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Comparative analysis of bioactive components across basil varieties

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ABSTRACT

Background: In every civilized nation, the stewardship of edible, aromatic, and medicinal plants holds a moral imperative for preservation and sustainable utilization. In Armenia, the rich gene pool of aromatic plants stands as a national treasure, deeply ingrained in the traditional Armenian diet. Among these, basil (*Ocimum basilicum* L.) emerges as a revered herb, steeped in ancient usage and renowned for its remarkable nutritional profile. With its abundant array of nutrients, basil earns its moniker as a 'sacred plant' in various cultures. Bursting with microelements, organic acids, vitamins, proteins, carbohydrates, sugars, and essential oils, basil serves as a vital source of essential components crucial for maintaining human health. Its antioxidant prowess renders it capable of combating hazardous chemicals and carcinogens, safeguarding the body against serious ailments. Additionally, basil boasts a wealth of vitamin C, beta-carotene, and polyphenols, further enhancing its therapeutic value.

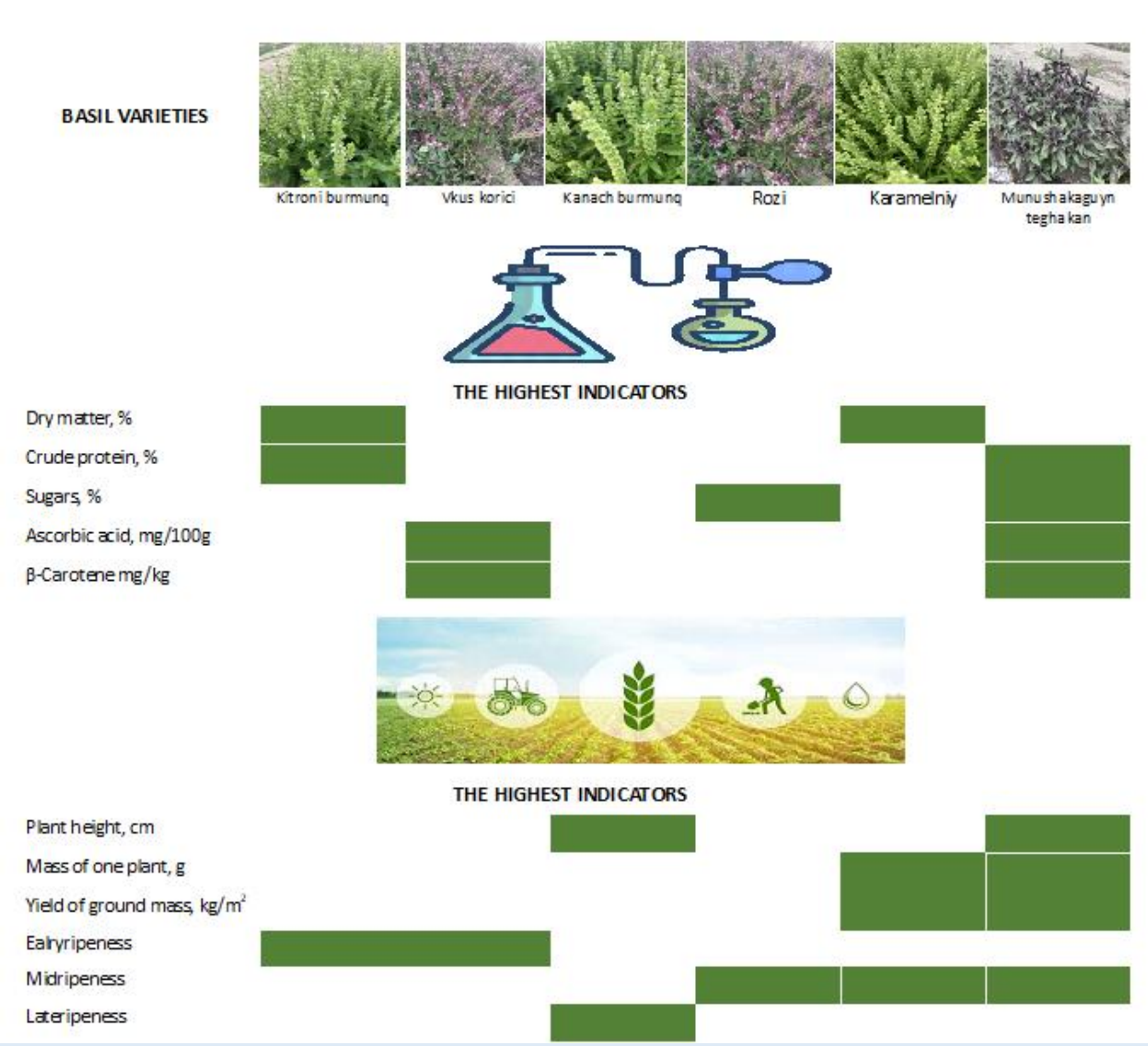
Objectives: To study the bioactive components and antioxidant properties of basil varieties with distinct tastes and aromas, cultivated under Ararat Valley conditions.

