than acceptable on the international market. This suggests introduction of hydroponic vegetables with a wider seasonal span, better quality, and a large export potential. The majority of farmers typically have small amounts of land, therefore they cannot afford high-tech and pricey commercial hydroponics equipment. Farmers prefer low-cost hydroponic systems that are based locally. However, in order to decrease construction costs and build local resources for the implementation of hydroponic systems, the development, operation, and maintenance of indigenous hydroponic systems is necessary. Conventionally, slabs imported from Sri Lanka are used as media carrier for off-season vegetable production in greenhouse conditions. To reduce import costs, different types of indigenous media carriers have been developed and their suitability for hydroponic gardening has been examined. Keeping in view the problems mentioned above, an experiment was designed to test the feasibility of different types of media carriers for tomato production.

MATERIALS AND METHODS

For testing the efficacy of various types of media careers, two new shapes (bottle and pipe) were developed. To compare the performance of newly developed shapes with conventional slabs, an experiment was conducted in district Rawalpindi, Pothwar region of Punjab, Pakistan. This region is exposed to two extreme temperatures. In summer, temperatures range from 30 to 45°C and peak at 48°C, whereas in winter, the range of temperatures is within 10-15°C, occasionally falling even below 0°C. The high summer season lasts from May to September, and the winter goes on from November to January. Humidity creates adverse conditions for crops in tunnels during monsoon. Normally, humidity ranges from 50 to 80 percent, but it soars to 99 percent during monsoon rains. The required temperature and humidity for crops in tunnels range from 20 to 30°C and from 45 to 65 percent, respectively.

Experimental groups/treatments

Plant roots require the best possible space for development, thus media carriers can be of any size and shape. In light of this, three distinct types of carriers with various shapes were designed for the present experiment: 1) slab, 2) pipe, 3) bottle.

A slab (Figure 1) is a plastic bag with the dimensions 102.0×20.3×7.6 cm and a weight of 1.7 kg of the growing medium. A PVC pipe (Figure 2) with an inner diameter of 11 cm and a length of 30.5 cm is filled with any grow-

