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Dynamics of bioactive substances accumulation during cauliflower maturation as a way to ensure functional crop properties

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ABSTRACT

Background: Cauliflower heads are recognized as a rich source of proteins, unsaturated fatty acids, numerous mineral elements, vitamins, and a high content of bioactive substances. Some studies report that the dynamics of accumulation of bioactive substances in cauliflower can be influenced by various factors.

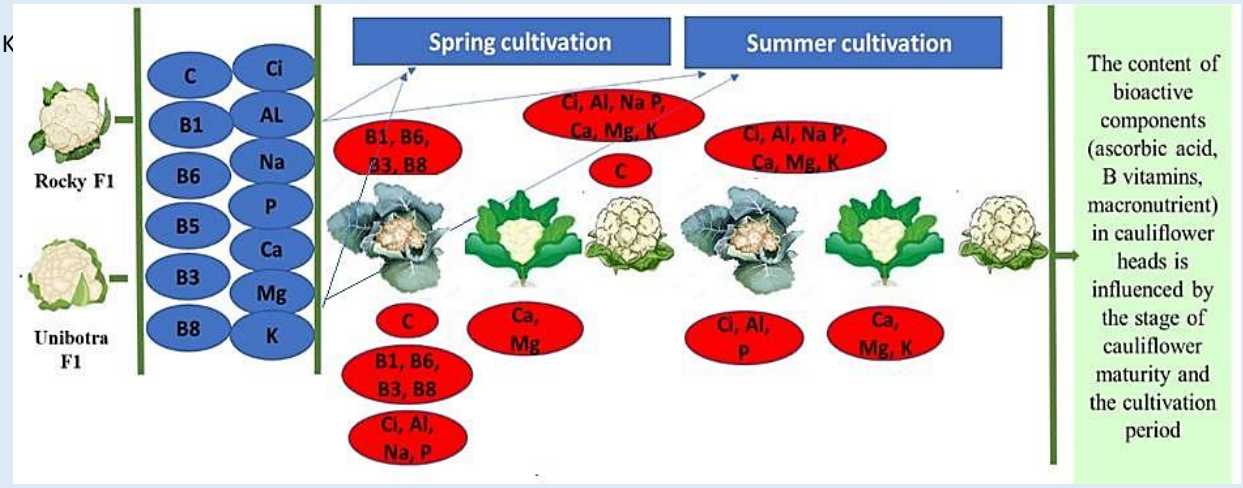
Objective: To determine the dependence of the content of bioactive components (ascorbic acid, B vitamins, macronutrients) on the stage of maturity of cauliflower heads and on the growing period.

Methods: The study investigated the variation in vitamin C, B group vitamins (thiamine, pyridoxine, pantothenic acid, nicotinic acid, inositol), and seven macronutrients (silicon, aluminum, calcium, magnesium, sodium, phosphorus, potassium) during different stages of head ripening and cultivation periods in medium-ripening hybrids of cauliflower, specifically 'Rocky F1' and 'Unibotra F1'. Ascorbic acid content in cauliflower heads was determined by the titration method. Quantitative analysis of the water-soluble B group vitamins was performed spectrophotometrically. The content of macronutrients was determined by the chemical-spectral method.

Results: The maximum content of ascorbic acid in cauliflower Rocky F1 hybrid was observed at the stage of the heads technical ripening in spring cultivation conditions, and in Unibotra F1 hybrid - in the phase of new head formation in

summer growing conditions. The content of group B vitamins, with the exception of pantothenic acid, was high in newly formed heads in both studied hybrids. In the conditions of spring cultivation, most of the studied macronutrients were high for Rocky F1 hybrid in the stage of technical ripening of heads, and for Unibotra F1 hybrid in the phase of new head formation (Si, Al, Na, P) and in middle ripening stage (Ca, Mg). Under the conditions of summer cultivation, most of the macronutrients were high for Rocky F1 hybrid in the phase of new head formation, and in Unibotra F1 hybrid - Si, Al, P were high in the phase of new head formation, and Ca, Mg, K - in middle ripening stage.