Methods: Dry matter content was determined using a refractometer, while raw protein content was analyzed via the Kjeldahl method. Total sugars, vitamin C, and carotene were quantified using a spectrometric method employing the Cary 60 UV-Vis. Essential oils were assessed using Ginsberg method. Throughout the vegetation period, the duration of phenological stages, bio-morphological indicators, and yield were investigated. The experiments were conducted with four repetitions, following accepted protocols for crop studies. Each experimental plot measured 10 m². Isolation nets were used to avoid cross-pollination between varieties. Statistical analysis was performed using the ANOVA method.

Results: The 'Vkus korici' and 'Kitroni burmunq' cultivars exhibited early ripening, while the 'Karamelni', 'Rozi', and 'Manushakaguin teghakan' cultivars showed medium maturity, and the 'Kanach burmunq' variety demonstrated late ripening. This characteristic is crucial for selecting suitable basil varieties based on agricultural zones and cultivation objectives. Yield indicators among the studied varieties ranged from 0.6 to 2.0 kg/m², with the 'Manushakaguin teghakan' variety showcasing the highest yield (2.0 kg/m²), which was 3.3 times greater than that of the 'Kitroni burmunq' variety with the lowest yield. Additionally, the 'Manushakaguin teghakan' variety exhibited a relatively larger above-ground plant mass. 'Karamelni' and 'Kitroni burmunq' varieties were distinguished by their dry matter content, measuring 10.8% and 10.3%, respectively. Conversely, the 'Manushakaguin teghakan' variety had the least amount of dry matter. However, it is worth mentioning that the difference is not significant. The crude protein content among the studied varieties ranged from 14.7% to 16.2%, with the 'Kitroni burmunq' variety boasting the highest amount and the 'Kanach burmunq' variety presenting the lowest. Similar to the content of dry matter, the difference is minor. Notably, the 'Manushakaguin teghakan' and 'Vkus korici' varieties exhibited high levels of vitamin C and beta-carotene content (4.5 mg/100 g and 145 mg/kg for 'Manushakaguin teghakan', and 4.2 mg/100 g and 144.5 mg/kg for 'Vkus korici'), which are correlated with antioxidant properties. Additionally, the 'Manushakaguin teghakan' and 'Kitroni burmunq' varieties were distinguished by their total essential oil content, measuring 0.75% and 0.74%, respectively.