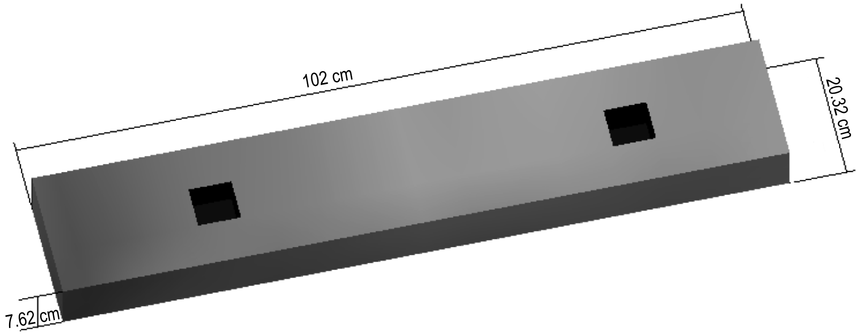

Fig. 1. Isometric view/3D view of a slab

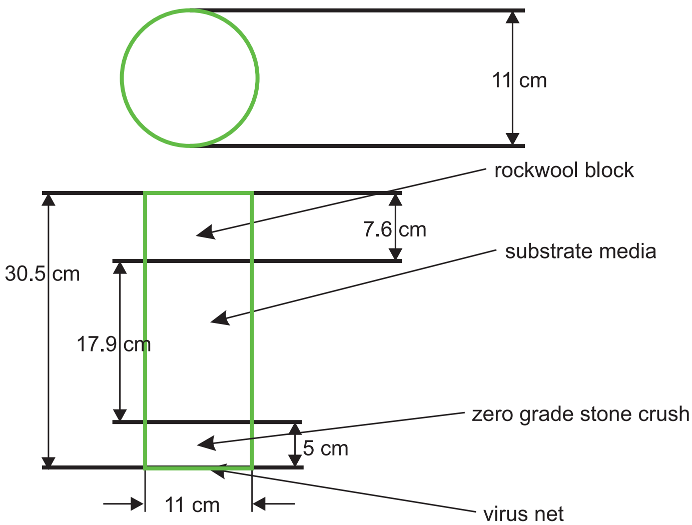

Fig. 2. Detail diagram of the pipe container

ing medium or substrate with the same densities as the substrate-filled slab above. A 30.5 cm pipe was buried in the ground to the half of its height. For better drainage from the pipe, the crush of zero-grade stone filled the lowermost 5 cm of the pipe. To help the medium stay in the pipe, the pipe's lower end was covered with insect-screen. The top 7.6 cm of the 30.5 cm-long pipe was where a portion of a rock-wool box was fitted, and the remaining 17.9 cm were filled with the chosen substrate. Before adding growth media, pipes were sterilized. The bottoms of used 2.5-liter plastic bottles (Figure 3) were taken and cut off to make the length 33 cm. The crush of zero-grade stone filled the lower 7.5 cm of the bottles to facilitate drainage across the bottle after they were inverted, the bottle tops were removed, and an insect screen was installed on the opening in the mouth of each bottle. The top 7.6 cm was where a rock-wool box containing a young nursery plant was fitted, and the remaining 17.9 cm were filled with the chosen substrate.

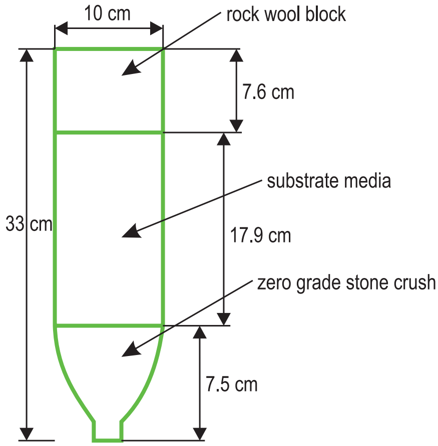

Fig. 3. Detail diagram of the bottle container

Water was pumped from rainwater harvesting ponds into an irrigation tank, where nutrients were mixed to adjust the required EC and pH. Basically, the fertigation system consisted of two tanks (Figure 4) to mix calcium, phosphate, and sulfate-based nutrient separately in each tank and to finally blend them in an irrigation tank carrying RO/rainwater for preparation of the mix of nutrients needed for plants and supplied through a drip irrigation system.

The composition of the nutrient solution in the current experiment is presented in Table 1, and the plant's nutrient requirements at different growth stages are given in Table 2. The nutrients are prepared as concentrated solution and mixed with RO/rainwater to obtain the dilution at the required EC and pH.

Fig. 4. Nutrient solution tank (concentrated stock solution)

Table 1

Mineral sources for nutrients in the hydroponics system

Tank	Mineral Sources	Source of purchase	Remarks
A	calcium nitrate	imported	locally available but expensive
A	potassium nitrate	imported	locally available but expensive
A	potassium chloride	locally available	-
A	nitric acid	locally available	-
B	mono-potassium phosphate	imported	locally available but expensive
B	magnesium sulphate	Locally available	-
B	zinc sulphate	Locally available	-
B	manganese sulphate	Locally available	-
B	ferrous sulphate	Locally available	-
B	copper sulphate	Locally available	-
B	boron (boric acid)	Locally available	-
B	sodium molybdate	Locally available	-

Table 2

Nutrient solution composition for tomato, bell pepper and cucumber (ppm)

Nutrients	Vegetative growth (first 8 weeks)	Reproductive growth (after 8 weeks)
Nitrogen (N)	210	180
Phosphorus (P)	50	40
Potassium (K)	235	300
Calcium (Ca)	200	170
Magnesium (Mg)	50	50
Sulfur (S)	65	60
Iron (Fe)	5	5
Manganese (Mn)	0.5	0.5
Zinc (Zn)	0.05	0.05
Boron (B)	0.5	0.5
Copper (Cu)	0.02	0.02
Molybdenum (Mo)	0.01	0.01

Variables for measurement

The literature review suggested measuring the following variables for exploring the differential responses to the different factors and their levels tested in the experiment.

Plant height

Height is a true indicator of plant growth. Heights of randomly selected tomato plants in each treatment combination were measured fortnightly through the cropping period. However, for the cropping seasons in Year-I and Year-II, the final heights of plants were recorded.

