BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA, September 2015. Vol. **12**(Spl. Edn. 2), p. 103-110

The Effect of Organic and Mineral Growing Mediums on Fruit Yield and Biochemical Quality of Tomato at Implementation of Reduced-volume Hydroponics

Gulzhan Kusainova, Evgenii Petrov, Sagynbay Kaldybayev, Kenzhe Erzhanova and Aigerim Shibikeeva

Kazakh National Agrarian University, Kazakhstan, Almaty, 050010, Abay avenue, 8

http://dx.doi.org/10.13005/bbra/2180

(Received: 05 June 2015; accepted: 29 August 2015)

The effect of mineral and organic growing mediums on fruit yield and biochemical quality, as well as cost-effectiveness of tomato growing at implementation of reduced-volume hydroponics, has been studied. It has been determined that, during the process of tomato growing, hydrophysical properties of growing mediums undergo changes.

Key words: Greenhouse, tomato, growing medium, mineral wool, Coconut husk chips, organic, mineral, perlite, vermiculite, sawdust, rice husk.

In terms of biology, tomato is the most complete vegetable crop. Rich complex of vitamins, macro and micronutrient elements, organic and amino acids and others makes this culture the most asked-for among people. However, fresh product from open ground is available for a relatively short time period – 2-3 months a year. Therefore, an alternative to obtaining fresh tomato product from open ground is its growing in greenhouses, which allows getting fresh tomatoes all year round (Belhoroev, 2006).

In recent years, Kazakhstan has enjoyed rapid construction of greenhouses, especially winter ones. Along with the traditional soil medium (sod soil, humus, manure), a growing number of farms starts cultivating vegetable plants on artificial growing mediums – mineral and organic.

Instead of the traditional hydroponic culture (pools filled with growing medium and periodically flooded with nutrient solution), in recent years, a steady tendency for growing vegetable plants by means of reduced-volume hydroponics has begun to show. Its essence lies in the placing inside a greenhouse of narrow trays filled with growing medium, to the top of which one feeds a nutrient solution (Savinova, 1988; Mairapetyan, 1984; Boiko, 1982).

For cultivation by means of the reduced-volume hydroponics method, various growing mediums are used. The most common of them is peat. However, Kazakhstan does not extract peat, but imports it mainly from Russia, Ukraine and Belarus. The second place in usage for hydroponics is taken by mineral wool, which is imported from the Netherlands and Finland. The third place in this list belongs to coconut husk chips, which Kazakhstan imports from Sri Lanka, the Netherlands and other countries (Vashchenko, 1984; Dyamurshaeva, 2012; Dyamurshaeva, 2010; Dyamurshaeva, 2012).

Quite problematic is the disposal of mineral wool after its usage. In addition, mineral wool, peat and coconut husk chips are the imported materials, their value and transportation costs impose themselves on prime cost of the products.

* To whom all correspondence should be addressed.
E-mail: gulzhan56@yandex.ru; shm.aigerim@mail.ru

This leads to the rise in vegetable product price, and the potential profit from the purchase of growing mediums remains outside the country. Therefore, it becomes necessary to find the cheapest growing mediums, preferably from locally available materials, that will be cheaper in cost and provide a possibility of effective utilization.

Since the mid-1990s, all the advanced farms have started cultivating by means of reduced-volume hydroponics method with mineral wool usage (Grodan, Gravilen or Vilan, but Grodan is more widespread) (Bulletin of statutory legal acts of central executive and other state bodies of the Republic of Kazakhstan, 2003; Dyamurshaeva, 2012; Sitnyanskaya, 1996; Bekseev, 1975).

The essence of the method is as follows. One wraps mineral wool in foil and places inside a special gutter. On the top of the film, there are holes with seedling blocks put on them. Seedlings root into Grodan mats. Seedling blocks are also made of mineral wool. Grodan herein serves only as a root-inhabited environment; nutrition reaches its goal through the solution fed. Excess solution is removed via the drainage system. In this case, the plant roots do not go beyond Grodan and have no connections with their own soil of greenhouse. Slabs of mineral wool may be reused during 4 years (Savinova, 1988; Vashchenko, 1984; Gaenko, 1971; Garan'ko et al., 1985).