Conclusion: Basil, as a unique spice crop, offers considerable potential for functional food applications owing to its antioxidant properties. Therefore, selecting the appropriate variety considering functional attributes, yield, and maturity period is paramount. Among the six basil varieties studied, the 'Manushakaguin teghakan' and 'Vkus korici' varieties displayed high levels of vitamin C and beta-carotene, what determines antioxidant activity. Notably, 'Vkus korici' and 'Kitroni burmunq' showcased early maturity in the conditions of the Ararat Valley of Armenia, while 'Karamelni', 'Rozi', and 'Manushakaguin teghakan' exhibited medium maturity, and the 'Kanach burmunq' variety demonstrated late maturity. These findings suggest the potential incorporation of all basil varieties into functional foods. Among the investigated varieties, the 'Manushakaguin teghakan' is of highest interest and potential, offering not only superior nutritional and functional benefits but also economic viability attributed to its high yield and quality.

Keywords: aromatic plant, vitamin C, beta-carotene, productivity, dry matters



INTRODUCTION

The rapid advancement of biological sciences has significantly enriched our understanding of the biochemical composition of plants and their consequential benefits for human health [1]. As our knowledge about the critical role of diet and nutrition in human life has expanded, today's consumers are increasingly demanding healthy food options [2]. One of the key developments in this arena is the concept of functional food [3], which refers to foods that have a potentially positive effect on health beyond basic nutrition [4]. Among the various plants recognized for their valuable functional properties are spicy-aromatic plants, which play a crucial role in promoting health and well-being. Spice plants have historically served as essential resources for human survival and societal development [5]. When used wisely and sparingly, they become valuable commodities that meet various human needs [6]. Every civilized country with edible, spicy, and medicinal plants bears a moral responsibility to preserve and use these resources economically [7]. In Armenia, the gene pool of spicy plants is considered a national

treasure and remains integral to the traditional Armenian diet [8]. Despite their low caloric content, these plants are rich in microelements, organic acids, vitamins, proteins, carbohydrates, sugars, and essential oils, all crucial for human health [9]. A deficiency in these nutrients can lead to serious health issues [10].

The distinctive aromas of spicy plants are attributed to the essential oils found in different parts of the plants [11]. These herbal spices are used in cooking, the food industry (including canning, confectionery, baking, and beverage production), perfumery, and medicine [12]. One such herb is basil (*Ocimum basilicum* L.), revered since ancient times for its remarkable properties and health benefits. Basil, often called a "sacred plant" in various cultures [13], thrives in hot climates and boasts over 60 species. Fresh basil, with its delightful aroma, is highly prized in culinary arts and is particularly rich in vitamin K, which is essential for blood clotting. Beyond its culinary uses, basil is a powerhouse of antioxidants, capable of neutralizing harmful chemicals and carcinogens. Antioxidants are crucial in protecting the body from free radicals - unstable molecules that can damage cells and DNA, potentially leading to aging and chronic diseases such as cancer, cardiovascular disease, and diabetes [14]. Basil is rich in vitamin C, beta-carotene, polyphenols, and eugenol, all of which help combat free radicals and mitigate their harmful effects [15]. Regular consumption of basil can significantly reduce the risk of cardiovascular diseases by clearing blood vessels of bad cholesterol and alleviating headaches, diarrhea, constipation, parasites, ringworm, kidney disease, and many other ailments. Basil's unique combination of aroma, flavor, and nutritional benefits, as well as its antioxidant, anti-inflammatory, and antimicrobial properties, makes it a valuable ingredient in numerous applications contributing to overall health and well-being.

Despite the recognized benefits of various basil varieties, Armenia currently has a very limited assortment available. To address this gap and meet the increasing demand for diverse and healthy food options, our research aims to investigate several basil varieties under the specific conditions of the Ararat Valley in Armenia. The primary objective of this study is to enrich the assortment of basil varieties available in Armenia, thereby enhancing the availability of this valuable functional food through studying the bioactive components and antioxidant properties of local and introduced basil varieties with distinct tastes and aromas, cultivated under plain conditions. By achieving this objective, this research will contribute to the diversification and enhancement of basil varieties in Armenia, promoting healthier dietary options for consumers and supporting the agricultural sector.