Stem diameter

Diameters of the stems of randomly selected tomato plants in each treatment combination were measured fortnightly through the cropping period. However, for the cropping seasons in Year-I and Year-II, the final average stem diameter of plants was recorded.

Number of flower trusses

To determine how well the selected plants responded to the various treatments in terms of flowering, the number of trusses bearing flowers was counted every two weeks. Trusses would only be counted in the length that they had reached over the previous two weeks. However, for the cropping seasons in Year-I and Year-II, the final average total number of trusses was recorded.

Number of cluster

The number of clusters served as a reliable signal of the plant's readiness to produce fruit. Every two weeks, the number of clusters on each plant was counted. However, for the cropping seasons in Year-I and Year-II, the final average of the total number of clusters was recorded.

Nodal distance

Distance between the consecutive clusters was recorded from the designated plants fortnightly. Averages of the cluster distances for various treatments are given for cropping seasons in Year-I and Year-II.

Number of fruits per plant

On each harvesting, the number of ripened fruits per plant was also recorded. Averages of total number of fruit harvested from designated plants of each treatment are shown for cropping seasons of Year-I and Year-II.

Yield/production

On each harvest, the weight of fruit from selected plants was recorded and finally the total plant production was calculated for all the treatments in the cropping seasons in Year-I and Year-II.

RESULTS AND DISCUSSION

Various crop (tomato) growth variables were measured during the cropping seasons, and the data collected were statistically analyzed. The means of the growth parameters are presented in tables.

Different shapes of media carriers may be used in greenhouse conditions, although slabs remain somewhat more common. Preparation of slabs requires specialized work, which is difficult at the farm level. The slabs (15794 cm^3) have been imported to Pakistan from Sri Lanka. The current initiative is to make slabs (15794 cm^3) locally, on farms, to support the hydroponics technology. In addition, two other carriers, bottle (1405 cm^3) and pipe (1700 cm^3), were chosen for comparison. The subsequent discussion will focus on the crop (tomato) response to the different carriers.

Effect of media carriers on plant height

The total heights of tomato plants grown in various media carriers were measured during the growing seasons in Year-I and Year-II (Table 3).

Table 3

Effect of media carriers on plant height (cm)

Treatment	Year I	Year II
T_1 (bottle)	544.43 C	404.23 B
T_2 (slab)	581.83 A	449.27 A
T_3 (pipe)	551.29 B	444.53 A
LSD	4.2857	6.2249

In Year-I, plant heights for all media carriers were averaged. The average heights of plants for treatment T_1 (bottle), T_2 (slab), and T_3 (pipe) carriers were 544.43, 581.83, and 551.29 cm, respectively. The maximum plant height (581.83 cm) was recorded in treatment T_2 (slab), the second highest plant height (551.29 cm) was in treatment T_3 (pipe), while the lowest height of plant (544.43 cm) was observed in treatment T_1 (bottle). The statistical analysis of the data showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab) and treatment T_3 (pipe), while treatment T_2 (slab) was also significantly different from treatment T_1 (bottle) and treatment T_3 (pipe) at a 5% level of probability. The experiment was continued in the second year. The heights of plants were monitored and statistically analyzed for a variety of reasons. The average plant heights for the bottle, slab, and pipe were 404.23, 449.27, and 444.53 cm, respectively. In Year-II, the maximum plant height (449.27cm) was reached in treatment T_2 (slab), and second highest plant height (444.53 cm) was in treatment T_3 (pipe), while the lowest plant height (404.23 cm) was in treatment T_1 (bottle). The statistical analysis of these data showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab) and treatment T_3 (pipe), while treatment T_2 (slab) and treatment T_3 were not significantly different from each other but they were significantly different from treatment T_1 (bottle) at a 5% level of probability. The slab carrier performed better than the other two solutions, since a slab provides more space, improved porosity, and availability of nutrients to the plant roots. Similarly, the pipe (1700 cm^3) was more spacious than the bottle (1405 cm^3) and consequently enabled the production of plants taller by10%. The results of the experiment are in agreement with the study of Gallegos et al. (2020), who conducted an experiment in a greenhouse by using different sizes and shapes of containers. Their results revealed that a greater size of a container stimulated the plant growth, resulting in its greater plant height and yield. Those authors also concluded that a larger size container increased the root surface. In another study by Lee et al. (2020), an experiment was conducted by growing potatoes in greenhouse condition and using different sizes of containers. It was concluded that by using a larger sized container, the plant height was increased and, as a result, the yield of the plant was improved.

