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Evaluation of several lettuce varieties based on economically valuable traits and nutritional value under vertical hydroponic cultivation conditions

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ABSTRACT

Background: The cultivation areas of Lettuce (Lactuca sativa L.) are increasing daily in both open and protected ground conditions. It is stable in the population's diet because it contains vitamins C, B1, B2, PP, P, E, K, folate, and carotene. The leaves are rich in over 30 mineral elements, such as nitrogen, potassium, calcium, iron, magnesium, and phosphorus. The chemical composition of lettuce varies depending on the cultivation conditions. In vertical hydroponic greenhouses, lettuce is cultivated year-round, providing eight to nine harvests. Introducing varieties rich in bioactive substances for an economically valuable production is crucial.

Objective: The research aims to evaluate the content of bioactive components such as ascorbic acid and vitamin A, macro and microelements, and productivity in local and imported lettuce varieties grown hydroponically, focusing on enhancing food functionality.

Method: The research objects are the Cencibel RZ, Levistro RZ, Manushak, and Veradarc varieties of lettuce (Lactuca sativa). Experiments were set with 3 repetitions.

The spectrophotometer (Carry 60 UV-Vis, Agilent Technologies, USA) was used to identify the content of ascorbic acid and vitamin A. The refractometric method determined the dry matter content, and the total sugars were measured according to Bertrand's method. The composition of elements N, K, Ca, Mg, and Fe was determined in lettuce at the Organic Agriculture Laboratory of Armenian National Agrarian University with a photometric LASA-AGRO 3900&1900 workstation.

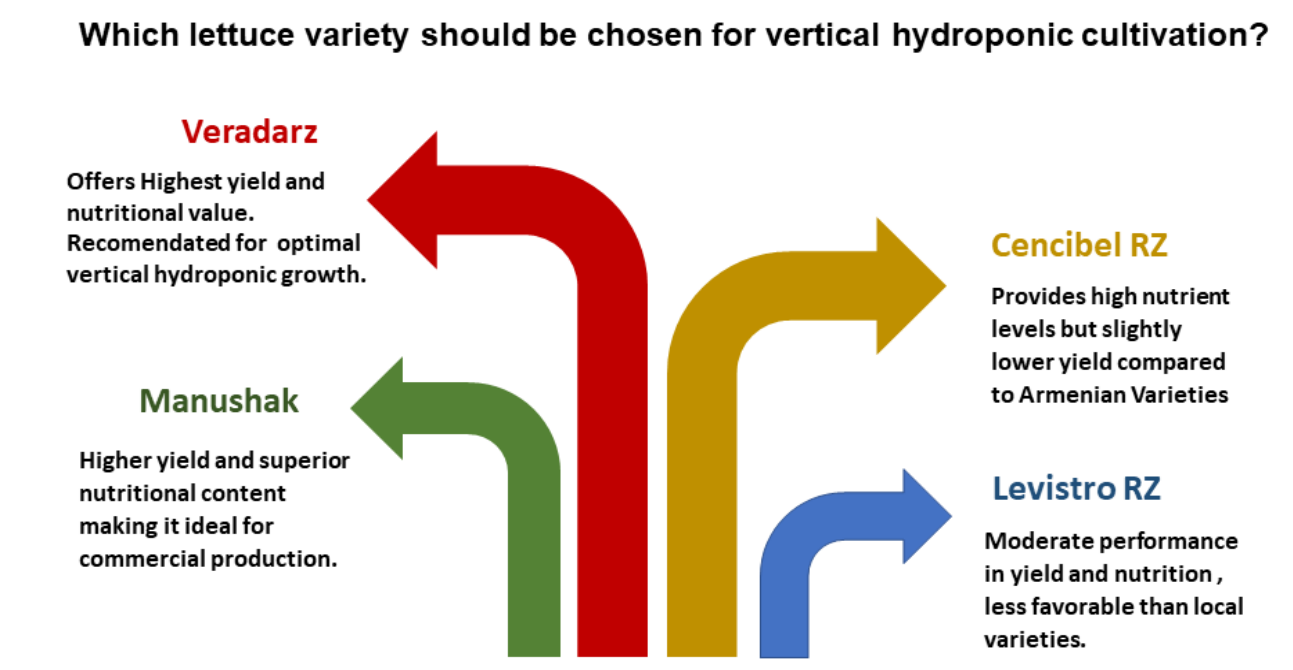
The total yield and marketability yield of the variants studied were recorded using the weighing method.