Agroperlit is a specially treated perlite, a natural material in form of a volcanic glass, which is composed of chemical elements: 70-75 % SiO_2, 12-14 % Al_2O_3, 3-5 % Na_2O, 3-5 % K_2O, to 1 % Fe_2O_3, CaO, MgÎ. Distinctive feature of perlite rock is that it contains from 2 to 5% of bound water (Mairapetyan, 1984, GOST 10832, 1991).

Due to the nature of its chemical composition, perlite, as well as any glass, is inert, chemically resistant and biologically stable. Possessing a good ability of being moistened with water, foam or as it is also called "expanded" perlite can absorb up to 400% of water (by weight) and perfectly hold it inside. Almost one volume of expanded perlite can consume one volume of fluid. Besides, it easily gives water back (GOST 30566, 1998).

Vermiculite is a mineral formed in nature during mica hydrolysing. Recently, agrarians have started using it as a growing medium for vegetable crop cultivation. It contains significant amounts of oxides of silicon, magnesium, aluminium, calcium, ferrous iron and many trace elements. When heated, vermiculite easily loses water and breaks up into separate structural elements with a low volume weight. High water-holding capacity, good water permeability, sterility and light specific weight attracted the attention of many researchers (Brovko, 2006).

Coconut growing medium is a product of coconut industry. One produces it in the form of shredded remains of coconut shell fibres. Coconut growing medium is an organic medium made of coconut husk chips. These are processed, dried and pressed coconut shell residues, which are a nutritious organic material, ready to grow a variety of plants on it. Large number of necessary for plants nutrient elements contained in growing mediums is conditioned by the fact that during the period of coconut formation and growth, a large number of essential nutrients, which remain in a coconut after its removing, passes through the surrounding it fibres.

Sawdust is small chips obtained at wood sawing. Length of the sawdust fractions depends on the type and process parameters of the cutting tool, which operation contributes to their formation.

Sawdust is the waste of wood processing industry, but they have been widely used as a fuel for the production of mould industrial products, bedding for animals (often when mixed with straw or peat), as a mulch material or as a medium for fungus mycelium.

Sawdust contains about 70% of carbohydrate (cellulose and hemicellulose) and 27% of lignin. Balance of chemicals: 50% of carbon, 6% of hydrogen, 44% of oxygen and about 0.1% of nitrogen. Apparent density of dried wood chips is 220-420 kg/m^3, humidity – 8-15%.

Traditionally agrarian use sawdust for soil mulching after sowing vegetable seeds in open ground. A layer of sawdust on the soil provides moisture retention. Besides, sawdust prevents from weeds growing, soil compaction and formation of a crust on its surface, it also contributes to the chemical processes in soil, reduces the amplitude of temperature fluctuations on its surface, retard leaching of nutrients from deeper soil layers, and prevents its wind erosion.

In comparison with manure and peat,

sawdust does not have the full range of positive attributes of organic fertilizers, but it is much cheaper and if using certain techniques can be successfully used for: improving soil fertility; improving its physical and mechanical properties; growing seedlings.

In the southern regions of Kazakhstan, people plant large areas with rice. After harvesting, they separate rice grains from skins (rice husk). Agrarian use rice husks as a loosening material, being brought into the soil of open ground and greenhouse soil.

In the Central Asian republics of the CIS, scientists have started testing rice husk as a growing medium for reduced-volume hydroponics, having showed prospects of its implementation.

The study of literature data has showed that when growing vegetables by reduced-volume hydroponics method there can be used a variety of growing mediums for plant root system. In different growing areas, primarily used are available growing mediums made from local raw materials. Thus, in most CIS countries the main growing medium is peat, which natural deposits located in Russia, Ukraine and Belarus are very large. In those areas where peat is not available, agrarians prefer growing vegetable plants on mineral wool or coconut husk chips – quite expensive imported materials.

In Kazakhstan, there are large natural deposits of perlite, vermiculite; rice production provides the almost never used waste – rice husks. Sawdust is also available in large volumes. Therefore, the search for the most suitable for the growth of vegetable plants growing mediums from local raw materials is a very urgent task of reduced-volume hydroponics in Kazakhstan.