Effect of media carriers on stem diameter

During the cropping seasons in Year-I and Year-II (Table 4), the diameter of the stem of plants was measured beneath the top leaf to determine

Table 4

Effect of media carriers on stem diameter (mm)

Treatment	Year I	Year II
T_1 (bottle)	2.5880 A	2.7191 B
T_2 (slab)	2.5563 B	2.7158 B
T_3 (pipe)	2.5664 B	2.7708 A
LSD	0.0166	0.0258

the media carrier's relative effectiveness. For the bottle, slab, and pipe carriers, the average plant stem diameters during Year-I were 2.59, 2.56, and 2.57 mm, respectively. The largest stem diameter in this study (2.59 mm) was recorded in treatment T_1 (bottle), the second largest (2.57 mm) – in treatment T_3 (pipe), and the smallest stem diameter (2.56 mm) was in treatment T_2 (slab). The statistical analysis of the current experiment showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab) and treatment T_3 (pipe), but treatment T_2 (slab) and treatment T_3 (pipe) were not significantly different from each other. In the next cropping season (Year-II), the experiment was repeated in the three mentioned carriers,. The diameters of the stems of plants were measured and statistically analyzed. For comparison to Year-I, the average diameters of the stems of plants in Year-II for bottles, slabs, and pipes as media carriers were 2.72, 2.72, and 2.77 mm, respectively. In this study, the stem diameter was recorded as the largest (2.77 mm) in treatment T_3 (pipe), the second largest (2.72 mm) – in treatment T_1 (bottle), and the same result (2.72 mm) was obtained in treatment T_2 (slab). The statistical analysis of the current experimental data showed that treatment T_1 (bottle) was not significantly different from from treatment T_2 (slab), but significantly different from treatment T_3 (pipe) at a 5% level of probability. The results of the experiment correlate with the study of Lima et *al.* (2021), who grew coffee in the greenhouse condition using two types of containers: polyethylene tubes and bags. Those researchers concluded that the growth of plant, height, stem diameter were better for plants grown in polyethylene bags.

Effect of media carriers on number of flowers trusses

During the cropping seasons in Year-I and Year-II (Table 5), the number of flower trusses was counted in each media carrier. For the media carrier's

Table 5

Effect of media carriers on number of flower trusses (No.)

Treatment	Year I	Year II
T_1 (bottle)	17.589 B	13.044 C
T_2 (slab)	18.911 A	13.544 B
T_3 (pipe)	17.789 B	13.867 A
LSD	0.2539	0.1902

bottle, slab, and pipe, the mean number of flower trusses was 17.59, 18.91, and 17.79, respectively. The quantity of flower trusses was evaluated and statistically analyzed in terms of the media carrier. In this experiment, the number of flower trusses was measured and the maximum number of flower trusses (18.91) was in treatment T_2 (slab) while the second highest number of flower trusses (17.79) was in treatment T_3 (pipe), and the minimum number of flower trusses (17.59) was in treatment T_1 (bottle). The statistical analysis of the current experiment showed that treatment T_2 (slab) was significantly different from treatment T_1 (bottle) and treatment T_3 (pipe) while treatment T_1 (bottle) and treatment T_3 (pipe) were not significant to each other at a 5% level of probability. Data was obtained for the next cropping season (Year-II) of the tomato crop. The total amount of flower trusses was recorded and statistically analyzed for various factors. For the bottle, slab, and pipe, the number of flower trusses was 13.04, 13.54, and 13.87 respectively. In this experiment the average number of flower trusses was recorded as the maximum (13.87) in treatment T_3 (pipe), the second highest number (13.54) in treatment T_2 (slab), and the minimum number of flower trusses (13.04) was in treatment T_1 (bottle). The statistical analysis of the current experiment showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab) and treatment T_3 (pipe) while all treatments were significantly different from each other at a 5% level of probability. The findings align with the results reported by Sánchez-del Castillo et al. (2021), who used two types of containers (25 and 250 mL) to grow tomatoes in greenhouse conditions. They concluded that the 250 mL container had plants with more flowers than plants grown in the smaller container; also, the larger container increased the yield of tomatoes.

