



Hydroponic Growth Media (Substrate): A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author s STP, USK, MSM, DMM and JSD designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. All authors managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IRJPAC/2020/v21i2330307

Editor(s):

(1) Dr. Richard Sawadogo, Research institute for health sciences Ouagadougou, Burkina Faso.

(2) Dr. Hao-Yang Wang, Shanghai Institute of Organic Chemistry, China.

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Complete Peer review History: <http://www.sdiarticle4.com/review-history/63366>

Review Article

Received 25 September 2020

Accepted 03 December 2020

Published 12 December 2020

ABSTRACT

From the reviewed literature, it is observed that scientist's worked on the various substrate medias used for hydroponic system. They also studied about different combinations of the media and their effect on crop growth. The reviewed literature shows that scientists have studied different organic and inorganic media viz. cocopit, saw dust, rice husk vermiculite, perlite, hydroton, pumice, sand etc. It was also found that these media are not easily, cheaply and locally available for users. Beside this, few scientists studied about physical and chemical properties of media such as particle size, porosity, bulk density, wettability, water holding capacity (WHC), Air filled porosity (AFP), Electrical conductivity, pH of these media. The crop specific suitability of combinations of the different media mixtures were also tested and reported by many scientists. It was revealed from reviewed literature that salinity of media caused linear reduction in the water consumption. The size and shape of particle size distribution are useful for estimating the hydraulic properties of the media The substrate under long cultivation period causes increase of organic matter content and microorganism activity which leads to an increased competition for oxygen in the root environment. The optimal EC levels

range from 1.5 to 4.0 dSm⁻¹ according to crop and its sensitivity to different salinity levels. It was also observed that level of growing medium temperature close to that of the surrounding air seems more suitable. The ideal substrate should have a total porosity of over 85 percent. Particles of smaller-sized individual grains have a larger specific surface area.

Keywords: Hydroponic; soilless; substrate; media, pH, EC.

1. INTRODUCTION

Many countries across the world such as Holland, Spanish, German, Canada, United States, Singapore, Taiwan, Japan, China, Newzeland and Australia are shifting there agriculture from soil to soilless culture. Media based hydroponic production combines crop quality and productivity, which results in higher competitiveness and economic incomes. In general, there were six basic types hydroponic system, which were used for soilless hydroponic farming, home gardening, and commercial hydroponics farming. Media based hydroponic technology can be an efficient mean for food production from extreme environmental ecosystems such as deserts, mountainous regions, or arctic communities. In highly populated areas, hydroponics can provide locally grown high-value crops such as leafy vegetables or cut flowers. The future use of controlled environment agriculture and aggregate hydroponics must be cost competitive with those of open field agriculture. Therefore the detailed review of study useful medias (substrate) conducted across the globe have paramount importance.

2. ORGANIC AND INORGANIC MEDIAS FOR HYDROPONIC

The study on different types of media to replace the soil is going across the globe. Various organic and inorganic substrates were searched out on which crop cultivation could be performed. Sabahy et al. [1] observed that the lack of suitable soils, disease contamination after repeated use and the desire to apply optimal conditions for plant growth are leading to the worldwide trend of growing plant in media. It was observed by El-Kazzaz et al. [2] that the soilless agriculture may be used with solid material such as gravel, sand, peatmoss, perlite and vermiculite as supporting mediators. Martin *et al.* [3] showed the production of vegetables without soil, in containers with water, or in low-cost natural substrates viz. sand, rice hulls, pumice stone, etc. is possible. It allows the growth of a wide variety of vegetables such as lettuce,

tomatoes, carrots, garlic, watercress etc. Marr [4] studied on the rockwool media and stated that rockwool is not only relatively inexpensive, but is also inert, biologically non-degradable, takes up water easily. He shown it is approximately 96 percent pores and has evenly sized pores which are important for water retention. It is so versatile that rockwool is used in plant propagation and potting mixes, as well as in hydroponics. Smith et al. [5] used sand as media and reported that sand is to be first purified with steam-heated 18% hydrochloric acid plus 1 % oxalic acid in a ' Keebush' sand-purification unit and then washed with deionized water. The particle size of the sand should range from 0-5 to 2-0 mm.