METHODS

The studies were carried out at the "Scientific Centre of Vegetable and Industrial Crops" CJSC of the Ministry of Economy of the Republic of Armenia from 2021 to 2023. Six varieties of basil were studied: two of Armenian origin - 'Manushakaguyn teghakan' and 'Kanach burmunq'; three of Russian origin -'Kitroni burmunq,' 'Karamelniy,' and 'Vkus korici'; and one of Dutch breeding -'Rozi'. Basil accessions from the Genebank of the Scientific Centre of Vegetable and Industrial Crops were propagated and used for research experiments [16]. Experiments were set up with four replications according to the accepted methods of crop accession studies [17]. The size of each experimental area was 10 m^2. To minimize the risk of outcrossing, isolation nets were used.

During the vegetation period, the duration of the transition of phenological stages [18], biomorphological indicators, yield, and quality characteristics were studied. Biochemical analyses were performed in the Plant Biotechnology, Phytopathology, and Biochemistry Laboratory of the Scientific Centre. Dry matter was determined by a refractometric method [19], crude protein by the Kjeldahl method [20], and total sugars,

vitamin C (ascorbic acid), and beta-carotene were determined by a spectrometric method using the Cary 60 UV-Vis (Agilent Technologies, USA) [21]. Essential oil content was determined by Ginsberg method [22]. The data were subjected to statistical analysis using the ANOVA method [23].

RESULTS AND DISCUSSIONS

Basil varieties from different geographical and ecological origins, exhibiting distinct morphological characteristics, were studied. A number of morphological traits of basil cultivars play a crucial role in breeding efforts. These traits include plant height, bush shape, and bush strength, which not only influence yield but also serve as criteria in breeding programs aimed at developing machine-harvestable varieties.

The morphological analysis of basil cultivars revealed significant variations, particularly in plant height. The variety 'Manushakaguyn teghakan' reached a height of 67 cm, while the variety 'Kanach Burmunq' attained a height of 62 cm, characterized by tall growth. Varieties 'Karamelniy,' 'Vkus Korici,' and 'Rozi' exhibited average growth of 50 cm, 58 cm, and 48 cm, respectively. Additionally, differences were observed in plant socket size and leaf dimensions. Varieties were classified based on the spread of their bushes: 'Manushakaguin teghakan' had spreading bushes, 'Vkus Korici', 'Karamelniy', and 'Rozi' had medium-sized bushes, while 'Kitroni Burmunq' and 'Kanach Burmunq' had compressed bushes. Varieties also varied in stem and leaf color (Table 1).

Table 1: Morphological characteristics of basil varieties

Morphological traits	**Basil varieties**					
	Manushakaguyn teghakan	Kanach burmunq	Kitroni burmunq	Karamelniy	Vkus korici	Rozi
Plant height, cm	65-67	60-62	35-45	47-50	55-58	45-48
Stem color	violet	green	light green	light green	purple	purple
Leaf shape	oval	elliptical	elongated oval	oval	ovate oblong	elliptical
Leaf length, cm	7.5-8.0	6.0-6.3	5.7-6.2	9.0-10.3	7.0-7.5	6.5-7.0
Leaf width, cm	4.2-4.4	3.9-4.6	3.1-3.6	3.5-3.8	4.0-4.5	4.1-4.6
Leaf color	purple	green	green	green dark	green olive with purple veined	dark purple

Taller and denser basil plants are more suitable for high-quality mechanized harvesting. For certain crops like basil, a compact branching structure is preferred, which facilitates inter-row cultivation. Low-growing basil plants can be utilized in breeding programs to develop decorative varieties and those suitable for cultivation in confined spaces.