Effect of media carriers on nodal distance

Internodal distances between two consecutive clusters were recorded for the cropping seasons in Year-I and Year-II (Table 6). It was observed that

Table 6

Effect of media carriers on internodal distance (cm)

Treatment	Year I	Year II
T_1 (bottle)	27.262 B	21.492 A
T_2 (slab)	27.506 A	21.365 A
T_3 (pipe)	26.970 C	20.838 B
LSD	0.0942	0.1669

the number of flowers and tomato yields increased with a decrease in the internodal distance. This explains why breeders are striving to reduce this distance. In the present study, the different media carriers were tested for their effects on the internodal distance. The average internodal distance in Year-I for bottle, slab, and pipe was recorded as 27.26, 27.50, and 26.97 cm, respectively. In this experiment, the average internodal distance was the highest (27.50 cm) in treatment T_2 (slab), the smallest (26.97cm) – in treatment T_3 (pipe), and intermediate (27.26 cm) – in treatment T_1 (bottle). The statistical analysis of the current experiment showed that treatment T_1 (bottle), treatment T_2 (slab), and treatment T_3 (pipe) were significantly different from each other at a 5% level of probability. The experiment was continued during Year-II, and average internodal distance was observed. The internodal distances were measured for various factors and statistically analyzed. The average internodal distance in Year-II for bottle, slab, and pipe was 21.49, 21.36, and 20.84 cm, respectively. In this experiment, the average internodal distance was the longest (21.49 cm) in treatment T_1 (bottle), the second longest (21.36 cm) in treatment T_2 (slab), and the shortest (20.84 cm) in treatment T_3 (pipe). The statistical analysis of the current experiment data showed that treatment T_1 (bottle) and treatment T_2 (slab) were not significantly different from each other, but both treatments are significantly different from treatment T_3 (pipe) at a 5% level of probability. The results are in line with Ayarna et al. (2021), who reported that the low node substrates restricted the roots of the plant and consequently the internodal distances were short, which decreased the quality and yield. Those researchers concluded that by increasing the high node size, the nodal distance will be increased and as a result the yield will be enhanced.

Effect of media carriers on the number of fruits

The number of tomatoes for particular media carriers was counted at the completion of both cropping seasons in Year-I and Year-II (Table 7). During the first cropping season, the average amount of tomatoes was recorded across the media carriers. For bottles, slabs, and pipes, the mean total number of tomatoes was 29.38, 37.37, and 33.74, respectively. In this experiment, the average number of fruits was recorded as the highest (37.37) in treatment T_2 (slab), the second highest number (33.74) in treatment T_3 (pipe), and the smallest number of fruits (29.38) was in treatment T_1 (bottle). The statistical analysis of the current experiment data showed that treatment T_1 (bottle), treatment T_2 (slab), and treatment T_3 (pipe) are significantly different from each other at a 5% level of probability. The experiment was continued for the next growing season in Year-II after thorough cleaning and fumigation, the crop was sown in the same media carriers. Fruit production rates per plant were measured and statistically analyzed. For the three media carriers: bottles, slabs, and pipes, the average number of fruits was 49.5, 55.67, and 55.88, respectively. As in Year-I, the performance of bottles as a media carrier was poor, probably because media carriers were placed in poorly drained soil, and the temperature and humidity were not adequately controlled. In Year-II, the average number of fruits was recorded as the highest (55.88) in treatment T_3 (pipe), the second highest (55.67) in treatment T_2 (slab), and the smallest number of fruits (49.5) was counted in treatment T_1 (bottle). The statistical analysis of the current experiment data showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab), and treatment T_3 (pipe), while treatment T_2 (slab) and treatment T_3 (pipe) were not significantly different from each other at a 5% level of probability. The findings are consistent with the study results reported by Baiyin et al. (2021), who found that the specific flow rate in different pot-sized containers affected the number of fruits per plant. The specific flow rate of water in large-sized containers resulted in a greater number of fruits than small-sized containers.

Table 7

Effect of media carriers on number of fruits (No.)