2.1 Selection of Media

Cultivation without soil is the science that uses an inert material such as gravel, sand, peat, vermiculite, pubice, saw dust, coco peat, vermicompost etc. in which the nutrient solution is added containing all the essential elements needed by the plant to fulfill its nutrients requirements for its normal growth and development [6,7]. New and advanced root zone substrates are currently tested as substitute for natural soils in greenhouse and hydroponic agriculture. These media should guarantee better rooting conditions and provide anchorage for the root system, supply water and nutrients to plants and suitable aeration environment to roots [8]. A wide selection of growing media is available and the choice depends on grower's financial and technical implications [9]. Gruda et al. [9] showed that most growers use substrates that are locally available as it is cheap and reliable. In tropical and subtropical area, coir which is a natural fiber material extracted from coconut husk are most popular. Essentially, an effective growing medium must have a physical structure that is capable of sustaining a favourable balance between air and water storage both during and between irrigation events in order to prevent root asphyxia and drought stress [10]. Anonymous [11] stated that most commercial greenhouse media for container crop production contains 30 to 60 percent peat moss alone or in combination with composted pine bark. Other materials such

as vermiculite and perlite are added to affect water retention and aeration.

2.1.1 Physical and chemical properties of individual and in combination of media

Abad et al. [12] compared physico-chemical and chemical properties of selected coir with *Sphagnum peat*. They observed that average coir pH (5.60) stayed within the optimal pH range (5.2-6.3) of media. Hence they stated that coir in comparison with peat requires little or no liming. They also found that cation exchange capacity was always significantly lower than that of *Sphagnum peat*. The carbon/ nitrogen (C/N) ratio, Phosphorous and Potassium, Chloride and Sodium levels, Boron was significantly higher than that of peat. They further revealed that part of the carbon in coir dust was in the form of lignin and cellulose which is resistant to microbial degradation and fiber content in coir dust were extremely high. Abad et al. [12] also stated that location specific variability in coir characteristics is due to differences in raw coconut fruit and husk processing method. Awang et al. [13] studied five types of growing media as 100% cocopeat (T₁), 70% cocopeat:30% brunt rice hull (T₂), 70% cocopeat: 30 perlite (T₃), 70 % cocopeat: 30% kenaf core fiber (T₄) and 40% cocopeat: 60% kenaf core fiber (T₅). They observed that pH of 100% cocopeat (T₁) and 70 % cocopeat: 30% kenaf core fiber (T₄) were higher than other media while 70% cocopeat:30% brunt rice hull (T₂) shown lowest pH. The pH of all the media dropped from initial pH of 4.7-6.6 to 4.4-4.7 after 42 days of cultivation. They observed that reduction of pH in the organic based media is associated with a poor roots and use of acid fertilizers. The EC of treatment 70% cocopeat:30% brunt rice hull (T₂) (0.48 mS cm⁻¹) was highest while 70 % cocopeat: 30% kenaf core fiber (T₄) and 40% cocopeat: 60% kenaf core fiber (T₅) had lowest EC (0.14 mS cm⁻¹). The EC of the other media were in the range of (0.16-0.2 mS cm⁻¹). The EC values reflect the total inorganic ion concentration. Low EC value indicates that the media did not contain excessive salts that could cause salinity injury but at same time contains insufficient amount of nutrients. The acceptable range of the initial EC of good soilless media should be between (0.4-1.5 mS cm⁻¹) [13]. The lowest bulk density was found in treatment 70% cocopeat:30% brunt rice hull (T₂) (0.12 g.cm⁻³). From the study they revealed that low bulk density media may be required for frequently irrigated greenhouse to avoid oxygen deficiency however such media