Taking into account the characteristics of basil plants, the main developmental phases observed were: germination to budding, germination to flowering, and germination to seed ripening. The germination to budding stage ranged from 35 to 43 days across the studied cultivars. 'Kitroni Burmunq' exhibited the shortest germination to budding period at 33 days. In contrast, 'Kanach Burmunq' had the longest period at 43 days. Literature indicates that early growth phases are often more robust and better suited for quick turnover crops [24], such as microgreens. From this point of view, basil varieties 'Kitroni Burmunq' and 'Karamelniy' can be recommended for microgreens production. Similar

variations were observed during the flowering to seed ripening phase, which ranged from 30 to 48 days. 'Vkus Korici' had the shortest flowering to seed ripening period at 30 days (Table 2). The early-flowering varieties might be preferred for quick seed production, while later-flowering varieties may be suited for extended green mass production. Considering this, 'Vkus Korici' and 'Rozi' may be recommended for seed production, while the cultivation of 'Kanach Burmunq' and 'Manushakaguin teghakan' will lead to more substantial biomass accumulation and green mass production.

Table 2: Duration of transition of basil cultivars to phenophases

Basil varieties	Number of days from germination to		Mass flowering-seed ripening, days	Vegetation period, days
	Bud-formation	Flowering		
Manushakaguin teghakan	40	58	43	100
Kanach burmunq	43	65	48	113
Kitroni burmunq	33	43	37	79
Karamelniy	35	45	39	84
Vkus korici	36	47	30	77
Rozi	38	50	32	80

Varieties were further categorized based on their ripening periods under the conditions of the Ararat Valley: 'Vkus Korici' and 'Kitroni Burmunq' were early ripening, 'Karamelniy', 'Rozi', and 'Manushakaguyn teghakan' were mid-ripening, and 'Kanach Burmunq' was late ripening. These characteristics are crucial for selecting basil varieties suitable for different agricultural zones and cultivation purposes. Describing phenological stages helps in selecting varieties best suited to specific climatic and environmental conditions, ensuring that the plants can thrive and produce optimally in their intended growing regions. In regions with shorter growing seasons, early maturing varieties are advantageous, while in regions with longer seasons, late-maturing varieties can be used to extend the harvest period. Early varieties like 'Vkus Korici' and 'Kitroni Burmunq' are ideal for early green mass production and microgreens cultivation, as well as seed production in lowland conditions. For seed production in foothills and mountainous regions, mid-ripening and late-ripening varieties are recommended.

The studied cultivars also exhibited variations in yield indicators and quality characteristics. These variations are crucial for assessing their potential as functional foods, as higher yield indicators often correlate with greater availability of bioactive compounds in horticuture crops, which enhance the nutritional and health benefits of the food [25, 26]. Among the varieties studied, yield indicators ranged from 0.6 to 2.0 kg/m² (weight of above-ground fresh mass per sq. m). Notably, the 'Manushakaguyn teghakan ' variety stood out with the highest yield, which was 3.3 times greater than the lowest yielding variety, 'Kitroni Burmunq'. Additionally, the 'Manushakaguyn teghakan ' variety showed a relatively larger above-ground fresh biomass (Table 3).

Table 3: Effectiveness and quality indicators of basil varieties

Varieties	Yield of ground mass, kg/m2	Fresh weight of one plant, g	Dry matter, %	Crude protein, %	Sugars, %
Manushakaguyn teghakan	2.0±0. 1	80±0. 07	9.1±0.3	15.8±0.8	3.6±0.2
Kanach burmunq	1.4±0. 06	56±0. 01	9.5±0.2	14.7±1.1	2.5±0.2
zKaramelniy	1.7±0. 08	68±0. 05	10.8±0.3	15.4±0.5	2.5±0.1
Kitroni burmunq	0.6±0. 01	24±0. 02	10.3±0.2	16.2±0.5	2.7±0.2
Vkus korici	0.8±0. 02	32±0. 03	9.3±0.3	15.5±0.7	3.0±0.2
Rozi	1.3±0. 05	61±0. 05	9.8±0.4	15.0±1.0	3.2±0.1

