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SUBSTRATE COMPOSITION EFFECT ON THE CHARD (*BETA VULGARIS* SUBSP. *VULGARIS*) GREEN MASS YIELD IN HYDROPONIC COMPLEXES

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SUMMARY

Protected soil ground, facing considerable variations with high risks to develop a dynamic agriculture, play a vital role for the year-round supply of fresh and vitamin-rich vegetables and greens in Kazakhstan. The agriculture sector needs further exploration with the development of innovative technologies. An available supply of green vegetables regardless of the season allows new technologies to grow the green chard (*B. vulgaris* subsp. *vulgaris*) crops using hydroponics. The presented study sought to develop the rational chard in seedling complexes using hydroponic shelving units (hereinafter HSI4) for year-round production of vegetable to ensure the profitability of greenhouse production. For seasons conveyor chard cultivation in winter greenhouses on HSI4, the recommended use of hybrids requires Rubyn, Nevesta, and Bychya krov; with dark-green leaf plate Nevesta and Bychya krov, and with light leaf plate hybrid Rubyn in winter-autumn. For all-season conveyor chard cultivation, the hybrid Bychya krov was the best option, with a mixture of peat (80%) and perlite (20%). However, the highest yield obtained came from the Bull's Blood and Bride hybrids (362.2 and 335.3 g plant^{-1}, respectively) in summer. The promising results may serve as bases for modern agricultural practices and technological innovation in greenhouse management, implementing hydroponic systems and substrate management for optimal crop yield.

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Keywords: Chard (*B. vulgaris* subsp. *vulgaris*), innovative technologies, conveyor growing, hydroponics, green mass, products, substrate

Key findings: For all-season conveyor cultivation of chard (*B. vulgaris* subsp. *vulgaris*) in winter greenhouses using low-volume hydroponics on HSI4, the study recommended using the Ox's Blood hybrid with organic substrates.

INTRODUCTION

Currently, worldwide research focused more on climate-optimized agricultural technologies and sustainable food production to meet the demand of an expanding population (Agegnehu et al., 2017; Xiao et al., 2017; Yuan et al., 2017). With this, farming communities intensively use synthetic chemical fertilizers that can damage the environment and harm ecological system and public health. In chard (B. vulgaris subsp. vulgaris) cultivation under greenhouse conditions, the organic additives positioned as a sustainable clean production technology. In addition, vegetable crops cultivation under greenhouse conditions is undergoing significant variations to develop a competitive branch of agriculture for supplying the fresh and vitamin-rich vegetables year-round in Kazakhstan.

Geobotanical map of the area influences how the agro-biocenosis massification develops (Ydyrys et al., 2020a). Medicinal plants served the treatment of various diseases for thousands of years, giving them special care, in addition to their nutritional values. Rich natural resources are dominant in numerous wild plants. However, the rapid deforestation, urbanization, and excessive use of domesticated plants result in a decline in these plant genetic resources' quantity, as well as, extinction of natural species (Ydyrys et al., 2020b), a considerable reduction in various species (Seilkhan et al., 2016, 2018), and the endemism crisis (Akhmetova et al., 2015, 2018). Therefore, cultivating medicinal plants in botanical gardens and fields is an alternative for obtaining more raw materials (Yeszhanov et al., 2020; Bukenova et al., 2019).

Growing vegetables by hydroponics using a complex of chemistry and biology is one of the newest areas of greenhouse production (Seilkhan et al., 2021; Seilkhan, 2024). Solving the problems of daily supply of green vegetables regardless of the season will allow new technologies for conveyor growing of green chard crops using hydroponics. With innovations, the hydroponic system is becoming increasingly important. The technical designs made for such systems make it possible to grow environmentally friendly products while reducing their cost. Therefore, the introduction into production of science-based chard, providing high intensification with production of vegetables, boosts chard in specialized hydroponic complexes.

Leafy vegetables come from various vegetable crops, such as, spinach, chard, lettuce, cabbage, leeks, chicory, and cabbage (Walorczyk, 2008). The contents of leafy vegetables are also variable, although, they tend to contain little fat and calories, their high content of iron, calcium, protein, phytochemicals, and dietary fibers make them essential for human health (Antipova, 2007; Ko et al., 2014). Chard, as a folk medicinal plant (Bolkent et al., 2000), has hypoglycemic, hemostatic, and anti-inflammatory effects (Kim et al., 2003). In Korean cuisine, leafy vegetables, such as Swiss chard, are ingredients in salads, eaten as raw vegetables, wrapping pieces of meat in them (Im et al., 2015).