may not provide adequate support for the plant. Mixing and transportation of the low bulk density media was found much easier. The results of water retention of media of their study shown that initially all the media held similar quantity of water. The air content at 1.0 kpa were 17.7, 27.9, 25.0, 12.8 and 23.0 % respectively for T₁, T₂, T₃, T₄ and T₅ respectively. The volume of available water differed among treatments with respective value of 54,61,36,44 and 20 % for T₁, T₂, T₃, T₄ and T₅ media. They observed that high available water was recorded in media containing high proportion of cocopeat. They further observed that highest water absorbing capacity after 6 hour occurred in 70% cocopeat:30% brunt rice hull (T₂) (432.2 ml) followed by 70% cocopeat: 30 perlite (T₃) (368.4 ml). High amount of fiber content in cocopeat shows low wettability. The percentage of air filled porosity shown that 100% cocopeat had 28.1% AFP while 70% cocopeat: 30 % brunt rice have 38 % AFP [13]. Marinou et al. [14] worked on sawdust, coco soil and pumice as individual and combinations 1) Pumice (Pum-100); (2) Sawdust (Saw-100); (3) Coco soil (Coc-100); (4) Pum-Saw (50-50); (5) Coc-Saw (50-50); (6) Coc-Pum (50-50). From study, they concluded that amount of pore space of media was critical physical characteristic which influences water and nutrient absorption and gas exchange by the root system. Ghehsareh [15] worked out the physical properties of date palm waste as a culture media and showed that composting process changed the physical properties of the media before planting. He further observed that composting process continued in culture media with and without plant but composting process were higher in culture media without plants. This was because under culture media with plant when fertigated with nutrient solution, some of the nutrient elements were used by plant and microorganism, but in culture media without plant these nutrient elements were used by microorganisms leading to more activity. Reshma and Salikutty [16] concluded better performance of plants in cocopit medium may be due to its higher water holding capacity, aeration and high potassium content, light weight and high total porosity of 94 per cent. Wan et al. [17] studied the physical characteristics of 3 cocopit: 1 perlite mixture (by volume). They found most of the mixture particles were in the range between 0.425 to 4 mm in diameter (82.93%). More than 90 % of the cocopit particles are less than 8 mm in size. They further found that bulk density of the mixture was 0.09 g cm⁻³ categorized as light media. They revealed that cocopit and perlite 3:1 proportion

mixture have acceptable porosity level of 79 % which is adequate for the root gas exchanges between the root zone and the environment. Wan et al. [17] also worked out water holding capacity and was found 912.54 % of dry weight of mixture. They stated that increased cocopit in growing media increases the water holding capacity and low value of hydraulic conductivity (0.1 cm s^{-1}) indicates mixture can hold water for much longer time in the particles. The wettability determines the aptitude of a material to reduce the surface tension of water in contact with the material so that it can wet and spread over the surface. From the experiment conducted by Wan et al. [17] observed for first 2 hour of soaking, the media absorbed water drastically until it reached a peak of water content 119 ml. After 2 hour, water content was increased slowly. Libia et al. [18] observed that substrate under long cultivation period causes increased organic matter content and microorganism activity which could leads to an increased competition for oxygen in the root environment. Anonymous (4) showed that optimal EC levels range from 1.5 to 4 dS m^{-1} according to crop and its sensitivity to different salinity levels, managing and maintaining pH and EC was a key component of successful hydroponic farming. Soares et al. [19] revealed that increase in the salinity caused linear reduction on the water consumption. It was also reported that the depth of the media in hydroponic aggregate systems should be 0.22 m. Luisa et al. [20] observed that soil temperature has a crucial impact on physiological process and growth of plants with important consequences on plant productivity and food safety including nitrate accumulation in leaf blades of leaf vegetables and concluded that level of growing medium temperature close to that of the surrounding air seems suitable. Suazo-Lopez et al. [21] was found convenient to utilize the nutrient solution at 75% in seven irrigations per day and substratum volume of 10 L for tomato production in hydroponics and greenhouse in order to obtain the highest profit (73.9%). Anonymous (4) stated that approximately 65 percent of the pore space is filled with water after the 6-inch pot has been saturated and allowed to drain and about 70 percent of that water is available and the rest is called unavailable water. Other materials such as vermiculite and perlite are added to affect water retention and aeration. Initial pH of growing media should be between 5.8 and 6.2. Verdonck and Demeyer [22] suggested to select the correct substrate before cultivation starts considering target change of the physical characteristics of