Dry matter content represents the portion of the plant that remains after water has been removed. A higher dry matter content typically indicates a higher concentration of nutrients, such as vitamins, minerals, and bioactive compounds, per unit weight [27]. Consequently, higher dry matter content can enhance the intensity of flavors and aromatics in basil, making it more desirable for culinary uses. Besides, varieties with higher dry matter content can be more economically efficient for producers, as they yield more marketable product by weight after drying processes [28]. The biochemical analysis results revealed distinct characteristics among the basil varieties. 'Karamelniy' and 'Kitroni Burmunq' exhibited the highest dry matter contents at 10.8% and 10.3%, respectively, while 'Manushakaguyn teghakan ' had the lowest, although the difference is not significant.

Crude protein content in basil contributes significantly to its nutritional and functional value [29], providing essential amino acids and promoting satiety. When combined with the plant's bioactive compounds, high-protein basil can be an excellent addition to functional foods aimed at enhancing overall health and well-being. Higher crude protein content means basil can contribute more significantly to daily protein requirements, making it a valuable addition to diets, especially for vegetarians and vegans. Additionally, some bioactive peptides derived from proteins can have antioxidant properties, contributing to the overall health benefits of basil. Crude protein content in the studied varieties varied from 14.7% to 16.2%, with 'Kitroni Burmunq' showing the highest and 'Kanach Burmunq' the lowest amounts. However, like in case of content of dry matter, the difference is minor.

Assessing the vitamin C and carotene content in various basil varieties is essential for maximizing their functional value, promoting better health, and meeting the needs of both consumers and the agricultural sector. As a potent antioxidant, vitamin C plays a significant role in protecting the body against oxidative stress, boosting the immune system, and enhancing iron absorption from plant-based foods [30, 31]. Determining the vitamin C content in basil varieties can guide consumers and healthcare professionals in selecting basil with the highest nutritional benefits. Carotenes, including beta-carotene, are precursors to vitamin A, essential for maintaining healthy vision, skin, and immune function [32]. Evaluating carotene levels helps identify basil varieties that offer substantial health benefits and can contribute to a balanced diet [33]. Basil varieties rich in vitamin C and beta-carotene can be promoted as functional foods, providing added health benefits beyond basic nutrition. This can be particularly appealing to health-conscious consumers looking for natural sources of essential nutrients [34].

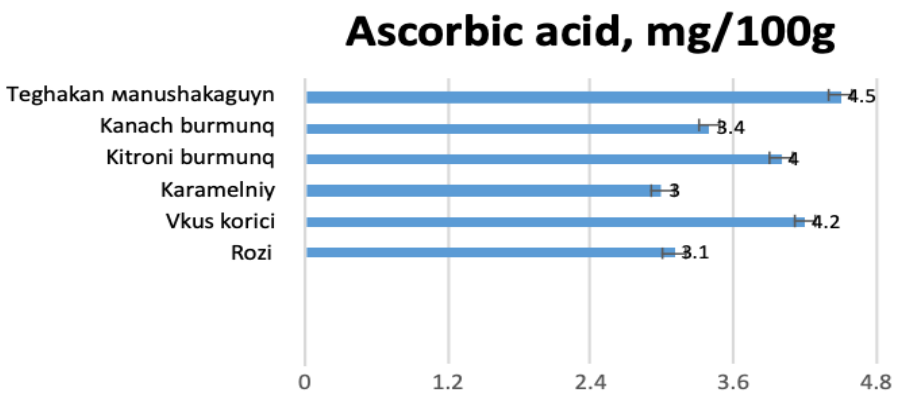


Figure 1. Ascorbic acid content in different basil varieties

In the context of the aforementioned varieties, 'Manushakaguyn teghakan ' and 'Vkus Korici' exhibited high levels of vitamin C and beta-carotene content, which are correlated with antioxidant properties. Specifically, 'Manushakaguyn teghakan' exhibited a vitamin C content of 4.5 mg/100g and β-carotene content of 145 mg/kg, while 'Vkus Korici' showed 4.2 mg/100g of vitamin C and 144.5 mg/kg of beta-carotene (Figure 1 and 2).