Chard (leaf beet, beetroot) is a subspecies of the common beet of the Chenopodium family, a 2-year-old vegetable plant with thick, fleshy wrinkled leaves and petioles with fibrous, vastly branched, and sometimes thickened inedible root. The flowers are small and greenish, with the pericarp growing together to form infructescence (Autko et al., 2006). Plants comprised extremely high productivity of leaf mass. The chard leaves are 2–3 times larger than those of table beet, often strongly wavy, and sometimes bubbly and curly. Chard leaves contain dry matter (10.6%–11.4%), sugar (2.7%–4.6%), protein (2–2.7 mg), ascorbic acid (20–30 mg), and 1–2 mg carotene per 100 g of raw mass (Golovatskaya, 2009). The chard is also rich in mineral salts and its 100 g contain calcium (102 mg), phosphorus (35 mg), iron (3.9 mg), and other trace elements (Belogubova et al., 2006; Avdeenko, 2012).

Chard is a valuable vegetable in children's nutrition, as its stalks have a superior taste, and numerous delicious dishes can also come from it. Rational year-round crop rotations in seedling complexes are reasonable, allowing to obtain environment-friendly vegetable products by the conveyor method. As a result, the profitability of production enhances from 47% to 142% (Gikalo and Gish, 2009). Leaves are essential, with juicy and fleshy stems having a diameter of 7–8 mm can be beneficial. Petioles and leaves are incredibly rich in vitamins, minerals, trace elements, and many valuable compounds (Golovatskaya, 2009).

Thus, the introduction into production of new types of vegetable precocious green crops, in particular chard, which has active physiological substances, can be effective for food and medicinal purposes to improve human health (Mamedov, 2014; Litvinov et al., 2015; Ydyrys, et al., 2021; Pires et al., 2023). The presented study contributes to advancing agricultural practices and serves as a valuable educational tool for green education programs focused on sustainable agriculture and food security in Kazakhstan. It integrates theoretical knowledge with practical insights, offering solutions to enhance the productivity and economic sustainability in protected agriculture. The present study aimed to develop and introduce the production of rational chard in seedling complexes using hydroponic shelving units (hereinafter HSI4) for year-round production of vegetable products that ensure the profitability of greenhouse production.

MATERIALS AND METHODS

In 2020–2022, the conduct of the presented research commenced under greenhouse conditions to study the influence of substrate composition on the green mass yield of chard (Beta vulgaris subsp. vulgaris) hybrids. The experimental objects were the hybrids of green-leafed vegetable chard (B. vulgaris subsp. vulgaris) and biofertilizers. Sowing of chard hybrids Rubin (control), Nevesta, and Bychya krov for seedlings took place in plastic cassettes in the last week of February to the first 10 days of March (winter turnover). In the last week of June, the same hybrids' sowing for seedlings ensued in cassettes in an unheated greenhouse (summer turnover). The planting of seedlings continued in the closed ground in the last week of March to the first 10 days of April (peat mixed with 20% perlite on the substrate had a ratio of 80% + 20%). The irrigation provision as required was during the spring and summer growing periods for maintaining 70%–80% soil moisture. The harvesting (cutting) proceeded in the last week of May to the first 10 days of June. Planting seedlings in the last week of July to the first 10 days of August helped obtain products for autumn consumption, with harvesting carried out in the second to third weeks of September. The experiment layout was in a complete randomized design (CRD) with three replications in the greenhouse. In the greenhouse pot experiment, four plant samples comprised each of the treatments, with a total of 16 potted plants used for processing (Figure 1).

The presented research relied on shelving cultivation of plants on plastic pallets irrigated with the 'ebb and flow method' and the use of artificial lighting. The additional cassettes–inserts, designed for growing chard, were helpful. The set of technological equipment comprised the following elements: single-tier racks, model HSI4 (Hydroponic Shelving Installation), systems for feeding and

Figure 1. General view of the experiment by growing chard hybrids in greenhouse conditions.

collecting nutrient solution, receiving and storage tanks with pumps, a mineral nutrition solution unit, a fertilizer pre-dissolution unit, artificial lighting systems, germination chambers, and lines for filling pots and sowing seeds. The use of HSI4 enabled to enhance the utilization rate of the usable area in the greenhouse at the level of 0.8–0.85. The HSI4 platform contained a sealed plastic pallet having deep longitudinal and shallow transverse grooves equipped for the nutrient solution's even distribution over the platform area. A system of trunk and distribution pipelines installed in the greenhouse allowed for supplying the nutrient solution to the plants, to recycle, and to delay them on HSI4. For this purpose, receiving and storage tanks, pumps, filters, and other equipment were also part of the system.