Results: Different varieties' growth and development phases varied between five to eight days. The Manushak variety was found to have biometric indicators, forming lusher, curled green leaves, and larger leaf rosettes. The Manushak variety excelled in yield per unit area (m^2), providing 4.8 kg/m^2, surpassing other varieties by 1.3-1.1 kg.

The highest amounts of vitamin A and C were recorded in the Manushak variety (0.35 mg and 15.1 mg, respectively). The Manushak and Cencibel RZ varieties showed high indicators of macro and microelements. For example, the amount of Vitamin K was 205.5 mg in the Manushak variety and 205.0 mg in the Cencibel RZ variety.

Conclusion: Comparative studies of local and imported lettuce varieties led to the following conclusions: the local variety "Manushak" excelled in vertical hydroponic conditions, demonstrating superior early growth, better morphology, higher yield, and enhanced nutritional value.

Keywords: lettuce, variety, vertical hydroponic, yield, phenology, chemical composition, nutritional value



Graphical Abstract: Evaluation of several lettuce varieties based on economically valuable traits and nutritional value under vertical hydroponic cultivation conditions

INTRODUCTION

Lettuce (*Lactuca spp.)* is an annual and self-pollinating crop that belongs to the *Asteraceae (Compositae)* family. It is one of the most globally essential commercial vegetable crops, commonly used in salads and sandwiches. Or lettuce leaves could be used to make cigarettes without nicotine. Seeds and stems contain edible oil and dried latex. [1]. Lettuce cultivation in Armenia is rapidly expanding in open fields and controlled environments. It is among the most grown hydroponic vegetables, with reports indicating that it yields high quality and productivity in soilless systems [2]. Lettuce holds a consistent place in the diet and is highly valued. Therefore, tasting, digestible, and meeting high nutritional standards should be pleasant. Studies suggest that processing and preservation can increase polyphenol content, potentially enhancing the amount of bioavailable phenolic compounds [3].

Lettuce is rich in water, containing 94–95%, and has low caloric content. It is also an excellent source of vitamins, minerals, and bioactive compounds such as polyphenols, carotenoids, and chlorophyll, which have associated health benefits [4-5].

Plant-based medicines have gained popularity recently due to their potency, purity, and cost-effectiveness [6-7]. Some epidemiological studies have indicated that vegetable consumption is linked to a lower risk of chronic diseases, such as cancer and cardiovascular diseases [7].

Lettuce has an antidiabetic effect, treating diabetes through enzymes like α-amylase and α-glucosidase, in which starch can be hydrolyzed, converting it into glucose entering the bloodstream [8].

Lettuce leaves contain vitamins C, B1, B2, PP, P, E, K, folate, carotene, and high amounts of vitamin C [9]. The leaves are rich in over 30 mineral elements, such as nitrogen, potassium, calcium, iron, magnesium, and phosphorus. Studies show that mature lettuce contains significantly higher Na, Ca, and K levels than microgreens. Although fiber is necessary to prevent constipation, excessive consumption can lead to diarrhea. Therefore, dietitians recommend consuming no more than 100 grams of lettuce daily. The combination of several positive bioactive compounds in lettuce contributes to various pharmacological properties, including cardioprotective, anticancer, and antidiabetic effects [10].

The diversity and different combinations of all components in lettuce determine its taste, color, aroma, and nutritional value. Lettuce contains 15 kcal per 100 grams of product. Red-pigmented lettuce has higher phenolic compounds compared to green lettuce. The chemical composition of lettuce can also vary depending on cultivation conditions [11-12]. For example, the efficiency of aquaponic lettuce cultivation in terms of biomass production and its nutritional and health value depends on the plant's genotype [13].

The essence of the vertical hydroponic method lies in growing plants without soil, providing them with the necessary nutrients from the solution in required amounts, which cannot be achieved when growing in soil. Lettuce grows faster and yields more in hydroponic systems. Deep water culture has reduced the growth period by 16% [14]. The advantages of vertical hydroponic systems over traditional agriculture include higher density of plants, reduced water usage, year-round crop production, rapid detection and elimination of diseases and pests, and cultivation without weeds. Hydroponic lettuce cultivation's efficiency in biomass production and its nutritional and health value depends on the plant's genotype [15-19].

