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Biochemical composition of Armenian chili pepper varieties: insights for functional food applications

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ABSTRACT

Background: *Capsicum annuum* L. (pepper) is economically significant in many countries, including Armenia, where it helps conserve the vegetable gene pool and supports public health. Its rich biochemical composition makes it a key dietary component, particularly for its antioxidant properties, which combat free radicals. The biochemical makeup of peppers vary by genotype and maturity, leading breeders to develop varieties with both agronomic and nutritional benefits. Chili peppers are especially valued for their high carotene and ascorbic acid content, earning them the title of "multi vitamin concentrate," along with other vitamins and bioactive compounds that enhance their health benefits.

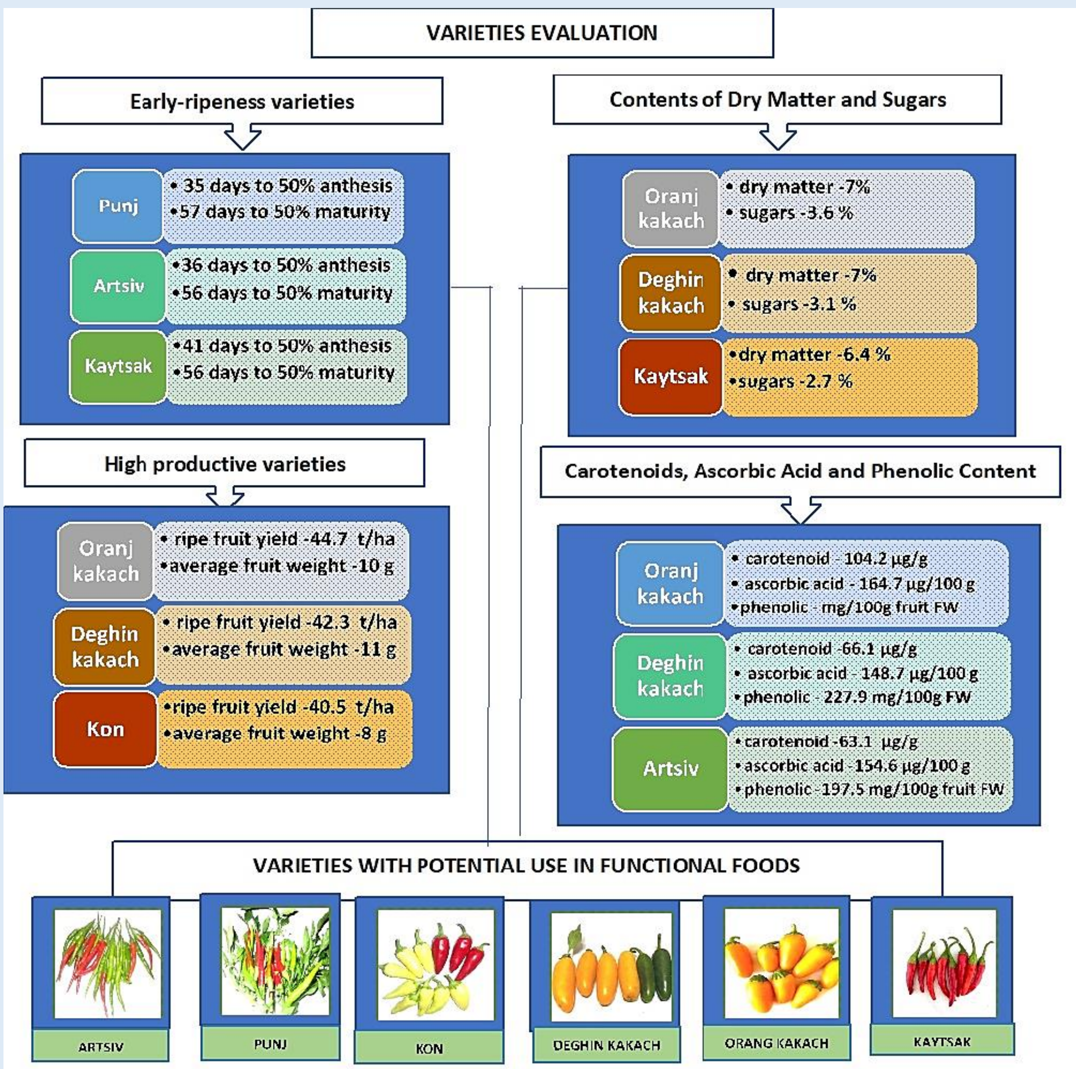
Objective: This study examines the biochemical profiles of various Armenian chili pepper varieties, highlighting their nutritional value and potential in agricultural systems. By analysing these unique varieties, the research aims to advance knowledge of their health benefits and promote sustainable farming practices.