Conclusion: The content of bioactive components (ascorbic acid, B vitamins, macronutrients) in cauliflower heads is influenced by the stage of cauliflower maturity and the cultivation period (spring, summer). This should be taken into account when developing targeting diets and growing cauliflower in semi-desert zones of the Republic of Armenia.



INTRODUCTION

In functional foods, plant-derived nutraceuticals and dietary supplements in a phased manner have embodied health-promoting components able to improve human health [1]. Besides the nutritional components functional foods and various dietary supplements contain, bioactive compounds with health benefits [2-3]. Bioactive compounds have attracted a great deal of attention due to their role in the prevention and treatment of a number of chronic diseases as well as diminishing the risk of numerous serious diseases [4-5]. Having been derived from plants, animals, or other sources they have a wide range of biological and functional activities such as anti-inflammatory, antiviral, anticancer, and antidiabetic activities [6-7]; most of which can be found in numerous vegetables and fruits, some grains [8] and their derived foods and beverages [9].

Among food products rich in biological compounds, vegetables occupy one of the first places. The combination of vitamins, minerals, phenolic antioxidants and fiber in vegetable crops leads to health-improving effects [10]. Vegetable crops function as the most powerful regulator of health, the richest source of natural vitamins, antioxidants, amino acids and other biologically active substances that are absent in other foods and directly affect people's life expectancy [11-13]. The value and irreplaceability of vegetables in human nutrition lies in the fact that they are a source of vitamins, sugars, acids and other

biologically active substances, which depend on the taste of food and its digestibility by the human body [14]. Among the numerous species of vegetable crops, cabbage occupies one of the leading positions in terms of the content of bioactive substances. Thanks to this, the level of cabbage consumption increases from year to year. Various types of cabbage are consumed by the population in greater quantities than other vegetables. Thus, the annual rate of consumption of vegetables per person is about 130-150 kg, and of this amount, cabbage species account for 45-50 kg [15-16,]. Cauliflower is one of the most common vegetables belonging to the Brassicaceae family (*Brassica oleracea* var. *botrytis*), which attracts attention due to its palatability traits and a high content of bioactive substances. It contains a number of flavonoids, carotenoids, phenols and isothiocyanates [17-19]. These compounds have antioxidant, anti-inflammatory and anti-cancer properties, they can help strengthen the immune system and can reduce the risk of various diseases, including cardiovascular disease and certain types of cancer [20-22]. For these reasons, it is recommended for people suffering from liver diseases, atherosclerosis and diabetes. Cauliflower is not inferior to meat and fish in its amount of sulfur-containing amino acids such as methionine and cysteine. Cauliflower contains pantothenic acid, the absence of which in the human body causes lethargy, dermatitis, hair loss [23]. Cauliflower ranks first among all types of cabbage in terms of its nutritional value and taste, properties, and digestibility. Due to its fine cell structure and low fiber content, cauliflower is considered a dietary remedy for various stomach and intestinal diseases. Cauliflower is also rich in vitamins C, B1, B3, B6, B8 [24]. In transformed cauliflower inflorescence (heads), there are significantly more nitrogenous substances, sugars, vitamins than in heads of white cabbage [25]. Cauliflower heads are considered a source not only of proteins, unsaturated fatty acids and fibers useful for the digestive system, but also of a large number of mineral elements [26-27].

A number of studies on the determination of bioactive substances in cauliflower indicate that the dynamics of accumulation of bioactive substances in cauliflower can be influenced by various factors. One of these factors is the genetic characteristics of varieties. Different varieties of cauliflower may have different levels and ratios of bioactive compounds [28-29]. In addition to genetically determined traits, the content of bioactive components in cauliflower and the resulting nutritional value are influenced by climatic conditions and the growing period [30-31]. Soil composition also plays an important role, which in turn depends on the application of proper agricultural technology, such as fertilization and irrigation [32-34]. Under optimal growing conditions, including adequate soil nutrition, proper watering and pest control, the content of bioactive substances can be significantly increased [35-36]. The cauliflower harvesting time also plays an important role in ensuring its functional properties. The published data shows that harvesting cauliflower at a late stage of ripening allows to reach the maximum content of bioactive substances [37-38].