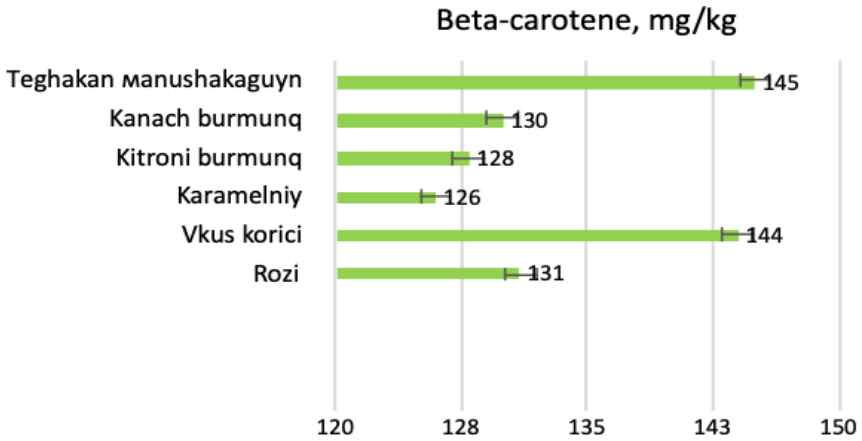


Figure 2. Beta-carotene content in different basil varieties

Essential oils in basil plays a crucial role in determining the plant's aromatic and medicinal properties. This oil, rich in compounds like linalool, eugenol, and methyl chavicol, contributes to basil's characteristic scent and flavor, and has been shown to possess antimicrobial, anti-inflammatory, and antioxidant properties [35]. Studying the total essential oil content in different varieties of basil is important for several reasons. It can help identify the most potent varieties for use in culinary, medicinal, and industrial applications. Moreover, understanding the variation in essential oil composition among basil varieties can aid in breeding programs aimed at enhancing specific desirable traits, such as increased oil yield or improved therapeutic properties. Essential oils contain biologically active compounds with diverse properties, including antimicrobial, anti-inflammatory, analgesic, and antioxidant effects [36, 37]. 'Manushakaguyn teghakan' (0.75%) and 'Kitroni Burmunq' (0.74%) were notable for their high total essential oil content, an important characteristic for the production of dried products and aromatic additives (Figure 3).

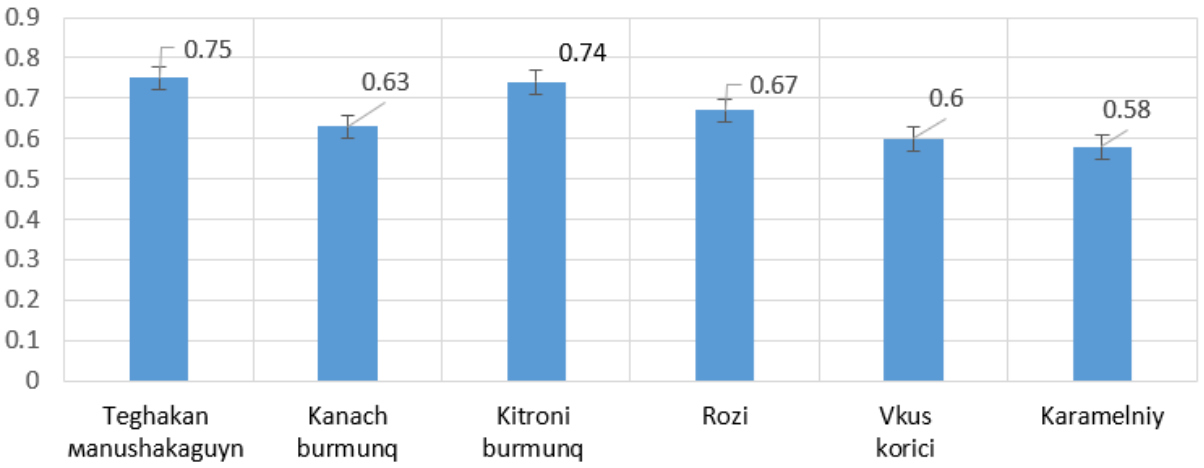


Figure 3. Essential oil content of studied varieties of basil (% of dry matter)