Methods: The study examined six locally bred chili pepper varieties—'Artsiv', 'Punj', 'Kon', 'Deghin kakach', 'Oranj kakach', and 'Kaytsak'. Ascorbic acid, carotenoids, and phenols were measured at both the technical and biological ripening stages using spectrophotometry. Dry matter was determined by the thermogravimetric method, and sugar content by Bertrand's method. Pungency was assessed using the Scoville heat units' method, and statistical analysis was performed using ANOVA.

Results: The study of six Armenian chili pepper varieties showed differences in fruit shape, color, ripening times, and productivity. 'Deghin kakach', 'Oranj kakach', and 'Kon' produce conical fruits that change to yellow, orange, and red, respectively, while 'Punj', 'Kaytsak', and 'Artsiv' have elongated fruits that ripen red. Early varieties like 'Punj', 'Artsiv', and 'Kaytsak' mature 11–17 days earlier. 'Oranj kakach' was the most productive (19.4 t/ha), while 'Kaytsak' had the lowest yield. 'Artsiv', 'Punj', and 'Kaytsak' were hot, while the others were moderately hot. Carotenoid content rose during ripening, ascorbic acid ranged from 115.0 to 175.6 mg/100 g, with 'Punj' highest, and total phenolics peaked in 'Deghin kakach'.

Conclusion: Armenian chili pepper varieties are rich in bioactive compounds—phenols, ascorbic acid, carotenoids, and capsaicin— suitable for functional foods. During ripening, carotenoids increased by up to 583.64%, ascorbic acid by 97.4%, and phenols by 96.43%. 'Punj' had the highest ascorbic acid, 'Oranj kakach' the most carotenoids, and 'Deghin kakach' the most phenols, highlighting the potential of ripening to boost the health benefits of these peppers.

Keywords: hot pepper, vitamin C, carotenoids, phenols, phenological stages, productivity



INTRODUCTION

In the face of today's pressing challenges— ranging from climate change and increasing pest virulence to shifting dietary preferences— diversification in agricultural systems has emerged as a critical focus for researchers and practitioners alike [1-3]. The need for species and varietal diversification is becoming more apparent, particularly as global food security remains a persistent concern [4]. At the same time, growing consumer awareness of the nutritional value of food has spurred a shift towards functional foods that offer health benefits beyond basic nutrition. Functional food products (FFPs) and their components, known as food bioactive compounds (FBCs), possess unique properties that may reduce the risk of certain diseases, positioning them as potential alternatives to conventional medicine [5-9]. Vegetables, in particular, are rich in vital elements such as vitamins, minerals, flavonoids, and anthocyanins, which play a crucial role in managing chronic disease symptoms [10].

In this evolving landscape, plant breeders face the dual challenge of developing new crop varieties that not only meet high productivity standards but also improve nutritional profiles [11-12]. Essential nutrients— including vitamins, minerals, and antioxidants— are becoming key metrics in crop value assessments, directly influencing public health and dietary choices [13].

Pepper (*Capsicum annuum* L.), widely cultivated across the globe, including in Armenia, exemplifies this context. This vegetable crop belongs to the *Capsicum* genus within the *Solanaceae* family, which encompasses 31 to 40 species of wild and cultivated varieties, each displaying diverse colours, shapes, sizes, and biochemical compositions [14-16]. Among these, chili peppers were among the first crops domesticated and utilized by humans, prized for their wealth of natural bioactive compounds. Peppers are consumed in various forms - fresh, cooked, grilled, or pickled - and play a significant role in the canning industry [17-19].