Treatment	Year I	Year II
T_1 (bottle)	29.378 C	49.500 B
T_2 (slab)	37.372 A	55.667 A
T_3 (pipe)	33.744 B	55.889 A
LSD	1.8032	0.9132

Effect of media carriers on the number of clusters

The numbers of clusters on randomly selected plants from the different media carriers were recorded for cropping seasons in Year-I and Year-II (Table 8). It is apparent that the number of clusters counts on plants from the three media carriers was quite small for bottles compared to slabs and pipes.

Table 8

Effect of media carriers on number of cluster (No.)

Treatment	Year I	Year II
T_1 (bottle)	12.811 C	09.856 B
T_2 (slab)	14.400 A	11.100 A
T_3 (pipe)	13.378 B	11.222 A
LSD	0.3023	0.2034

When comparing the number of clusters with the number of flower trusses, it was observed that about 1/3 of flower trusses could not transform into fruit clusters. It is becoming a challenging situation for the greenhouse farmers. To avoid this problem, growers have to consider key issues like variation in humidity, temperature, unavailability of bumblebees, dry and wet stresses, and carriers of infections in a greenhouse. The average number of clusters for bottle, slab, and pipe carriers was 12.8, 14.4, and 13.4, respectively. The performance of treatment T_2 (slab) was the best, with the highest number of clusters (14.4), followed by treatment T_3 (pipe) with 13.4 clusters on average, and the smallest number of clusters (12.8) was in treatment T_1 (bottle). The statistical analysis of the current experiment data showed that treatment T_1 (bottle), treatment T_2 (slab), and treatment T_3 (pipe), were significantly different from each other at a 5% level of probability. The data on the total number of clusters were collected as the experiment was continued in the next cropping season (Year-II). The average number of clusters for bottle, slab, and pipe carriers was 9.86, 11.10, and 11.22, respectively. The highest number of clusters (11.22) was in treatment T_3 (pipe), followed by treatment T_2 (slab) with 11.10 clusters on average, and the smallest number of clusters (9.86) was in treatment T_1 (bottle). The statistical analysis of the current experiment data showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab) and treatment T_3 (pipe), while treatment T_2 (slab), and treatment T_3 (pipe) were not significantly different from each other at a 5% level of probability. The results coincide with the report by Yano et al. (2018), who reported that the size, volume, shape, depth, color, and even texture of the inside walls of containers have an impact on the plant's growth characteristics (clusters), particularly the strength of its root system. The results also agree with the data obtained by Fikre & Boto (2024), who concluded that the pot size significantly affected the growth and number of clusters of the plant. Those authors concluded that by increasing the pot size, it was possible to increase the growth and number of clusters, and vice versa.

Effect of media carriers on yield per plant

Tomato yield in different media carriers was recorded for the cropping seasons in Year-I and Year II (Table 9). The total yield for Year-I was averaged across the three media carriers.

Table 9

Effect of media carriers on yield per plant (kg)

Treatment	Year I	Year II
T_1 (bottle)	5.0938 C	5.5036 C
T_2 (slab)	7.6058 A	6.6374 A
T_3 (pipe)	6.1784 B	6.4181 B
LSD	0.3562	0.1509

The differences in the yield data for the slab compared to the bottle and the slab compared to the pipe are 49.55% and 23.1%, respectively, and the average amount of fruit/yields from mature tomatoes was higher for the slab than for the other carriers. When compared to slabs, the yield declined for pipes and bottles, which may be due to the limited space for root growth, density, permeability, capacity for holding water, and drainage in the two latter media carriers. The data (yield) collected in the media carriers were statistically analyzed. The average yields per plant for the bottle, slab, and pipe as carriers were 5.09, 7.60, and 6.18 kg, respectively. The maximum yield (7.60 kg) was recorded in treatment T_2 (slab), the second highest yield (6.18 kg) was in treatment T_3 (pipe), and the smallest yield (5.09 kg) was in treatment T_1 (bottle). The statistical analysis of the current experiment data showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab), and treatment T_3 (pipe), while treatment T_2 (slab) and treatment T_3 (pipe) were also significantly different from each other at a 5% level of probability. The experiment was continued in Year-II, and after the fumigation process, tomatoes were sown in the same media carriers. The yield of tomatoes was assessed for a number of factors and statistically analyzed. The average yields per plant obtained from bottle, slab, and pipe media carriers were 5.50, 6.63, and 6.41 kg, respectively. The highest yield (6.63 kg) was recorded in treatment T_2 (slab), followed by 6.41 kg in treatment T_3 (pipe), and the lowest yield (5.50kg) was obtained in treatment T_1 (bottle). The statistical analysis of the current experiment data showed that treatment T_1 (bottle) was significantly different from treatment T_2 (slab) and treatment T_3 (pipe), while treatment T_2 (slab) and treatment T_3 (pipe) were also significantly different from each other at a 5% level of probability. The findings of this study are in accord with results of Papadimitriou et al. (2024), who concluded that the weight of fruits in the greenhouse increased as the container size increased from 15 to 25 cm in height. The results shows that the substrate and media carrier significantly affect the total weight of the produce.