Scheme of conducting experiments

The effects of the substrate composition and container parameters on the yield and quality of vegetable products grown on HSI4 underwent assessment. The study also determined the effect of the composition of organic and mineral substrates on the growth and development of chard grown by a low-volume technology in containers with different volumes. The scheme of the experiment included the following options: a) Control (seedling mixture), b) Peat P. (80%) + perlite (20%), and c) Peat R. (80%) + perlite (20%). In the variants with an organic substrate, the main component was riding peat, produced by Rostorphinvest (R) and Pelgorskoe M (P). The experience of the varieties of chard had a fourfold repetition. Using the method of full randomization, placed the variants; the size of the accounting rack was 3.0 m^2. In the study of chard, the control was the hybrids widely grown in hydroponic systems, i.e., hybrids Rubyn (st), Nevesta (dark green), and Bychya krov (light green), and the control was a precocious, all-season, red-petioles, and high-yielding hybrid.

During the experiment period, organic substrates based on peat from two domestic producers bore scrutiny. This was riding sphagnum peat, with low degree of decomposition, neutralized with complex fertilizers Pi-Ji-Mix (pH 5.5–6.0). The peat's mixture with 20% perlite in a ratio of 80% + 20% helped improve the agrophysical properties of the substrate. As a control, a seedling mixture used consisted of horse peat neutralized to 5.8–6.0, mixed with 20%

sawdust and filled with mineral fertilizers at the rate of mg/l: N-NO3 (107–162), P (water-soluble) 55–60, K (200–320), Ca (120–180), Mg (35–65), and bringing pH (6.2) (Table 1). Growing chard seedlings continued in round pots with a volume of 0.5 and 0.35 liters. For chard grown on an organic substrate, flooding proceeded with a standard solution.

The recording of data included the plant mass, plant height, and leaf area, and after compilation, assessing the data used the analysis of variance (ANOVA). Observations in the experiment under greenhouse conditions followed the methodology of Tolmacheva (2005) and Kokoreva (2013).

RESULTS AND DISCUSSION

Farming communities intensively used synthetic chemical fertilizers, which can harm the environment, ecological system, and plants' health. The use of organic additives in field conditions, as well as, in a controlled environment, has become a sustainable clean technology (Abbey et al., 2020). The conducted phenological observations of the growth and development of chard (B. vulgaris subsp. vulgaris) revealed a noticeable difference in the developmental phases of studied hybrids. Obtaining high yields of vegetable crops like chard largely depends on the preparation of seedlings and their quality, particularly crucial for growing plants in a low-volume way. The presented study aimed to select the optimal composition of substrates and containers for growing seedlings in a low-volume means through hydroponics on HSI4 (hydroponic shelving installation). The experimenters used organic substrates based on top, transitional peat with the addition of perlite, sawdust, as well as, cubes of mineral wool (10 cm × 10 cm × 7.5 cm) (Table 1). For choosing substrates, attention focused on the optimal content of nutrients necessary for growing chard.

The moisture content in the nutrient medium and the content of biologically active compounds significantly affected the productivity of chard produced under greenhouse conditions. Similarly, the yield of leaves grown in wet conditions was 33% higher than that of leaves grown in dry conditions (Mogren et al., 2016). Additionally, several studies have shown biochar can improve the biological, physical, and chemical properties of the nutrient medium. These include enriching soil structure, slow release of nutrients, carbon sequestration, cation exchange capacity, sorption capacity, water retention capacity, and soil fertility (Agegnehu et al., 2015; Khan et al., 2016).

Based on three-year (2021–2022) results, it was evident that the yield and quality of chard seedlings grown by hydroponics received considerable influences from the substrates origin and their composition. Growing chard seedlings on an organic substrate carried out flooding with a standard solution. The duration of the developmental phases of chard hybrids and the substrate variants differed sharply. Organic substrates contributed to an increment in the growing season up to four days production of seedlings (Table 2). Thus, the chard hybrids Bychya krov and Nevesta were distinct not only by precocity, but also by better alignment, while achieving the highest marketability of grown products. During the research, the studied substrates revealed a significant effect on enhancing the germination of chard seeds and on biometric parameters, such as, plant height, leaf length and width parameters, number of leaves, and leaf area (Table 3). The productivity of the structural elements of the crop, such as, plant height, stem diameter, leaf mass, and total leaf area, exhibited improvements by treating with growth stimulants (Hove et al., 2020).