Chili peppers, in particular, are rich in key bioactive substances, including carotenoids, ascorbic acid (vitamin C), phenolic compounds, capsaicinoids, and capsinoids, which confer a range of health-promoting properties. These include antioxidant, anti-inflammatory, and anticancer effects, as well as benefits for pain relief, cardiovascular health, gastrointestinal function, and potential protective effects against diabetes and obesity [20-21].

Specifically, pepper fruits are excellent sources of metabolites such as ascorbic acid, tocopherols (vitamin E), carotenoids (provitamin A), flavonoids, and capsaicinoids. They can contain up to 200 mg of vitamin C per 100 grams of fresh fruit, contributing significantly to daily nutritional intake. The ascorbic acid content varies depending on the variety and cultivation conditions. The vibrant colours of pepper fruits are attributed to specific carotenoids, leading to the production of yellow, orange, red, and brown varieties. In red fruits, the dominant carotenoids are capsanthin and capsorubin, while violaxanthin, β-carotene, lutein, antheraxanthin, and zeaxanthin are prevalent in yellow fruits [22-23].

The quantities of these components vary depending on genotype, maturity, and cultivation conditions. Armenian chili pepper varieties provide an illustrative case in this regard. Rich in essential vitamins, antioxidants, and bioactive compounds, these peppers hold significant potential for functional food applications. At the Scientific Centre of Vegetable and Industrial Crops, 15 varieties of sweet peppers and 16 varieties of chili peppers were developed and released. However, not all of these varieties have been thoroughly investigated for their biochemical composition. The Centre's seed genetic bank contains approximately 3,600 seed accessions of traditional and modern varieties, as well as promising lines and hybrids, serving both as a strategic repository and a source of initial breeding material [24]. Among these accessions are 270 chili pepper varieties, which form the basis of the current study.

This research aims to explore the biochemical composition of various Armenian chili pepper varieties, highlighting their nutritional benefits and potential roles in diversified crop systems. By identifying and characterizing these unique varieties, we aim to deepen our understanding of their health-promoting properties while supporting sustainable agricultural practices.

METHODS

The experiments were conducted in 2022-2023 in Armenia, specifically in the Ararat Valley, using locally bred chili varieties: 'Artsiv', 'Punj', 'Kon', 'Deghin kakach', 'Oranj kakach', and 'Kaytsak'. The experiment followed a block-randomized design with four replications. Ascorbic acid, carotenoid, and phenols content were measured in technical and biological ripening phases using spectrophotometry [25] on a Cary 60 UV-Vis spectrophotometer. Analyses of dry matter, and total sugars in the chili fruits were performed at the stage of biological ripening phase for all experimental variants. Dry matter content was measured using the thermogravimetric method, while sugar content was assessed using Bertrand's method [26]. For a comprehensive evaluation of pepper pungency, the organoleptic Scoville heat units (SHUs) method was applied. In the Scoville organoleptic test, dried pepper samples are dissolved in alcohol to extract capsaicinoids, then diluted in sugar water. A panel of five trained tasters assessed decreasing concentrations until at least three could no longer detect the heat. The heat level is rated in multiples of 100 SHU based on this dilution [27].

Experimental data were statistically processed using the ANOVA method to determine treatment effects significant at $p \leq 0.05$. Significant differences between individual means were identified using Fisher's protected least significant difference (LSD) test. Data points represent the means ± SE of four independent experiments.

RESULTS AND DISCUSSIONS

Horticultural Characteristics of Experimental Pepper Varieties: The studied Armenian chili pepper varieties exhibit diverse horticultural traits, including variations in fruit shape, colour, and ripening times. These characteristics are not only essential for crop breeding and agricultural productivity but also play a crucial role in determining the peppers' suitability for functional food applications. The conic shapes, vibrant colours, and distinct ripening phases contribute to the accumulation of bioactive compounds such as carotenoids and ascorbic acid, which are known for their health benefits [28].