In Armenia cauliflower cultivation has been practiced since the 1950s. The main cultivation area used to be the Shirak plain. In recent years, the cultivation area of cauliflower has been expanding due to ever-increasing consumer demand. In the conditions of the Ararat valley of Armenia, the cultivation of cauliflower is possible both in spring and summer.

Objective: The objective of the study conducted was to determine the dependence of the content of bioactive components (ascorbic acid, B vitamins, macronutrients) on the stage of maturity of cauliflower heads and on the growing period.

MATERIALS AND METHODS

Materials: Two cauliflower hybrids were selected for the studies. 'Rocky F1' is high-yielding, medium-maturing hybrid of cauliflower with compact plant habit and white, deep, smooth, and heavy heads of 1.8-

2.0 kg with high taste qualities. The leaves are pointed upwards and spirally close the heads. 'Unibotra F1' is a medium-maturing cauliflower hybrid, which is characterized by large, white, very dense round flat of 2-2.5 kg. The leaves are large and protect the heads from the sun's rays. The heads have high palatability traits. These plants are also cold-and heat-resistant.

Experimental site: The studies were implemented at the experimental farm of the Scientific Centre of Vegetables and Industrial Crops located in community Darakert of Ararat Marz (province) of Armenia between 2020-2022. The experimental site is 650-700º above sea level where the average temperature of the coldest month (January) is −2.6 °C, and the hottest month (July) is 26.2 °C; the calculated long-term precipitation rate is 289 mm [39]. The site's favorable climate allows for cauliflower cultivation in both spring and summer due to the abundant number of favorable days each year. All experiments were conducted with four trials.

Biochemical analyses: The content of vitamin C, B group5 vitamins (thiamine, pyridoxine, pantothenic acid, nicotinic acid, inositol), 7 macronutrients (silicon, aluminium, calcium, magnesium, sodium, phosphorus, potassium) at different stages of head ripening, in different periods of cultivation at medium-ripening hybrids of cauliflower 'Rocky F1' and 'Unibotra F1' was studied. Biochemical analyses were conducted at the Laboratory of Biotechnology, Phytopathology and Biochemistry of the Scientific Centre. Ascorbic acid content in cauliflower heads was determined by the titration method [40]. Quantitative analysis of the water-soluble B group vitamins was performed spectrophotometrically using Cary 60 UV-Vis spectrophotometer (Agilent Technologies, USA). The method is based on the determination of reduced and oxidized riboflavin at a wavelength of 445 nm in relation to a solvent (0.1N HCl solution) [41]. The content of B group vitamins was calculated according to the calibration graph. The content of macronutrients was determined by the chemical-spectral methods.

Statistical Analysis: The experimental data was subjected to statistical processing through application of the Analysis of variance (ANOVA) tool in Microsoft Excel software. Analyses data were expressed as means ± standard deviations (SD). The collected research data was analyzed using an F-test at level 5% to determine variance results of the analyzed vitamins and macronutrients in cauliflower heads.

RESULTS

One of the key factors determining the content of bioactive substances in cauliflower is its maturation stage. Studies show that the process of accumulation of bioactive substances occurs throughout the entire growth cycle of cauliflower.

According to the results of the study, it was established that the content of ascorbic acid changes depending on the stage of ripening of heads of cabbage. Thus, in the 'Rocky F1' hybrid, the content of ascorbic acid gradually increased under summer growing conditions. The maximum level was observed at the stage of technical ripeness of cabbage heads (46.8mg/%), which is 18.8% more than under spring cultivation conditions. Hybrid 'Unibotra F1' was distinguished by a high content of ascorbic acid at the initial stage of head formation under summer growing conditions (36.1mg/%). From the data presented in Figure 1, it is clear, that under spring growing conditions, according to the stages of ripening of cabbage heads, in both hybrids there is an increase in the accumulation of ascorbic acid in heads of cabbage. Additionally, in summer growing conditions, the process of accumulation of ascorbic acid has a wave-like character.