The currently used for reduced-volume hydroponics growing mediums are not produced in Kazakhstan and are imported from the near and far abroad. Besides, they are quite expensive (some of them are not recycled). Taking into account these facts, a question has been raised of finding growing mediums produced from local materials. Such mediums shall be notable for low cost and possibility of their reusage after being worked in reduced-volume hydroponics in the open ground to improve the water-physical properties of natural soils.

The Kazakh National Agrarian University and the Research Institute of Potato and Vegetable performed the studies in 2012-2014.

MATERIALS AND METHODS

The objects of study were mineral and organic growing mediums both imported and locally produced. For the experiment, the authors of the article have taken greenhouse tomato hybrid F_1 Querido of the "Rijk Zwaan" company (the Netherlands).

Main part. Research findings

The experiment took place in the winter greenhouse produced by the "Bokyng Greenhouses ltd" Company in South Korea in accordance with the technology of growing by reduced-volume hydroponics.

Plant care was to maintain an optimal temperature in the greenhouse, tie up plants, remove side shoots, and remove the lower leaves.

During the work, scientists determined water-physical properties of growing mediums taken for the experiment conduction and after finishing of the tomato turnover (volume and specific weight, hygroscopic moisture, total and capillary moisture capacity), strength of plant development, biological value of fruits (content of dry substance, ascorbic acid, total acidity, sugars, nitrates, and metals); phenological observations were carried out. The scientists also maintained yield records and counted the cost-effectiveness of tomato cultivation on different growing mediums.

For the study, the authors of the article took the following growing mediums: mineral wool (control); perlite; vermiculite; coconut husk chips; sawdust; rice husk.

Discussion of the findings

Before planting seedlings, the growing mediums taken for the experiment were subject to determination of their water-physical properties. The volume and specific weight, hygroscopic moisture, total and capillary moisture capacity were determined (Table 1).

The obtained data showed significant distinctions of different growing mediums by these indicators. Thus, the lowest volume weight out of all mineral mediums belonged to mineral wool (0.056 g/cm^3) and the largest – to perlite (0.120 g/cm^3). The lowest volume weight out of all organic mediums belonged to rice husk (0.101 g/cm^3), and the largest – to coconut husk chips (0.125 g/cm^3).

The lowest specific mass out of all mineral mediums belonged to mineral wool (0.297 g/cm^3), the largest – to perlite (0.480 g/cm^3). The lowest specific weight out of all organic mediums belonged to sawdust (0.222 g/cm^3), the largest – to coconut husk chips (0.335 g/cm^3).

Determination of hygroscopic moisture content in mineral mediums showed that the smallest value belonged to the mineral wool (2.214%) and perlite (0.914%), the largest hygroscopic moisture content in organic mediums belonged to coconut husk chips (10.358%) and rice husk (5.620%).

The largest total moisture capacity of mineral mediums belonged to mineral wool (81.0%), the lowest – to vermiculite (64.5%). Out of all organic mediums, the largest total moisture capacity belonged to rice husk (54.0%), the lowest – to coconut husk chips (47.9%).

The largest capillary moisture capacity out of mineral mediums belongs to vermiculite (710.460%), the lowest – to perlite (403.320%). The largest capillary capacity out of organic mediums belongs to coconut husk chips (837.133%), the lowest – to sawdust (14.001%).

Tomato plants growing on mineral mediums showed that, when grown in perlite, entry into the next phases of plant development was 4-5 days earlier than in mineral wool and vermiculite.

The dynamics of tomato plants growth in a vine-ripe phase showed that the highest tomato plants were those growing in mineral mediums such as vermiculite – 191.7cm, and in organic mediums such as coconut husk chips (189.0 cm^2). The largest leaf surface belonged to plants growing in mineral mediums such as vermiculite – 5523 cm^2, and in

Table 1. Water-physical properties of the growing mediums taken for the experiment starting, (2012- 2014)