Chard hybrids of three Swiss cultivars (Ruby, Bride, and Bulls Blood) continued planting in an innovative greenhouse for seedlings in plastic trays from the last week of February to the first week of March. Biometric measurements' recording ensued at the commercial maturity stage, revealing Swiss cultivars Bulls Blood and Bride with taller plants with widest diameter, highest leaf count, and overall largest leaves. The Bulls Blood hybrid attained a leaf size of 27.6 cm under the Peat P. (80%) + perlite (20%) (Table 3). Biometric measurements also transpired at the

Table 1. Agrochemical characteristics of the substrates used for growing chard hybrids (2020–2022).

Option	pH_{wat}	N (mg/l)			P (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
		Ngen	N-NO_3	N-NH_4				
Control (seedling mixture)	6.2	200	162	18	60	320	65	120
Peat P. 80%+ perlite 20%	5.8	120	107	13	40	200	35	120
Peat R. 80%+ perlite 20%	6.1	200	162	18	55	300	50	180

commercial maturity of these Swiss chard cultivars. The results indicated cultivars Bulls Blood and Bride exhibited superior growth characteristics compared with the cultivar Ruby. Specifically, Bulls Blood and Bride displayed taller plants, widest diameter, and greater leaf count, resulting in the production of larger leaves.

The substrate, mixed in different proportions, affects the growth and productivity of chard. This indicates the levels of nutrients in the medium, which vary depending on the mixing ratio, influenced the growth and development of chard (Hove et al., 2020). Moreover, other studies (Mogren et al., 2016) placed a layer of fertilized peat soil with a thickness of 4.5 cm at the bottom of the tray and a layer of peat soil for seedlings with a thickness of 1.5 cm on top. The studied chard hybrids demonstrated uniformity, simultaneous achievement of commercial maturity, and the highest marketable yield of harvested produce. The leaves of the chard hybrids Bulls Blood and Bride exhibited 2% greater plant height than the hybrid Ruby. A single leaf cutting showed the highest yield (total and marketable) resulted from the Bulls Blood hybrid. During summer and in the last week of June, sowing the same hybrids for seedlings ensued in trays in an unheated greenhouse. Phenological observations of the growth and development of green plants revealed high temperature during summer months noticeably influenced the developmental phases. Mass germination of Swiss chard occurred 2–3 days earlier compared with early spring planting. The onset of commercial maturity in green plants also occurred earlier, with an average of 2–3 days, compared with the spring period.

Among the studied chard hybrids, except the Ruby Swiss chard plants, which were 2.4 cm shorter than those planted in early spring, all other genotypes exceeded for the said trait. Bulls Blood stood out particularly, with plants surpassing the plant height by 4.5 cm. The Bulls Blood cultivar should be excellent for summer planting. Biometric measurements indicated an increase in all studied morphological characteristics, i.e., plant height, number of leaves in the rosette, and leaf width by 1.1 times, and leaf length by 1.3 times. By comparing the results of biometric traits for early spring and summer cultivation periods of various Swiss chard hybrids, it was evident the determining factor for productivity during the summer period was the photosynthetic activity of the leaves. A significant increase in leaf blade length and width, as well as, the number of leaves, appeared. During the summer planting period, generally, all the Swiss chard cultivars yielded a total harvest exceeding the spring planting period. Thus, the growth and yield of chard plants rose by adding biohumus to the soil (Smith et al., 2001).

In accumulation of nitrates, the highest differences depending on the time of cultivation can be due to the differentiated light regime, like shorter day length and lower intensity of lighting before harvesting in October, considerably slowing down plants' growth rate (Singh et al., 2019). In general, by comparing the biometric indicators of the early spring and summer period of various chard varieties, it revealed the photosynthetic activity of the leaves was the determining factor of productivity during the summer period. A considerable increase was evident in

Table 2. Duration of the development phases of the chard hybrids on various substrates (2020–2022).