CONCLUSION

Basil, as a unique spice crop, holds significant potential for use in functional foods due to its antioxidant properties. Therefore, selecting the appropriate variety for cultivation is crucial, considering factors such as functional attributes, yield potential, and maturity period.

The results of investigations carried out by several researchers provide an overview of how yield and postharvest handling impact the quality and functional properties of horticultural crops [38, 39]. Environmental factors dependent on agro-climatic zones also affect yield and nutritional quality, thereby contributing to the functional properties of plants. Considering this correlation, the 'Manushakaguyn teghakan' variety stood out with the highest yield of 2.0 kg/m² and a plant fresh above-ground mass of 80g. This variety can be highlighted for its comparatively high functional value due to its yield indicators and bioactive compound availability.

Observations on the duration of phenophases, especially from germination to budding and flowering, among the cultivars are essential for choosing basil varieties suitable for various agricultural zones and cultivation purposes. Under the low altitude conditions of Ararat Valley, among the six varieties studied, 'Vkus Korici' and 'Kitroni Burmunq' demonstrated early maturity; 'Karamelniy', 'Rozi', and 'Manushakaguin teghakan' exhibited medium maturity; and the 'Kanach Burmunq' variety showed late maturity. Early growth phases are generally more vigorous and suitable for quick turnover crops like microgreens, with early-flowering varieties preferred for quick seed production. Therefore, 'Kitroni Burmunq' and 'Karamelniy' are recommended for microgreens production, along with 'Vkus Korici' and 'Rozi' for early green mass and seed production in lowland areas of the Republic of Armenia. For seed production in foothill and mountainous regions, mid-ripening and late-ripening varieties such as 'Manushakaguyn teghakan' and 'Kanach Burmunq' are advised. Understanding phenological stages aids in selecting varieties that thrive and produce optimally in specific climatic and environmental conditions.

Both the 'Manushakaguyn teghakan' and 'Vkus Korici' varieties boasted high levels of vitamin C and beta-carotene, what determines antioxidant activity. 'Kitroni Burmunq' showed, with minor difference, the highest content of crude protein (16.2±0.5%). This makes 'Kitroni Burmunq' suitable for marketing as a functional food, offering not only traditional culinary benefits but also improved protein intake and associated metabolic advantages. Farmers and producers can benefit by

focusing on cultivating basil varieties with higher vitamin C and beta-carotene content to meet the growing demand for nutrient-rich herbs, thereby enhancing market value and consumer preference for these superior varieties.

Additionally, 'Manushakaguyn teghakan' and 'Kitroni Burmunq' stood out due to their high total essential oil content, a significant feature for the production of dried products and aromatic additives. These findings support the recommendation of all studied varieties of basil for functional food applications. Among them, 'Manushakaguyn teghakan' demonstrates a robust combination of high nutritional quality and economic viability, driven by substantial yield, positioning it as an ideal choice for maximizing both health benefits and profitability.

List of abbreviations: kg, kigogram; g, gram; m^2, square meter; mg, milligram

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

Authors' contributions: LT, RB and AA designed the research. LT, IV and ZH performed biochemical analysis. GM performed statistical analyses. LT, RB, AA, ITs and GM participated in data collection and analysis of the results and drawing the graphs. GS contributed to writing the abstract and introduction. AA edited the article. All authors read and approved the final version of the manuscript.

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