Objective: The main goal of the research is to evaluate and select valuable lettuce varieties for cultivation in vertical hydroponic greenhouses and recommend the best one as a functional food.

MATERIAL AND METHODS.

The studies were conducted in the vertical greenhouse during 2023-2024. The seeds were sown in mineral wool cubes in the greenhouse seedling division in the first ten days of March. The cavities were watered and covered with vermiculite. The nutrient solution had an EC of 0.5 ms/cm and a pH of 5.5. A temperature of 18-19°C was maintained day and night. After germination, the plants were watered with a solution of EC = 0.5-1.0 ms/cm.

At 20 days of age, the seedlings were transferred to a previously disinfected vertical hydroponic greenhouse. The temperature in the greenhouse was maintained at 18-19°C for the first 2-3 days and later at 22-23°C during the day and 18-19°C at night. The relative humidity of the air was kept at 65-70% throughout the period. The plants were placed on charged nets filled with expanded clay with specific diameter grains and positioned in the gaps of the pipes. Artificial lighting was used at 150 mmol per square meter.

The frequency and concentration of the nutrient solution application were adjusted based on light intensity and air temperature. Total quantities of nutrients in the liquid are presented below: Nitrogen - 14% (of which, Nitrate Nitrogen - 11.7%, Urea nitrogen - 2-3%), Phosphorus Pentoxide - 7%, Potassium Oxide - 14%, Calcium Oxide (CaO) - 14%, Boron - 0.01%, Iron - 0.16%, Copper - 0.01%, Manganese - 0.06%, Molybdenum - 0.006%, and Zinc - 0.01%.

The experiments were conducted with three replicates. Based on the varieties, the duration of vegetation, height, width, mass of the plants, and number of leaves were determined. Biochemical analysis was performed during the maturation phase at the Organic Agriculture Laboratory of the Armenian National Agrarian University. The amounts of vitamins A and C, as well as macro and microelements Na, K, Ca, Mg, and Fe, in the leaves of the plants, were measured. Vitamin C, macro, and microelements were measured with a spectrometer (DR 3900), and Na was measured with a flame photometer.

The yields of the studied variants were recorded based on the head weight and productivity. The following varieties were studied: two local and two imported.

Veradarz - The Armenian variety is productive, mid-maturing, with a 300-350g plant mass.

Manushak—The Armenian variety is mid-early, characterized by high yield, delicious, delicate leaves, and a compact head. The imported variety Cencibel RZ is a productive variety with green leaves and purple tips. The plant's height is 14-16 cm. The Imported Levistro RZ is a high-yielding variety with green, finely waved leaves. Taste evaluation was done with a 5-unit scale, organoleptic.

Statistical Analysis: The experimental data underwent statistical processing using the ANOVA tool in Microsoft Excel.

RESULTS AND DISCUSSION

According to some authors, the nutrient solution recirculation system in vertical hydroponics ensures more effective disease management in lettuce cultivation, increases plants' early maturity and yield, and reduces water consumption compared to soil-based production of leafy vegetables [15-17]. Our study investigated the phenophase transition periods of four lettuce varieties (Veradarz, Manushak, Cencibel RZ, Levistro RZ) under a vertical hydroponic greenhouse (see Fig. 1).

Table 1. Phenological Phases of Lettuce Varieties in Vertical Hydroponic Greenhouses (Days)

Varieties	From sowing to			
	Mass formation of leaves	Head formation	Harvesting	
			start	end
Veradarz	10±1.0	43± 0.8	49±0.7	55±0.8
Manushak	9±0.7	39± 0.6	44±0.5	60±0.6
Cencibel RZ	10±0.5	41± 0.2	46±0.2	57±0.4
Levistro RZ	12±1.1	43±1.0	48±1.1	53±0.8
LSD	0.5	0.9	1.1	1.4

The sowing was carried out on March 10 in all variants. The table shows that the earliest mass leaves formed in the Manushak variety – 9 days after sowing, while the latest were in the Levistro RZ variety – 12 days after sowing.

Head formation varied by variety, ranging from 2 to 4 days. The earliest occurred 39 days after snowing in Manushak, followed by Veradarz and Levistro RZ at 43 days and Cencibel RZ at 41 days. Harvest began 7 days after head formation, with Manushak harvested first on the 44th day.

The varieties also differed in harvest timing. The period between the first and last harvest was the longest for the Manushak variety – 16 days. The shortest period was about 5 days for the Levistro RZ variety.