Growing medium	Volume weight, g/cm^3	Specific weight, g/cm^3	Porosity, %	Hygroscopic moisture, % capacity, %	Total moisture capacity, %	Capillary moisture
Mineral wool(control)	0.056	0.297	18.9	2.214	81.0	620.455
Perlite	0.120	0.480	25.0	0.914	74.8	403.320
Vermiculite	0.109	0.307	35.5	1.765	64.5	710.460
Coconut husk chips	0.125	0.335	37.3	10.358	47.9	837.133
Sawdust	0.105	0.222	47.3	6.148	51.7	14.001
Rice husk	0.101	0.226	44.7	5.620	54.0	31.728

Table 2. Content of dry substance, sugars, acids, nitrates, and metals in plant organ of tomato F_1 Querido cultivated in different growing mediums, (2012-2014)

Option	Dry substance, %	Sugars, % per dry	Ascorbic acid, substance	Total acidity mg%	Nitrates , mg/kg by malic acid, %	Zinc, mg/k	Copper , mg/kg g	Lead, mg/kg	Cadmium , mg/kg
Mineral wool(control)	5.3	3.22	14.49	0.53	32.6	1.03	0.71 found	not found	not
Perlite	5.5	3.10	16.27	0.60	32.6	0.98	0.76 found	not found	not
Vermiculite	5.2	3.00	14.54	0.50	33.4	1.08	0.67 found	not found	not
Coconut husk chips	5.8	2.78	15.14	0.52	32.4	0.91	0.70 found	not found	not
Sawdust	5.3	2.77	15.49	0.52	31.2	1.17	0.71 found	not found	not
Rice husk	5.4	2.97	16.55	0.54	32.7	1.24	0.81 found	not found	not

Table 3. Yield and weight of the F_1 Querido tomato fruit in various growing mediums, (2012-2014)

Option	Yield from 1 m²				Yield increment, kg/m²		Fruit weight, gr	
	during 3 kg	cropping %	during kg	vegetation %	early	during vegetation	during early cropping	during vegetation
Mineral wool(control)	4.3	100	16.0	100	-	-	139	108
Perlite	4.8	111.6	19.2	1200	0.5	33	159	121
Vermiculite	2.9	67.4	15.9	99	-	-	108	88
Coconut husk chips	4.5	104.6	22.7	141.9	0.2	6.7	143	102
Sawdust	4.0	93.0	16.9	105.6	-	0.9	124	94
Rice husk	3.4	79.0	11.8	73.8	-	-	111	89
$HCP_{0.5}$	0.06-0.760.17-0.76							
S×%	1.4-5.1 1.6-3.9							

Table 4. Cost-effectiveness F_1 Querido tomato cultivation in various growing mediums, (2012-2014)

Option	Yield, kg/m²	Earnings, tenge/m²	Cultivation costs, tenge/m²	Net income, tenge/m²	Prime cost of 1 kg, tenge	Profitability, %
Mineral wool(control)	16.0	5867	5882	5	366.4	-
Perlite	19.2	7017	4288	2729	223.3	63.6
Vermiculite	15.9	5617	4383	1234	275.7	28.2
Coconut husk chips	22.7	8207	8662	-	381.6	-
Sawdust	16.9	6133	4288	1845	253.7	43.0
Rice husk	11.8	4393	4288	105	363.4	2.4

organic mediums such as sawdust (5375 cm²).

Study of biochemical quality of tomato fruits revealed differences in content of dry substance, sugars, acids, nitrates, and metals depending on the type of growing medium (see Table 2).

The largest content of dry substance when grown in mineral medium belonged to the tomato fruits grown in perlite – 5.5%, the lowest – in vermiculite (5.2%). Cultivating plants in organic mediums showed that the largest content of dry substance belonged to tomato fruits grown in coconut husk chips – 5.8%; growing in sawdust and rice husk contributed to less accumulation of dry substance in fruits. The highest content of sugars when grown in mineral mediums was in tomato fruits cultivated in mineral wool – 3.22%, and the lowest – in vermiculite.

Cultivation of tomato plants in organic mediums increased content of sugars in those plants grown in rice husk – 2.97%, while plants grown in coconut husk chips and sawdust contained 2.78 and 2.77% of sugars, respectively.

