Research on vegetable farming in vertical hydroponic system

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Abstract: Vertical farming is the practice of growing plants in a multi-layer system. This often includes agriculture in a controlled environment, whose purpose is the optimisation of plant growing, together with soil-free agricultural techniques, such as hydroponics, acquaponics and aeroponics. Some of the structures used for setting-up the vertical farming systems are: buildings, ship containers, underground tunnels and mine shafts.

This paper presents the study of several vegetable cultivars grown in a vertical hydroponic system, with a vegetation period of 7 to 18 days. The analysed species were: green mizuna, red mustard, green pak choi, red radish, green peas. At the end of the established vegetation period, the plants were cut, then mixed in a tasty fresh salad. Besides the explosion of tastes and special nutritional intake, this relatively new agricultural concept was proven to have a higher yield compared to the conventional farming techniques. This yield is given by the following factors: high productivity, water consumption reduced up to 70%, decrease of pesticides consumption by creating an ideal growing environment, perfectly controlled according to the requirements of each species, possibility to use such a system anywhere, even in non-agricultural areas (areas with disused agricultural land, mountain areas or even directly within shops).

Keywords: microgreens, vertical farming, hydroponics,

1. Introduction

Microgreens, also known as shoots, are vegetable and aromatic plants consumed in their cotyledonal-leaf stage or when they have developed their first pair of real leaves. These are a new exotic type of greens, popular at first in high-end (/luxury) restaurants and markets and they have become a new culinary trend in the last years. In time, they have become more and more demanded, and today they actually number over 80 species [14, 17]. Microgreens are generally three to ten centimetres tall, they are harvested 7 to 14 days after germination and marketed as stems with cotyledons. They are appreciated for their wide range of intense savour, colours, textures and shapes, therefore they are served as ingredients in salads, soups, sandwiches and used as seasonings in a great variety of main courses [1, 4, 6, 12]. There is a great number of studies that have shown that microgreens may contain high levels of health-beneficial vitamins, minerals and phytonutrients. Some studies have shown that, seven days after germination, young plants of lettuce (*Lactuca sativa*) had the highest total phenolic concentration and antioxidant activity, as compared to the leaves of more mature plants [9, 13], while young spinach leaves (*Spinacia oleracea L.*) had a higher content of phytonutrients, such as: vitamins C, B9 and K1 and carotenoids (lutein, violaxanthin, zeaxanthin and beta-carotene), as compared to mature leaves [8]. A high quantity of vitamin C is found in broccoli, pea, sorrel, lentil, garden cress and chickpea microgreens. A high content of vitamin D is found in sunflower microgreens, while in red beet and green basil microgreens there is an important quantity of calcium. Wheatgrass and red beet have a strong antioxidant effect [2, 3, 7, 10, 11, 15].

Hydroponics – or the idea of growing plants without using soil as root support and source of water and minerals – took shape in Europe in the 17th century and it has evolved spectacularly up until today. Between 1860 and 1861, Julius von Sachs and W. Knop studied and tried to standardise a nutritive solution for soil-free farming systems, and they have managed to grow plants in water. The first formula of calculating the necessary nutritive substances was drafted by Dennis R. Hoagland and it is still the basis of today's nutritive recipes. The surfaces of soilless cultures are growing at global level. In 1980, 20,000 ha were cultivated in a hydroponic system, and this surface increased to 25,000 until 2001. Hence a rapid growth of surfaces follows, and in 2011 330,000 ha were declared. The concept of vertical farming was advanced in 1999 by Dickson Despommier, professor at the University of Columbia. Together with some of his students, he designed such a vertical farm that could feed over 50,000 people. Although the project was never put into practice, it still triggered the awareness on the concept, its research and development. [19].

Benefits of the vertical farming:

- ensuring the necessary food for urban areas – some estimates show that 80% of the world's population will be living in urban areas by 2050. As a consequence of this growth of urban population, the areas adjoining the cities will have to provide for this considerable growth of food consumption;

- production growth – this new type of agriculture allows for the exponential growth of the production depending on the number of cultivated layers using the same ground surface.