CONCLUSION

The experimental results have shown that a slab performed the best as a media carrier, followed by pipe and bottle. The lesser volume of substrate that prevented root proliferation may be related to the lower plant heights observed in the bottle and pipe. For bottles, slabs, and pipes, the average production was 61.1, 91.3, and 74.2 tons of tomatoes per acre, respectively. However, 112 tones of imported-coco slab were used on average per acre.

ACKNOWLEDGEMENTS

This research was supported by the Institute of Hydroponic Agriculture, PMAS-Arid Agriculture University Rawalpindi.

Author contributions

R.N.A and J.K.S – planned and designed the research; Z.U.H and J.K.S – conducted the experiment; Z.U.H, A.S and A.A.K – wrote the article and analyzed the data. All authors agreed on the final content of the article.

Conflict of interest

No potential conflict of interest was reported by the authors.

Data availability statement

The data and material that support the analysis of this study are available from the corresponding author on request.

REFERENCES

Al-Menaie, H.S., Al-Ragam, O., Al-Dossery, N., Zalzaleh, M., Mathew, M., and Suresh, N. (2012) 'Effect of pot size on plant growth and multiplication of water lilies (Nymphaea sp.)', *American-Eurasian Journal of Agricultural & Environmental Sciences*, 12(2), 148-153, available: http://www.idosi.org/.../3.pdf(20123123844)

Ayarna, A.W., Tsukagoshi, S., and Oduro Nkansah, G. (2021) 'Effect of root restriction on the performance of three-truss cultivated tomato in the low-node pinching order at high-density cultivation system', *Horticulturae,* 7(3), 60.

Baiyin, B., Tagawa, K., Yamada, M., Wang, X., Yamada, S., Yamamoto, S., and Ibaraki, Y. (2021) 'Effect of the flow rate on plant growth and flow visualization of nutrient solution in hydroponics', *Horticulturae,* 7(8), 225.

Bar-Tal, A., and Pressman, E. (1996) 'Root restriction and potassium and calcium solution concentrations affect dry-matter production, cation uptake, and blossom-end rot in greenhouse tomato', *Journal of the American Society for Horticultural Science,* 121(4), 649-655, available: https://doi.org/10.21273/JASHS.121.4.649

Caso, C., Chang, M., and Rodríguez-Delfín, A. (2008, August) 'Effect of the growing media on the strawberry production in column system', In International Symposium on Soilless Culture and Hydroponics, 843 pp. 373-380, available: https://doi.org/10.17660/ActaHortic.2009.843.50

Chirino, E., Vilagrosa, A., Hernández, E.I., Matos, A., and Vallejo, V.R. (2008) 'Effects of a deep container on morpho-functional characteristics and root colonization in *Quercus suber* L. seedlings for reforestation in Mediterranean climate', *Forest Ecology and Management*, 256(4), 779-785, available: https://doi.org/10.1016/j.foreco.2008.05.035

Fikre, H., and Boto, N. (2024) 'Effects of varieties and pot sizes on the early shoot and root growth of enset (Ensete ventricosum (Welw) Cheesman)', *Cogent Food & Agriculture,* 10(1), 2370396.

Gallegos, J., Álvaro, J.E., and Urrestarazu, M. (2020) 'Container design affects shoot and root growth of vegetable plant', *HortScience*, 55(6), 787-794.