substrates or substrate mixtures within a culture. De Boodt and Verdonck [23] showed that the porosity or total pore space (TPS) does not account for pore size distribution or water and air content in the pores; it is often used when characterizing substrates. The TPS of substrates is higher than in soils, where it is approximately 50 percent of the volume. Fonteno et al. [10] pointed out that an ideal substrate should have a TPS of over 85 percent. Depending on shape, arrangement and particle size, organic substrate TPS is about 85–95 percent (Michiels et al. [24]. Raviv et al. [25], observed that in general TPS of the growing media should contain 60–90 percent TPS. Wallach [26] showed that the size and shape of particle size distribution are useful for estimating the hydraulic properties of the media, such as water retention and hydraulic conductivity. He also observed that to prevent container instability in windy conditions, high volume weight media are required, while for frequently irrigated high intensity greenhouse crops, media of low volume weight are required. Low volume weight is also important when transporting growing media [25,26]. Raviv et al. [25] found that particles of smaller-sized individual grains have a larger specific surface area, increasing the drag on water molecules that flow through the medium. Therefore water flows off fastest in coarse growing media, followed by substrates and mixtures with smaller-sized particles.

2.1.2 Suitability of crop specific media

The various scientists worked on crop specific media selection. Jovicich and Cantliffe [27] observed that type of soilless media did not influence in salt accumulation at the base of the stem. Depth of seedling plantation plays major role in salt accumulation and epidermal wounds. The plants transplanted at half of the cell height have more salt accumulation than plants transplanted at cotyledonary level. Marinou *et al.* [14] observed that the performance of plants grown on Pumice-Sawdust (50-50), followed by the Cocopit-Sawdust (50-50) and then by Cocopit-Pumice (50-50) is markedly influenced by the media due to the alteration of physicochemical properties (such as porosity, water content and air capacity) of raw material and hence the air and water balance in the root environment. Ghehsareh [15] observed that mature composted media increased the number and yield of tomato fruits. Tzortzakis et al. [28] studied impacts of the three main substrates, perlite, pumice and maize shredded stems and

their selected mixtures on tomato yield and fruit quality in soilless cultivation. They found that greatest yield was obtained from perlite + 50% maize as well as from pumice + 50% maize, i.e. 27% followed by maize with 19%. They further revealed that the maize and pumice produced remarkable early yield. The study on T_0 = fine sand, T_2 = peat + fine sand (25% + 75%), T_3 = peat + fine sand (50% + 50%), T_4 = perlite + peat (75% + 25%), T_5 = perlite + peat (50% + 50%), T_6 = perlite + peat (25% + 75%), T_7 = perlite + peat + expanded clay (25% + 70% + 5%), T_8 = perlite + peat + expanded clay (50% + 25% + 25%), T_9 = perlite + peat + expanded clay (25% + 50% + 25%), T_{10} = perlite + expanded clay (50% + 50%), T_{11} = coco peat, T_{12} = coco peat + perlite (75% + 25%), T_{13} = coco peat + perlite (50% + 50%), and T_{14} = coco peat + perlite + expanded clay (50% + 25% + 25%) and observed that perlite + peat + expanded clay mix (25% + 70% + 5%) produced significantly maximum number of flowers per plant and other quality characteristics among different media [29]. Majdi et al. [30] studied an effectiveness of substrate as vermiculite + sand, peat + perlite and rock wool on growth indices and they concluded that substrate of peat + perlite had most promising effect on growing traits and yield of green pepper. Joseph et al. [31] worked on three different media combinations, i.e., cocopeat+gravel+silex stone, cocopeat+pebble+silex stone and cocopeat+perlite+silex stone and concluded that treatment trough with cocopeat+gravel+silex stone performed best and can adopted for commercial production of tomato. Popescu et al. [32] used fallow soil (FS), Biolan peat (BP), acid peat (AP), leaf compost (C), and perlite (P) in different proportions. In their study, they revealed that growing media with the 60% biolan peat, 30% acid peat and 10% perlite formula seem to be the most adequate growth substrate to develop profitable crops for petunias and ornamental tobacco with high decorative value. Kratky [33] found that sheet of extruded polystyrene is useful for transplanting net pots in floating hydroponic. Wahome et al. [34] used three different aggregate/medium components i.e. sawdust, river sand and vermiculite. The result of their study reported that growing *Gypsophila* in bag culture with saw dust gives highest yield of cut flowers. Alexander et al. [35] cultivated Cherry tomatoes on powder of coconut fiber in the hydroponic system and revealed that the media can store nutrient solution of 3.02 liter per pot promoting economy of electricity in hydroponic cultivation system. Nagasuga et al.