Option	Duration of development phases (date/number of days)														
	Seedlings			One leaf			Five leaves			Seven leaves			Ending		
	Organic substrate														
	Bychya krov	Nevesta	Rubin (st.)	Bychya krov	Nevesta	Rubin (st.)	Bychya krov	Nevesta	Rubin (st.)	Bychya krov	Nevesta	Rubin (st.)	Bychya krov	Nevesta	Rubin (st.)
Control (seedling mixture)	29.12 5	30.12 4	10.01 6	3.01 5	2.01 4	20.01 10	11.01 8	10.02 8	29.01 9	13.01 2	15.02 2	05.02 7	15.01 22	17.01 20	7.02 34
Peat P. 80% + perlite 20%	30.12 6	31.12 5	12.01 8	4.01 5	3.01 4	24.01 12	13.01 9	12.02 8	3.02 10	15.01 2	13.02 2	09.02 6	17.01 24	19.01 22	11.02 38
Peat R. 80% + perlite 20%	29.12 5	28.12 4	10.01 6	3.01 5	3.01 4	22.01 12	11.01 8	10.02 8	31.01 9	13.01 2	15.02 1	07.02 7	15.01 22	17.01 20	09.02 36

Table 3. Morphological characteristics of the chard hybrids during spring and summer planting periods (average for 2020–2022).

Name	Height spring/summer planting time (cm)	Leaves parameters in spring/summer planting times (cm)		
		Number of leaves (pcs.)	Length (cm)	Width (cm_
Rubin (st.)				
Control (seedling mixture)	14.2	21.0	13.1	13.9
	19.0	20.0	16.1	15.0
Peat P. (80%) + perlite (20%)	16.0	27.0	18.5	14.1
	20.5	22.0	17.0	16.4
Peat R. (80%) + perlite (20%)	15.3	20.0	16.0	14.0
	19.9	21.0	16.9	16.8
Nevesta				
Control (seedling mixture)	16.0	27.0	13.0	14.0
	20.5	29.0	21.8	23.7
Peat P. (80%) + perlite (20%)	16.1	32.0	14.3	15.9
	21.8	32.0	24.1	24.5
Peat R. (80%) + perlite (20%)	16.8	29.0	13.9	14.8
	21.0	31.0	22.9	24.0
Bychya krov				
Control (seedling mixture)	18.2	30.0	19.6	20.0
	15.0	24.0	21.7	20.4
Peat P. (80%) + perlite (20%)	28.9	47.0	24.8	20.4
	29.9	51.0	27.6	25.3
Peat R. (80%) + perlite (20%)	16.9	26.8	17.9	18.0
	22.5	32.0	25.0	22.6

Table 4. Green mass yield of chard hybrids (2020–2022).

Hybrids	Years of research						Mean green mass yield (g/plant)	
	2020		2021		2022			
	Spring turnover	Summer turnover	Spring turnover	Summer turnover	Spring turnover	Summer turnover	Spring turnover	Summer turnover
Rubyn (st.)	275	285	283	248	289	250	282.3	261.0
Nevesta	287	315	290	343	291	348	289.3	335.3
Bychya krov	292	365	298	353	295	370	295.0	362.6

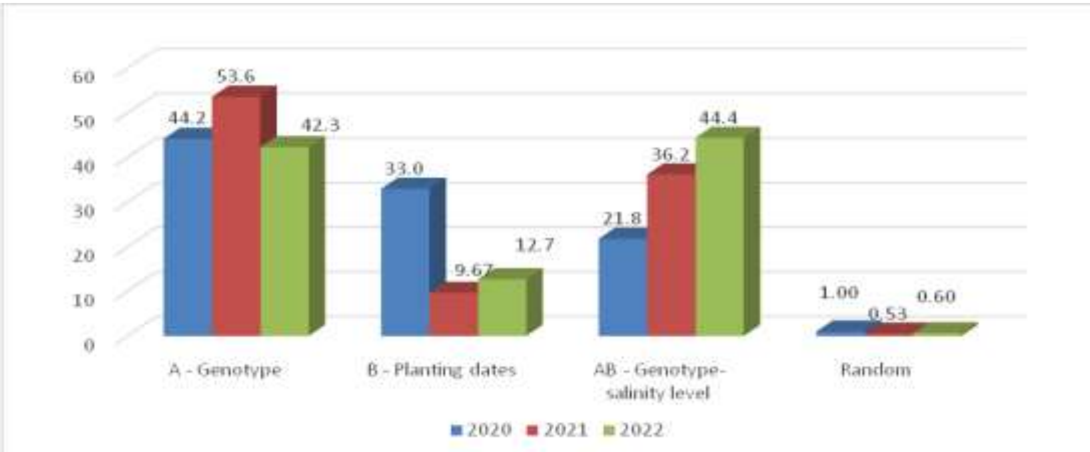

Figure 2. Analysis of two-way ANOVA of the green mass yield of three chard hybrids: A) genotypes, B) planting dates, and AB) genotype by planting dates interactions.