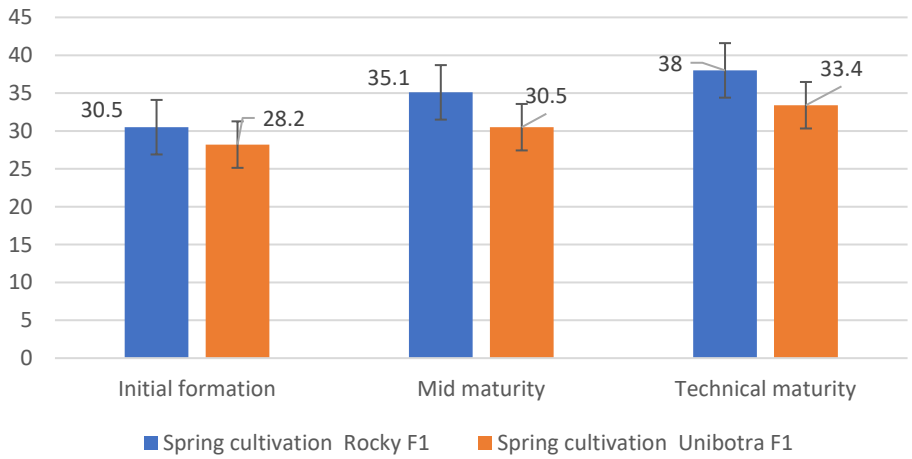


Fig 1. Dynamics of ascorbic acid synthesis and accumulation at different stages of maturation of cauliflower heads, mg/%

The statistical analysis of the results of ascorbic acid content at the different stages of cauliflower ripening showed fluctuations in the least significant difference. This can be explained by the fact that, firstly, fluctuations in environmental factors have a significant impact on the synthesis of vitamin C [42]. In addition, for this analysis, the titration method was used, which was chosen on the basis of, comparison of titration methods and spectrophotometry carried out by other researchers [43], showed that there is not much difference between the two methods. However, the titration method produced a higher error rate, which is consistent with data of other researchers [44] indicating that the spectrophotometric method is more accurate with error rate of less than 5%.

As in the case of ascorbic was, the dynamics of accumulation of B vitamins were also studied depending on the stage of development and timing of cultivation. The results of the study showed that the content of B vitamins, with the exception of pantothenic acid, is high in newly formed heads of cabbage and decreases with ripening (Fig.2,3,4). This is explained by the participation of B vitamins in the synthesis of many organic compounds. Thiamine, for instance, stimulates the growth, yield quality and key biochemical processes of cauliflower [45].