As we can see from the data in Table 2, the height of the plants varied by variety, ranging from 20.4 to 24.0 cm. The tallest plants were of the Veradarz variety, measuring 24.0 cm, while the shortest were from the Levistro RZ variety, which fell short by 3.6 cm. The Cencibel RZ variety stood out with the most leaves at 22.0, while the others had leaf counts ranging from 18.0 to 21.0.

Table 2. Morphological particularities of different varieties of lettuce.

Varieties	Height of plants (cm)	Number of leaves(pieces)	Head diameter(cm)	Head mass(kg)
Veradarz	24.0±0.7	21.0±0.2	18.0±0.1	0.47±0.01
Manushak	23.5±0,5	20.0±0,3	27.0±0.2	0.44±0.02
Cencibel RZ	21.0± 1,1	22.0±0,7	27.0±0.2	0.45±0.03
Levistro RZ	20.4±1.0	18,0±0.5	25.5±0.2	0.43±0.01
$LSD_{0.05}$	1.2	0.8	1.8	0.05

When recording the morphological parameters of the tested varieties, measurements of head diameter were taken, varying between 17.0 and 27.0 cm. The Veradarz variety had the shortest diameter at 18.0 cm, 9.0 cm less than the Manushak and Cencibel RZ varieties, and 7.5 cm more than the Levistro RZ variety.

The same pattern is reflected in the plants' weights. The average weight of the Veradarz variety was 0.47 kg, while the Manushak variety was slightly lower at 0.44 kg. The Levistro RZ variety had a smaller weight of 0.43 kg, 0.02 kg less than the Cencibel RZ variety.

Thus, the Veradarz variety should be preferred for obtaining large, compact, and substantial plants.

Food provides the necessary energy and nutrients, and a person's daily well-being and long-term longevity depend on whether they have a sufficient quantity of these. Lettuce contains macro- and microelements,

vitamins, sugars, and more. In our research, we studied the qualitative indicators of 100 g of green mass harvest. The obtained results are presented in Tables 3 and 4.

According to the research results, the Veradarz variety stood out with a high ascorbic acid content of 16.2 mg/%, exceeding the local Manushak variety by 1.1 mg/% and the imported varieties by 1.7-2.2 mg/%, respectively. Regarding vitamin A content, the Manushak variety also excelled with a value of 0.35 mg/%, higher than the other varieties by 0.08-0.1 mg/%.

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Table 3. Content of vitamins in different varieties of lettuce.

Varieties	Content per 100g FW	
	Vitamin A, mg	Vitamin C, mg
Veradarz	0.25±0.03	16.2±0.14
Manushak	0.35±0.01	15.1±0.15
Cencibel RZ	0.27±0.01	14.5±0.06
Levistro RZ	0.25±0.02	14.0±0.1
LSD $_{0.05}$	0.02	0.1

Table 4. Content of minerals in leaves of different varieties of lettuce

Varieties	Natrium mg	Potassium, mg	Calcium, mg	Magnesium, mg	Ferrum, mg
Veradarz	21.0±0.2	180.0±1.0	64.0±0.6	30.1±0.8	0.60±0.02
Manushak	28.0±0.1	205.0±1.2	74.3±0.9	38.0±1.1	0.86±0.05
Cencibel RZ	22.2±0.1	182.5±1.3	70.2±0.8	25.5±1.2	0.60±0.04
Levistro RZ	20.5±0.2	150.4±1.2	65.1±0.8	22.4±1.1	0.55±0.02
LSD$_{0.05}$	0.9	2.5	3.2	2.1	0.04

The Manushak variety also showed significant macro and microelements, although the differences among the three other varieties were pronounced. For example, the amount of Na in the leaves of the Manushak variety was 28.0 mg, which is 7 mg higher than the Veradarz variety, 5.8 mg higher than the Cencibel RZ variety, and 7.5 mg higher than the Levistro RZ variety. The Levistro RZ variety recorded a low vitamin K content of 150.4 mg, while the Manushak variety had a higher content of 205.0 mg. The Ca content in the leaves of the Manushak variety was 74.3 mg, while for the three other varieties, it varied as follows: 64.0, 70.2, and 65.1 mg.