- healthier food – as a consequence of growing plants in a totally controlled environment, the need for pesticide use is significantly reduced;

- decrease of water consumption – up to 70-80% less water, as compared to conventional agriculture. This is essential for the next several decades, considering that at present agriculture uses 70% of the fresh water for irrigations, while the water becomes inappropriate for consumption, due to its contamination with fertilisers, pesticides, herbicides etc. [18].

Vertical farms can be set-up in abandoned buildings within each town, thus turning them into real urban oases that will produce healthy food a few steps away from home. The greatest advantage of this method is probably the possibility to develop these farms on any ground, as there is no requirement for agricultural land. This offers the possibility of development of the agricultural sector in areas less prone to this kind of activity [16].

This research follows a comparative analysis of two systems adequate for microgreens farming, i.e. conventional ebb&flow hydroponic system and vertical hydroponic system using the same technique – ebb&flow.

Materials and methods

2.1. Growing method

The research was made in the commune of Gorgota, Prahova County, approximately 40 km away from Bucharest. The farm grows microgreens in a conventional ebb&flow hydroponic system, with horizontal growing benches, as well as in vertical hydroponic systems in various configurations, using the same ebb&flow technique, with stacked growing benches and artificial lighting.

The vertical farming module (the rack) has the following dimensions: L = 800 cm; W = 160 cm; H = 480 cm. It has 5 layers with benches made of UV-resistant plastic, controlled temperature, artificial lighting and permanent ventilation. Moreover, the module is also equipped with its own irrigation system, as well as with a system for automatic pH and EC adjustment, and everything can be remotely controlled via a laptop connected to the Internet. These modules are placed within several shops in the capital city of Bucharest and they produce healthy fresh food all the year round.

For both versions of culture, the microgreens are sown in 9x7 cm plant pots made of plastic. These are placed in support-trays containing 16 pots in order to ease the technological process, particularly the works of sowing and manoeuvring at harvest.

Microgreens have a vegetation cycle that varies depending on the species. Thus, the vegetation period may vary from 7-8 days (peas, red radish) to 17-19 days (red mustard, green mizuna, green pak choi).

Currently the farm has a number of 40-45 species in a continuous dynamic dictated by the customers' needs and preferences. In this experiment, 5 species were studied: red radish, green peas, green mizuna, red mustard, green pak choi. The growing substrate was a mix of peat (80%) and perlite (20%). High-quality, certified, untreated seeds were used.

Microgreens growing technique: the growing pot is filled with a mix of peat and perlite up to 75-80% of its volume, then the substrate is gently pressed. After filling, it is placed in the support-tray and a small quantity of water is sprayed over its surface. Thus, the seeds will have the moisture required for germination both at soil level (moisturised peat) and in the atmosphere (controlled relative air humidity). After sowing, the trays are put in the germination room. Depending on the species, the trays will spend here from 2 to 4 or 5 days, at a temperature of 18-20 Celsius degrees and an atmospheric humidity of 95-98% (dense mist). After coming out of the germination room, the trays are left for 2-3 hours in a room with a temperature of 20-22 Celsius degrees and diffuse light; during this period the acclimation of the plantules takes place. After this period, the trays are placed on the growing benches – either unfolded in the greenhouse or on vertical racks – where the entire process of growing takes place. Immediately after placing the trays on the benches, the first irrigation is carried out, which moisturises the whole substrate.

The administered water has a pH of 5.8-6 and an EC of 0.8. From the third day onward the cultures are watered daily with a medium volume of water of approximately 270-280 l/bench, with a pH between 5.8 and 6.2 and an EC of 1.0-1.2.