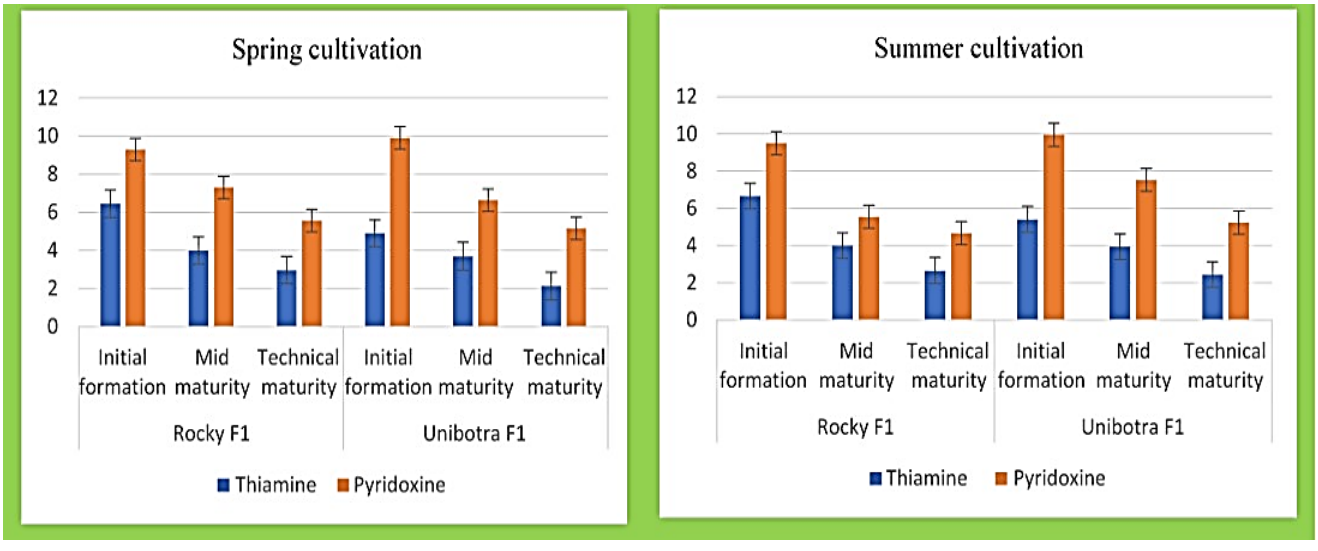


Fig 2. Dynamics of synthesis and accumulation of B1 and B6 vitamins in cauliflower heads in spring cultivation conditions, µg/ml

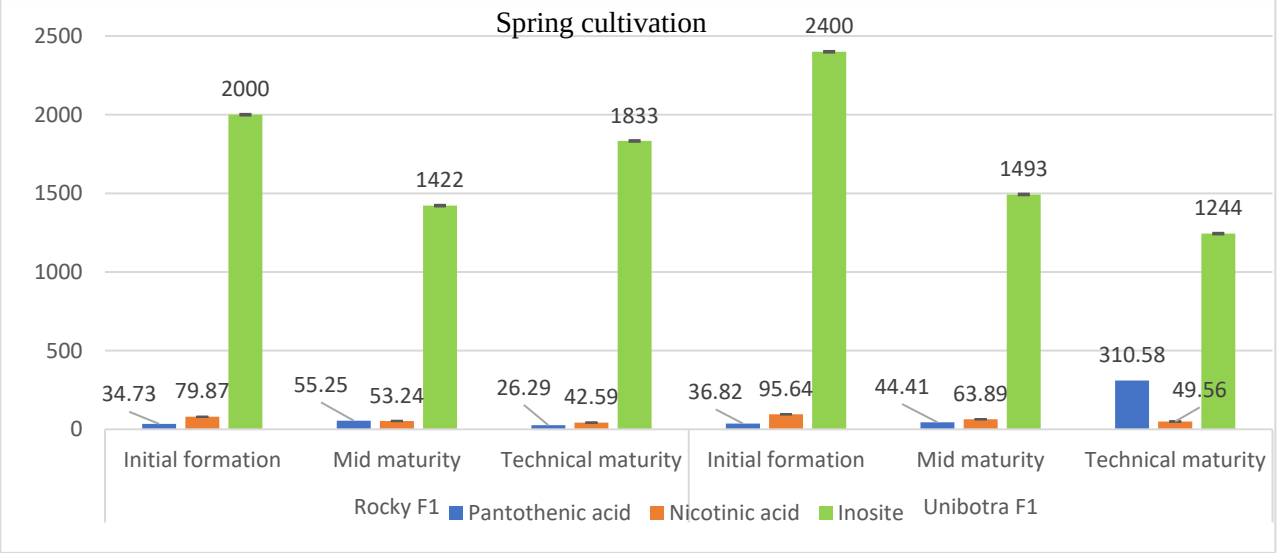


Fig 3. Dynamics of synthesis and accumulation of B5, B3 and B8 vitamins in cauliflower heads in spring cultivation conditions, µg/ml

Under summer growing conditions, the quantitative decrease in vitamins in mature heads of cabbage is also due to a decrease in air temperature and a slowdown in growth processes (Fig. 4).