Gruda N. (2009) 'Do soilless culture systems have an influence on product quality of vegetables', *Journal of Applied Botany and Food Quality*, 82, 141-147, available: https://doi.org/10.18452/9433

Hadizadeh, H., Tehranifar, A., Shour, M., and Nemati, S.H. (2010) 'Investigation of dwarfness effect of paclobutrazol on tuberose (*Polianthes tuberosa* L.) and possibility of pot tuberose production', *Journal of Horticultural Science*, 24(1), available: https://doi.org/10.22067/JHORTS4.V1389I1.3637

Jackson, R.B., Canadell, J., Ehleringer, J.R., Mooney, H.A., Sala, O.E., and Schulze, E.D. (1996) 'A global analysis of root distributions for terrestrial biomes', *Oecologia*, 108, 389-411, available: https://doi.org/10.1007/BF00333714

Lee, G.B., Park, H.J., Cheon, C.G., Choi, J.G., Seo, J.H., Im, J.S., ... & Chang, D.C. (2022) 'Effect of plant container type on seed potato (*Solanum tuberosum* L.) growth and yield in substrate culture', *Potato Research*, 65(1), 105-117.

Lima, A.E.D., Guimarães, R.J., Cunha, S.H.B.D., Castro, E.D.M., Carvalho, A.M.D., & Faria, M.M.L. (2021) 'Seedling production of *Coffea arabica* from different cultivars in a modified hydroponic system and nursery using different containers', *Ciência e Agrotecnologia*, 45, e017821.

Mascarini, L., Lorenzo, G., Svartz, H., Pesenti, S., and Amado, S. (2012) 'Container size and growing media affects water use efficiency in a Gerbera jamesonii cut flower crop', *Revista Brasileira de Horticultura Ornamental,* 18(1), 71-77, available: http://www.sbfpo.com.br (20123322544)

Papadimitriou, D.M., Daliakopoulos, I.N., Louloudakis, I., Savvidis, T.I., Sabathianakis, I., Savvas, D., and Manios, T. (2024) 'Impact of container geometry and hydraulic properties of coir dust, perlite, and their blends used as growing media, on growth, photosynthesis, and yield of Golden Thistle (*S. hispanicus* L.)', *Scientia Horticulturae*, 323, 112425.

Poorter, H., Bühler, J., van Dusschoten, D., Climent, J., and Postma, J.A. (2012) 'Pot size matters: a meta-analysis of the effects of rooting volume on plant growth', *Functional Plant Biology,* 39(11), 839-850, available: https://10.1071/FP12049

Poorter, H., Fiorani, F., Stitt, M., Schurr, U., Finck, A., Gibon, Y., and Pons, T.L. (2012) 'The art of growing plants for experimental purposes: a practical guide for the plant biologist', *Functional Plant Biology*, 39(11), 821-838, available: https://doi.org/10.1071/FP12028

Roosta, H.R., and Afsharipoor, S. (2012) 'Effects of different cultivation media on vegetative growth, ecophysiological traits and nutrients concentration in strawberry under hydroponic and aquaponic cultivation systems', *Advances in Environmental Biology,* 6(2), 543-555.

Sánchez-del Castillo, F., Portillo-Márquez, L., Moreno-Pérez, E.D.C., Magdaleno-Villar, J.J., and Vázquez-Rodríguez, J.C. (2021) 'Effects of container volume and seedling density on late transplanting and number of flowers in tomato', *Revista Chapingo. Serie Horticultura*, 27(2), 71-84.

Taherpazir, S., and Hashemabadi, D. (2016) 'The effect of cycocel and pot Size on vegetative growth and flowering of Zinnia (*Zinnia elegans*)', *Journal of Ornamental Plants,* 6(2), 107-114, available: http://jornamental.iaurasht.ac.ir/article_523302_311ef21871a5d8bc8cdd23bc6dfe167d.pdf

Yano, T., Morisaki, A., Ito, S. I., and Kitano, M. (2018) 'A generalized linear model to predict the growth of potted seedlings of Satsuma mandarin (*Citrus unshiu* Marcow.) under different initial plant conditions, environmental conditions, and pot size', *The Horticulture Journal,* 87(4), 490-498, available: https://doi.org/10.2503/hortj.OKD-112