Many microelements, such as Mg and Fe, were observed in the Manushak variety. For instance, Mg was recorded at 38.0 mg, exceeding the Veradarz variety by 7.9 mg and the Cencibel RZ and Levistro RZ varieties by 12.5 and 15.6 mg, respectively. The same pattern was noted for Fe, where the Manushak variety had a content of 0.86 mg, compared to 0.60 mg in the Veradarz variety, which is 0.26 mg less than that of the Manushak variety.

The amount of Fe in the Cencibel RZ variety was 0.60 mg, and in the Levistro RZ variety, it was 0.55 mg.

Yield is considered a crucial criterion for evaluating crop effectiveness, as it reflects all indicators of plant vitality. Table 5 presents the yield data and taste evaluation results of the tested varieties under vertical hydroponic greenhouse conditions.

Table 5. Productivity of varieties in vertical hydroponic greenhouse and taste evaluation.

Variants	Total yield, kg/m²	Early yield, kg/m²	Marketable yield, kg/m²	Taste evaluation, unit
Veradarz	4.3	1.4	4.3	5
Manushak	3.8	1.6	3.7	5
Cencibel RZ	3.7	1.4	3.6	5
Levistro RZ	3.5	1.3	3.4	5
$LSD_{0.05}$	0.1	0.1	0.05	

As the data in the table show, the Veradarz variety stands out with a yield of 4.3 kg/m² per unit area (m²). The yield of the other tested varieties ranged from 3.5 to 3.8 kg/m², falling short by 0.8 to 0.5 kg compared to the Veradarz variety.

In terms of early yield, the Manushak variety exceeds the Veradarz variety by 0.2 kg, providing a 1.6 kg/m² yield. The early yield of the Levistro RZ variety is quite low compared to the others, at only 1.3 kg, while the Cencibel RZ variety provided a 1.4 kg/m² yield.

The Veradarz variety again stands out for marketable yield, providing 4.3 kg/m² of marketable produce. The Manushak variety follows with 3.7 kg/m² of marketable yield, while the Cencibel RZ and Levistro RZ varieties yield 3.6 and 3.4 kg/m², respectively, 0.7 to 0.9 kg lower than the best variety. Harvest in the morning when the leaves are fresh and juicy. Growing lettuce multiple times allows for several harvests within the season. Lettuce can be completely harvested, the leaves can be gradually cut as they grow, and the produce can be collected just before use. Lettuce is ready for harvesting when a firm core has formed. Thus, when cultivating lettuce in a hydroponic greenhouse, preference should be given to the Veradarz and Manushak varieties, which ensures both a high yield and a significant quantity of marketable produce.

The taste evaluation for the four compared varieties is also rated at 5, indicating that the lettuce plants were high quality.

For producing functional food, it is important to understand its definition, classification, and the steps involved in creating functional food products [20-22]

Vegetables are a good choice for a healthy diet as they contain a high amount of macro and microelements, as well as vitamins A and C. This information has also been confirmed by several researchers [23-29]. The nutrient composition and antioxidant compounds vary among lettuce varieties, especially between green and red varieties [30-32]. We obtained similar results.

Novelty: This study uniquely evaluates local and imported lettuce varieties under vertical hydroponic cultivation, focusing on economically valuable traits and nutritional enhancement. By specifically comparing the local Armenian Veradarz and Manushak varieties with imported cultivars, this research identifies its superior performance in yield, growth, and bioactive compound content, such as vitamins A and C and macro and microelements. This comparative analysis provides novel

insights into optimizing lettuce cultivation for enhanced food functionality within controlled, vertical hydroponic environments, highlighting the potential of local varieties to excel in modern agricultural systems."

CONCLUSION

Comparative studies of local and imported lettuce varieties resulted in the following conclusions: the Armenian varieties Veradarz and Manushak outperformed others in vertical hydroponic conditions, showing superior early growth, improved morphology, higher yield, and greater nutritional value.

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List of Abbreviations: C: Carbon, B1: Thiamine, B2: Riboflavin, PP = Niacin, E: Tocopherol, N: nitrogen, P: phosphorus, K: Potassium, Na: Sodium, Ca: Calcium, Mg: Magnesium, Fe: Iron, FW: fresh weight

Competing interests: The authors declare that they have no competing interests.

Authors' contributions: TA, GM, and GN designed the research. GM, TG, TH, and GN conducted the research. TA and TG performed biochemical analysis. GM performed statistical analyses. GM and TA wrote the manuscript. All authors read and approved the final version of the manuscript.

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