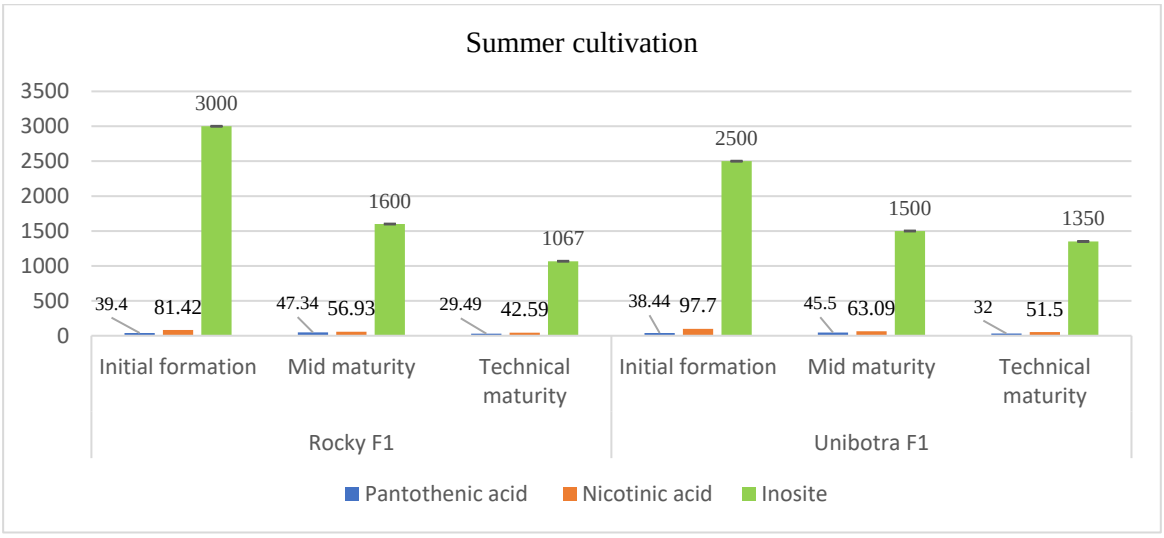


Fig 4. Dynamics of synthesis and accumulation of B5, B3 and B8 vitamins in cauliflower heads in summer cultivation conditions, µg/ml

Considering the fact that macronutrients play an essential role in cabbage-head formation, side by side with vitamins a content of seven macronutrients was determined at the different stages of development. Potassium, calcium, and magnesium dominate in terms of their content among the 7 macroelements found in cauliflower heads at different stages of maturation. At the same time, a higher content of potassium was recorded in both hybrids in the middle maturation stage under the conditions of summer cultivation, and in the technical ripening stage under the conditions of spring cultivation (Fig.5,6). The Rocky F1 hybrid stood out for its high content of calcium and magnesium under the conditions of spring cultivation at the stage of technical maturation of the head, making 851.4 and 567.6 mg/kg, respectively, and the above-mentioned macronutrients were high in the Unibotra F1 hybrids at the head mid maturity stage, making 675 ,4 and 222.1 mg/kg respectively.