the length and width of the leaf blade and in the number of leaves. During the summer period of chard cultivation, all varieties have a total yield exceeding this indicator at the spring planting period, from 10 to 75 g per plant (Table 4). Phenological observations of the growth and development of green plants showed the high temperature in summer months significantly affected the said phases. In comparison with early spring sowing, mass shoots of chard at the summer sowing period appeared 2–3 days earlier. The onset of commercial ripeness in green plants also emerged ahead of time, on average by 2–3 days, compared with the spring.

Based on the results, the hybrids Nevesta and Bychya krov were superior for all-season cultivation, forming homogeneous leaves of high commercial quality. Under experimental conditions, their yield was 248–370 g per plant. However, the highest yields were notable for the hybrids Nevesta and Bychya krov in the summer turnover, while in the control hybrid in the winter turnover. The outcomes indicated the chard hybrid Bychya krov turned out as the most productive with hydroponic cultivation using domestic equipment. The formation of crop yield mainly depends upon the contributory factors in multifactorial experiments. It is noteworthy that grain yield largely depends on the genotypes, and this dependence only increases in relation to the growing conditions. Moreover, the influence of varieties on yield formation amounts up to 60%, while the effect of the growing year ranges from 60% to 90% (Kunypiyaeva et al., 2023; Zhapayev et al., 2023a, b).

By processing the two-factor analysis of variance (ANOVA), the genotypes, planting dates, and their interactions revealed a reliable influence (Figure 2). Genotypes, planting dates, and their interactions significantly influenced the productivity of chard hybrids.

However, the genotypes' share was leading in the formation of the green mass harvest of chard plants, ranging from 42.3% to 53.6%. Meanwhile, the plant's planting dates' share was 9.67% to 33.0%, and the share of genotype by planting dates' interactions was 21.8% to 44.4%. The chard genotypes have a significant influence on the formation of the green mass harvest, while planting times and their interaction with genotypes had a little effect. In addition, the environmental conditions of the study years also influenced the formation of the harvest of the green mass of chard plants. The year 2022 turned out to be the most favorable year for obtaining the highest yield compared with previous years. Precipitation also has a major impact on crop output, particularly during the plant's growing season. Accordingly, adopting soil protection technology with drought-resistant crops is necessary for the reasonable use of rainfed lands in Southeast Kazakhstan (Beisenbayeva et al., 2021; Turebayeva et al., 2021; Zhapayev et al., 2023c).

Chard can grow on any soil, when well drained, containing organic fertilizers, and with a temperature of 7 °C to 24 °C. It is half frost-resistant and can withstand light frosts. Usually, in hot climate conditions, leaves remain small and fewer (; Maboko et al., 2017; Hailay and Haymanot, 2019). In the course of the research, the technology of growing green crops progressed, with the leaf chard comprising sequentially performed technological operations. These comprised preparation of the substrate, stuffing cassettes with pots with the substrate, sowing seeds and installing them in the germination chamber, installing cassettes with chard seedlings on HSI4 for growing seedlings, arrangement of cassettes–inserts on HSI4, arrangement of chard seedlings in cassettes–inserts, and collection and packaging of the leaf chard. The permissible maximum air temperature was 23 °C. The optimal temperature of the nutrient solution in the hydroponic system should be 18 °C – 20 °C, however, not lower than 8 °C. At a critical low relative humidity (40%), the edges of the chard leaves dry out quickly and turn brown, losing their presentation.

CONCLUSIONS

For all-season, conveyor chard (B. vulgaris subsp. vulgaris) cultivation in winter greenhouses on HSI4, the study recommended using the chard hybrid Bychya krov with a mixture of peat (80%) and perlite (20%). The highest marketability of the products produced by the chard hybrids emerged during winter and summer turnovers. However, the highest green mass yield resulted in the chard hybrids Bychya krov and Nevesta during the summer planting period. The studied chard hybrids, planting time, and their interaction had a significant influence on the plants' green mass yield.

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