The lowest content of ascorbic acid in tomato fruits when grown in mineral mediums such as mineral wool was 14.44 mg %, and the largest was in those grown in perlite (16.27 mg %). When growing in organic mediums, the lowest content of ascorbic acid was found in tomato fruits cultivated in sawdust – 51.49 mg %, and the largest – in rice husk (16.55 % mg).

The lowest content of total acidity in tomato fruits when grown in mineral mediums was found in those plants cultivated in vermiculite – 0.50%, and the largest – in perlite (0.60%). Growing plants in organic mediums showed that the lowest acidity belonged to tomato fruits grown in coconut husk chips and sawdust (0.52%), and the largest – in rice husk (0.54%).

Permissible level of nitrates, according to SanPiN (Sanitary Regulations and Norms) 42-123-4619-88 and SanPin (Sanitary Regulations and Norms) 4.01.71.03, is in tomato grown in sheltered areas – 300 mg/kg.

Less nitrates, when grown in mineral mediums, were accumulated by tomato fruits cultivated in perlite and mineral wool – 32.6 mg/kg; more nitrates were found in those fruits grown in vermiculite (33.4 mg/kg). When growing plants in organic mediums, the lowest nitrate level was found in those tomato fruits grown in sawdust – 31.2 mg/kg, and the largest – in rice husk (32.7 mg/kg). Thus, the nitrate content in tomato fruits cultivated in different growing mediums is by 9-9.6 times lower than the maximum permissible concentration (MPC).

When growing plants in mineral mediums, fruits cultivated in vermiculite accumulate more zinc – 1.08 mg/kg, and less – in perlite (0.98 mg/kg). Growing plants in organic mediums shows that fruits cultivated in rice husk accumulate more zinc – 1.24 mg/kg, and less – in coconut husk chips (0.91 mg/kg).

The lowest copper content belongs to the tomato fruits when grown on mineral mediums such as vermiculite – 0.67 mg/kg, and the largest – in perlite (0.76 mg/kg). Out of organic growing mediums, the lowest accumulation of copper in tomato fruits is contributed to by coconut husk chips – 0.70 mg/kg, and the largest – by rice husk (0.81 mg/kg).

Environmental degradation requires the production of environmentally friendly products of vegetable crops, which do not accumulate heavy metals, such as lead and cadmium. These metals are not found in the tomato products cultivated in different growing mediums.

The highest yield in early cropping, at tomato cultivation in mineral growing mediums, was obtained at perlite option – 4.8 kg/m^2, and when grown in organic mediums – at coconut husk chips option (4.5 kg/m^2).

Yield gathered during the vegetation season, at tomato cultivation in mineral mediums, was the largest at perlite option (19.2 kg/m^2), and when grown in organic mediums – at coconut husk chips option (22.7 kg/m^2). Mathematical processing of the data showed significant increases of yield (Table 3).

Table 5. Changes in water-physical properties of the growing mediums after cultivation of F_1 Querido tomato in various growing mediums (2012-2014)

Growing medium	Volume weight, g/cm^3	Specific weight, g/cm^3	Porosity, %	Hygroscopic moisture, %	Total moisture capacity, %	Capillary moisture capacity, %
Mineral wool(control)	+0.007	-0.018	+3.7	-1.993	-3.6	-98.972
Perlite	-0.042	+0.032	-9.8	+0.074	+10.0	-176.224
Vermiculite	+0.053	-0.111	+47.2	+3.010	-47.5	-320.063
Coconut husk chips	+0.010	-0.175	+47.1	-4.703	-32.1	-106.581
Sawdust	+0.049	-0.021	+29.3	-2.126	-28.1	+11.230
Rice husk	-0.018	-0.071	+8.8	-1.908	-7.4	+20.644

Comparative evaluation of tomato fruits weight at different options of the experiment showed that out of the studied mineral mediums the heaviest fruits were gathered from perlite medium (in early cropping – 159 g, during vegetation season – 121 g). When grown in organic mediums, the heaviest tomato fruits were in coconut husk chips, a bit lighter – in sawdust.

The cost-effectiveness calculation has shown that when tomatoes were grown in mineral mediums, the highest net income was obtained from perlite cultivated fruits – 2729 tenge/m^2; when grown in organic mediums, the highest net income was obtained from sawdust cultivated fruits – 1845 tenge/m^2. When one grows tomatoes in coconut husk chips, the income is not received, as the cost of cultivation is higher than the sales revenue (Table 4).