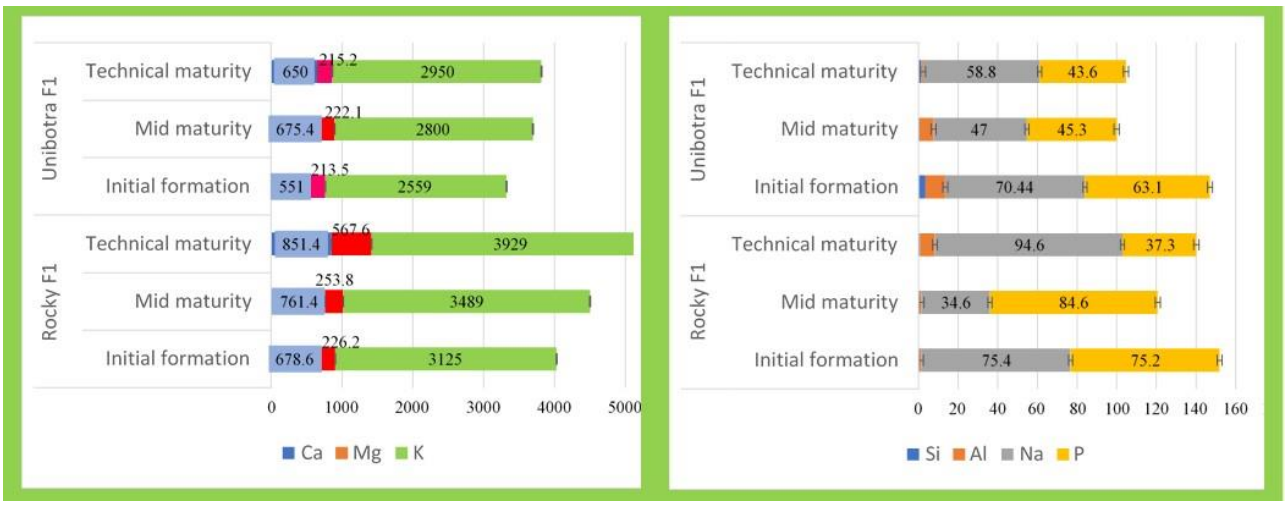


Fig. 5 The content of macronutrients at different ripening stages of cauliflower heads in spring cultivation conditions, mg/kg

Under the conditions of summer cultivation, the Rocky F1 hybrid stood out with a high content of calcium and magnesium in the initial head formation stage (779.2 and 266.4 mg/kg), and the Unibotra F1 hybrid in the mid-ripening stage of the head (719.1 and 239.7 mg/kg) (Fig 6).

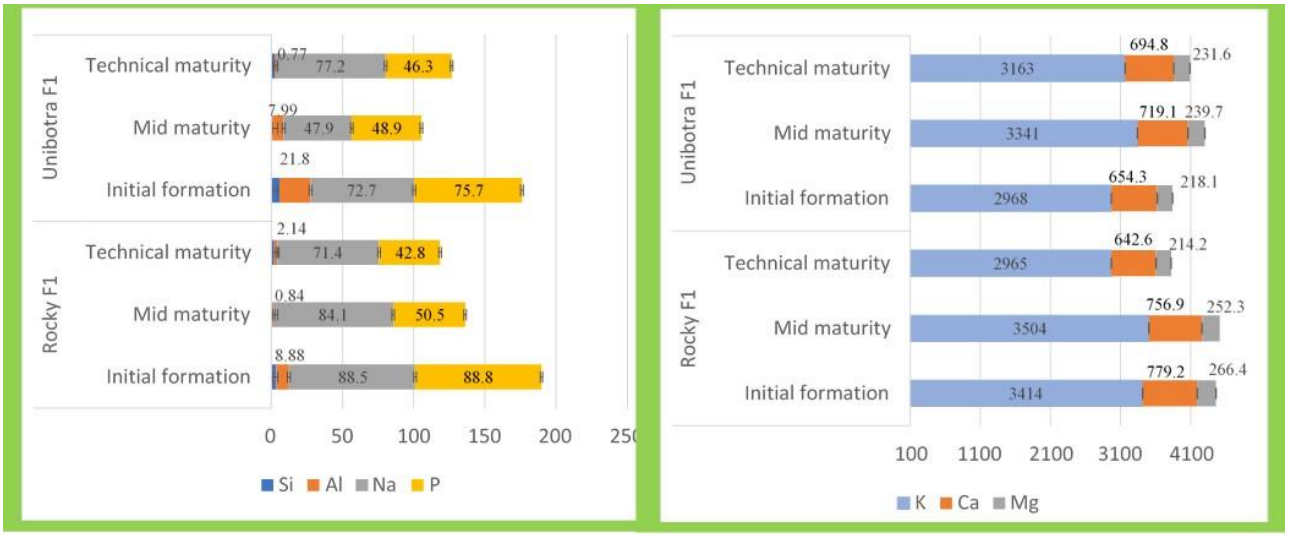


Fig. 6. The content of macronutrients at different ripening stages of cauliflower heads in summer cultivation conditions, mg/kg