[36] grew rice seedlings in controlled environment at temperature 25 °C at day and 20 °C at night with light intensity at 250 $\mu\text{mol m}^{-2}\text{s}^{-1}$ for 23 day. After 12 day after start of germination low temperature treatment at 14.0 $\pm 0.1^\circ\text{C}$ by circulating cooled water was given to roots. They observed that low temperature of the roots/media results reduction in total dry weight, leaf numbers, root water content (RWC), transpiration, root dry weight (66%), root length (30%) and total root surface area (48%) of control. Suazo-Lopez et al. [21] observed that it was convenient to utilize the nutrient solution at 75% in seven irrigations per day and substratum volume of 10 L for tomato production in hydroponics and greenhouse in order to obtain the highest profit (73.9%). The average cucumber yield for open fields was approximately 2.0 kg m^{-2} per year and in an energy-saving hydroponic system with coconut coir as the growth media was 8.5 kg m^{-2} , which was 4.2 times the yield for a 2.5-month farming season (37). Moboko and ploy [37] observed that cherry tomato production under 75% nutrient concentrations and sawdust gives best results. Almeida et al. [38].cultivated strawberries in coconut substrate and observed that strawberries cultivated in conventional farming have better shelf life than hydroponic.

3. COMPARISON OF MEDIA (SUBSTRATE) CULTIVATION AND SOIL CULTIVATION SYSTEM

The drastically restricted volume of the rooting medium and its uniformity are the characteristics of soilless cultivated crops differentiating them from crops grown in the soil (32).The fertilizers containing the nutrients to be supplied to the crop are dissolved in the appropriate concentration in the irrigation water and the resultant solution is referred to as "nutrient solution" (32). In soilless crops, the plant roots may grow either in porous media (substrates), which are frequently irrigated with nutrient solution, or directly in nutrient solution without any solid phase. The soilless cultivation allows absence of soil-borne pathogens; safe alternative to soil disinfection; nutrients and water are applied more evenly to the plants, No risk of accumulation of phytochemical residues, increased yield. crop production improvement more than 10-fold, No need for tillage, manuring, initial fertilization, possibility to cultivate crops even in saline or sodic soils, or in non-arable soils with poor structure, enhancement of early yield in crops planted during the cold season, respect for

environmental. Therefore, in many countries, the application of closed hydroponic systems in greenhouses is compulsory by legislation, particularly in environmentally protected areas, or those with limited water resources [39,8]. Despite the considerable advantages of commercial soilless culture, there are disadvantages limiting its expansion in some cases [8] such as high installation and energy costs and technical skills, environmental problems (disposal of exhausted substrates such as rockwool, losses in the soil of draining nutrient solution, use of huge amounts of plastics), absence of suitable cultivars, possibility of the groundwater pollution. No indications for the distribution of pesticides with the nutrient solution. Dependence on electricity and other economic sectors.

4. CONCLUSION

It was observed from the study conducted worldwide by various researchers that farming is shifting from soil to soilless farming. For the purpose different media, their combinations, their physical and chemical properties were worked out. The selection of the suitable media individually or in combinations and its suitability for crop cultivation was examined through repeated experimentations. The reviewed literature shows that scientists have studied different media as vermiculite, perlite, hydroton, pumice, cocopit, vermicompost, rockwool, saw dust etc. and other locally available media. It was also revealed that media which are easily, cheaply and locally available for users should be identified and studied. Beside this, few scientists studied about particle size, porosity, bulk density, wettability of these media. These properties of the media were found helpful for deciding time of irrigation and irrigation interval.

ACKNOWLEDGEMENT

I am expressing deep gratitude towards the help, guidance and inspiration rendered by Chairman Prof. Dr U.S. Kadam and Advisory, Dr. M.S. Mane, D.M. Mahale, J. S. Dhekale. I am also thankful to the Dr. B.S. Konkan Krishi Vidyaapeeth, Dapoli for giving opportunity to do Ph.D work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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