Fig.1 Vertical module inside the store

2.2 Results

Table no.1 General results

Crt. No.	Cultivar	Growing system	Height (cm)	Weight (g/tray)	Annual production per bench (kg)	Annual production per greenhouse – 32 benches (kg)	Growing period (days from sowing)	Number of cycles per year
1	Green pak choi	Vertical	12.5	378,4	973.73	31,159.36	16	23
		Conventional	13.7	331,2	741.44	23,726.08	18	20
2	Red mustard	Vertical	12.1	322,6	829.47	26,543.04	16	23
		Conventional	12.9	297,5	698.54	22,353.28	17	21
3	Green mizuna	Vertical	12.2	339,9	913.92	29,245.44	15	24
		Conventional	13.1	316,8	745.48	23,855.36	17	21
4	Peas	Vertical	12.1	241,7	1403.6	44,915.20	7	52
		Conventional	12.4	224,8	1028.61	32,915.52	9	41
5	Red radish	Vertical	11.5	274,8	1601.6	51,251.20	7	52
		Conventional	11.9	251,5	1154.89	36,956.48	9	41

The general results obtained within this experiment are summarized in Table 1. It is worth mentioning that, despite the additional height recorded for the conventional system, the average weight of the trays in the vertical system is greater by 47.2 g/tray for the pak choi culture or 25.1 g/tray for the red mustard etc. This is mainly due to the process of elongation of the plants' stems and the weak development of the leaves, as a consequence of the differences in the quantity of light that reaches the plant.

Furthermore, the actual time of growing in the conventional system is 1-2 days longer for the same species, which allows a greater number of yearly cycles in the vertical system. When calculating the potential production over one year for both systems, we can see that the additional production increase for the vertical system is 31% for the pak choi culture, 23% for mizuna, 39% for red radish etc.

Table no. 2 Electricity consumption for a conventional greenhouse

Equipment	Power consumed	Power consumed 1 month
Leds	**kWh0.00**	**kWh0.00**
Sowing machine	**kWh12.00**	**kWh372.00**
Cooling/ dehumidification installation	**kWh24.00**	**kWh744.00**
Cutting machine	**kWh1.00**	**kWh31.00**
Packing machine	**kWh1.00**	**kWh31.00**
Recirculation pump	**kWh7.00**	**kWh217.00**
Irrigation pump	**kWh40.00**	**kWh1,240.00**
ventilation	**kWh200.00**	**kWh6,200.00**
Cost/ year (EUR)		**10160.25**

Table no.3 Electricity consumption for a vertical greenhouse

Equipment	Power consumed	Power consumed 1 month
Leds	**kWh700.00**	**kWh21,700.00**
Sowing machine	**kWh12.00**	**kWh372.00**
Cooling/ dehumidification installation	**kWh24.00**	**kWh744.00**
Cutting machine	**kWh1.00**	**kWh31.00**
Packing machine	**kWh1.00**	**kWh31.00**
Recirculation pumps	**kWh7.00**	**kWh217.00**
Irrigation pump	**kWh40.00**	**kWh1,240.00**
Ventilation	**kWh200.00**	**kWh6,200.00**
Cost/ year(EUR)		**23180,25**

When analysing the results from the tables 2 and 3, we can notice that in the case of the vertical greenhouse the power consumption is 128% higher as compared to the traditional greenhouse. It is very important to mention in this case that the vertical greenhouse has a production surface 3 times bigger than the conventional greenhouse. Thus, the power consumption for a sector of the vertical greenhouse corresponding to the surface of a traditional greenhouse rises to 7,726 euro/year, which means a consumption lower by 24%. This is also applicable in the case of the thermal energy consumed for the heating of the greenhouses during the cold season.

Considering this economic streamlining of the resources consumed in the production process, cumulated with the production growth recorded in the vertical system and the extremely reduced space available for agricultural activities in the proximity of or even within towns, this innovative idea not only aims for idealistic projections pertaining to the agriculture of the future, but also promises to be a motivating realistic project for the present.

Conclusions:

1. Although relatively recent, vertical agriculture will become the agriculture of the future, particularly in the vicinity of great urban clusters.

2. Through its small ground surface, its possibility to control all the plant growth factors and to obtain high quantities of high quality produce, vertical farming will increasingly replace traditional agriculture.

3. Vertical farming uses all the necessary resources for plant growing in a responsible and efficient manner, recording a 70-80% lower water consumption and a 20-30% lower power consumption on the surface unit, while yielding 30-40% higher quantities of produce, as compared to conventional agriculture.

4. The produce obtained through this technique are healthier and "cleaner", due to the considerable decrease of the pesticide quantity used in the process of plant growing. This is due to the full integrated control of the growing environment, wherein even an ecological production is possible.

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