The studied macronutrients Si, Al, Na, with the exception of the P, stood out in the Rocky F1 hybrid during the heads technical maturation stage under spring growing conditions, and were high in the newly formed heads in the Unibotra F1 hybrid. The results of the research showed that in the summer cultivation conditions the mentioned macronutrients stood out for their content in Rocky F1 hybrid in newly formed heads, while in Unibotra F1 hybrid at the same stage Si and P were high. Al were high in the mid-ripening stage and Na in the stage of technical maturation (Fig.5,6). Moreover, a higher potassium content was recorded in Rocky F1 (3504 mg/kg) and Unibotra F1 (3341mg/kg) hybrids in the mid-ripening stage of the head under the conditions of summer cultivation, and in the technical maturation stage of the head under the conditions of spring cultivation, making 3929mg/kg and 2950mg/kg respectively. The Rocky F1 hybrid stood out for its high content of calcium and magnesium under the

conditions of spring cultivation at the stage of technical maturation of the head, making 851.4 and 567.6 mg/kg, respectively, and the above-mentioned macroelements were high in the Unibotra F1 hybrids at the stage of medium maturity of the head, making 675.4 and 222.1 mg/kg. Under the conditions of summer cultivation, the Rocky F1 hybrid stood out with a high content of calcium and magnesium in the newly forming stage of the head (779.2 and 266.4 mg/kg), and the Unibotra F1 hybrid in the mid-ripening stage of the head (719.1 and 239.7 mg/kg).

DISCUSSION

In recent years, the Brassicaceae family of crops are increasingly consumed for possible health benefits as a good source of bioactive compounds. The review data of the information available about bioactive compounds present in the Brassicaceae family (phenolics, vitamins) in relation to human health demonstrate that such compounds as carotenoids β-carotene, lutein and zeaxanthin, as well as vitamins (C, E, K) and some macronutrients have been considered as nutrients with biological activity [46-47]. A comprehensive analysis of the influence of the ripening stage and cultivation time on the content of vitamins and macronutrients in cauliflower was conducted for the first time. The data obtained as a result of the experiments provide information on the content of various vitamins and macroelements in cauliflower heads at various stages of growth. The significance of the results obtained is due to the fact that their quantity has a significant impact on the yield and quality indicators of cauliflower [48], which, in turn, determine the functional significance of the products. With regard to the influence of the growing period on the content of bioactive components in cauliflower and the resulting nutritional and functional value, our data confirm the statements of other authors, as noted in the introduction section. Analysis of the collected data can be useful in determining the optimal in terms of functional value timing of harvesting cabbages that are highest in certain macronutrients and vitamins, which may have implications for the development of nutritious foods and diets.

CONCLUSION

Of the two cauliflower hybrids studied, Rocky F1 had a high level of ascorbic acid at the technical stage of head ripening under summer growing conditions, and the Unibotra F1 hybrid had a high level of ascorbic acid at the stage of new heading formation. This indicates some level of genetic determination of the dynamics of vitamin synthesis in different cauliflower hybrids. The content of B vitamins in cauliflower heads depends on both the stages of its development and external conditions determined by the timing of cultivation. In both hybrids, the content of the studied B vitamins, with the exception of pantothenic acid, is high in newly formed heads of cabbage and decreases as they ripen. In cauliflower heads in both growing periods, the macroelements K, Ca and Mg predominated. Thus, the dynamics of accumulation of bioactive substances during the cultivation of cauliflower plays a significant role in ensuring the functional properties of plants. The optimal harvest stage and growing conditions influence the content of bioactive compounds. A better understanding of these processes is facilitating the development of cauliflower cultivation techniques aimed at creating functional foods that promote human health and well-being.

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

Authors' contributions: LT and AA designed the research. LT, IT and GM conducted the research. LT and IV performed biochemical analysis. GM performed statistical analyses. LT and AA analyzed data and wrote the manuscript. MZ edited the article. All authors read and approved the final version of the manuscript.

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