After cropping completion, scientists defined water-physical properties of mediums, in which the tomatoes were grown.

The lowest volume weight out of mineral mediums belonged to mineral wool (0.063 g/cm^3), the largest – to vermiculite (0.162 g/cm^3). The lowest volume weight out of organic mediums belonged to rice husk (0.083 g/cm^3), and the largest

– to sawdust (0.154 g/cm^3).

The lowest specific weight out of mineral mediums belonged to rice husk (0.155 g/cm^3), the largest – to sawdust (0.201 g/cm^3).

The highest content of hygroscopic moisture out of mineral mediums belonged to vermiculite (4.775%), the lowest – to mineral wool (0.221%). The highest content of hygroscopic moisture out of organic mediums belonged to coconut husk chips (5.655%), the lowest – to rice husk (3.712%).

The largest total moisture capacity out of mineral mediums belonged to perlite (84.8%), the lowest – to expanded clay (17.0%). Out of organic mediums, the largest total moisture capacity belonged to rice husk (46.6%), the lowest – to coconut husk chips (15.8%).

The largest capillary moisture capacity out of mineral mediums belonged to mineral wool (521.483%), and the lowest – to perlite (227.096%). Out of organic mediums, the largest capillary moisture capacity belonged to coconut husk chips (730.552%), the lowest – to sawdust (25.231%).

Comparative analysis of water-physical properties of growing mediums taken for the experiment and after the end of tomato cultivation turnover revealed certain changes in these properties (Table 5).

CONCLUSION

Out of mineral mediums, the more increased was the volume weight of vermiculite, and the less – of mineral wool; perlite's volume weight decreased after the tomato turnover. Out of organic mediums, the volume weight increased more in sawdust, and less – in coconut husk chips; the volume weight of rice husk also decreased.

After tomato turnover, perlite and vermiculite demonstrated an increased percentage of hygroscopic moisture content, and mineral wool – a reduced one. All organic mediums reduced content of hygroscopic moisture after tomato cultivation.

Tomato growing in perlite increased its total moisture capacity, mineral wool and vermiculite – reduced. Organic mediums reduced the total moisture capacity after tomato cultivation.

Tomato growing in mineral mediums reduced their capillary moisture capacity. Tomato growing in sawdust and coconut husk chips increased their capillary moisture capacity, and rice husk – reduced.

The findings lead to the following **summary**:

1. Out of the mineral mediums studied, perlite growing produces the largest tomato yield at the lowest production cost.
2. Tomato plants cultivation in various mineral and organic growing mediums influenced on the biochemical quality of fruits. The highest dry substance content was in fruits of the plants grown in coconut husk chips; sugars – in mineral wool and perlite; ascorbic acid – in perlite and rice husk. The lowest content of total acidity was in tomato fruits grown in vermiculite. The lowest content of nitrates scientists found in the fruits of those plants grown in sawdust, which was by 9.6 times lower than the maximum permissible concentration (MPC).
3. Tomato growing in coconut husk chips proved to be economically inefficient due to the high cost of growing medium.
4. Tomato growing in sawdust yielded high returns with low production costs.
5. It is desirable to continue the research: to explore and select the optimal combination of organic and mineral mixture in relation to quantity and quality.

The development offered by us will promote providing the population of Kazakhstan with the fresh out-of-season vegetables which are grown up on substrata of domestic raw materials. For the first time in Kazakhstan for small-volume hydroponics the technology of use of cheap substrata of local raw materials is offered. The domestic substrata allowing receiving big, environmentally friendly crops of a tomato on small-volume hydroponics are established. Scope: the farms, the enterprises which are engaged in cultivation of vegetables in greenhouses by method of small-volume hydroponics.

ACKNOWLEDGEMENTS

The authors of this article are deeply obliged for the publication of scientific research data results. This article was prepared within the framework of projects of the Ministry of Education and Science and "KazAgroInnovation" JSC, the Ministry of Agriculture of the Republic of Kazakhstan.

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