The 'Deghin kakach', 'Oranj kakach', and 'Kon' varieties produce conical fruits (fruit index 2.2-2.7) (Table 1) that undergo distinct colour changes during ripening. In the technical ripening phase, 'Deghin kakach' and 'Oranj kakach' are dark green, while 'Kon' is light yellowish-green. In the biological ripening phase, 'Deghin kakach' turns yellow, 'Oranj kakach' becomes orange, and 'Kon' ripens to red. The fruit colour, which is determined by the carotenoid content, directly correlates with their potential as sources of provitamin A, contributing to eye health and immune support [29]. The 'Punj' and 'Kaytsak' varieties produce elongated conical fruits, with 'Kaytsak' being shorter. Both varieties are green in the technical phase and turn red when biologically ripe.

The early-ripening varieties 'Punj', 'Artsiv' and 'Kaytsak' reached anthesis and maturity stages 17 and 11 days earlier than 'Deghin kakach' and 'Oranj kakach', respectively, with the difference in maturity stages being 18-21 days. These early-ripening varieties ('Punj' 'Artsiv' and 'Kaytsak') not only provide higher yields earlier in the season but also retain significant levels of antioxidants, positioning them as prime candidates for fresh functional food products.

Among the varieties studied, 'Oranj kakach' was the most productive, yielding 2.4-19.4 t/ha more than the other varieties. In contrast, 'Kaytsak' had the lowest productivity (Table 1).

Table 1. Horticultural Characteristics and Productivity of Pepper Varieties

Variety	Days to 50% anthesis (DAT)*	Days to 50% maturity (DAT)	Total/fresh biologically ripe fruit yield, t/ha	Average fruit weight, g	Fruit index
Artsiv	36 ±1.3	56 ±2.2	30.3 ±0.4	5.3 ±0.1	5.0 ±0.2
Punj	35 ±1.2	57 ±2.1	27.3 ±0.5	4.2 ±0.1	4.7 ±0.1
Kon	51± 2.1	76 ±2.3	40.5 ±0.7	8.0± 0.2	2.2±0.1
Deghin kakach	52± 0.2	77± 1.7	42.3 ±0.3	11.0±1.0	2.5 ±0.3
Oranj kakach	52±0.2	75 ±1.2	44.7 ±0.2	10.0± 0.4	2.7±0.2
Kaytsak	41 ±1.5	56±1.0	25.3±0.2	2.2±0.2	4.5 ±0.1
LSD			0.7		

*DAT-days after transplanting

Biochemical Characteristics of Experimental Pepper Varieties: The biochemical analysis of the experimental Armenian chili pepper varieties reveals significant variations in their nutrient profiles and bioactive compounds. These characteristics not only contribute to the overall quality and flavour of the peppers but also enhance their potential as functional foods, offering various health benefits associated with their unique biochemical compositions. Overall, the vibrant colors of fruits not only make them visually appealing but also indicate their nutritional value, particularly in terms of carotenoids and other beneficial compounds [30-31].

The experimental varieties differ in pungency, aroma, and flavour, as measured in Scoville Heat Units (SHUs). According to SHU ratings, 'Artsiv', 'Punj', and 'Kaytsak' are classified as hot chili peppers, while 'Kon', 'Deghin kakach', and 'Oranj kakach' are moderate in heat (Table 2). There is a direct correlation between capsaicin content and pungency. Pungent chili varieties are cultivated not only for their nutritional value and flavour but also for their health benefits, particularly their capsaicinoid content, which has medicinal uses. [32-33].

Biochemical analyses at the biological ripeness stage measured dry matter content and total sugars. The dry matter content and total sugars in chili peppers are critical factors that influence their sensory qualities and nutritional value, making them suitable candidates for functional food applications. Higher dry matter content often correlates with increased concentrations of essential nutrients and bioactive compounds, while optimal levels of total sugars contribute to flavour and palatability, enhancing the overall consumer acceptance of functional food products [34]. Dry matter content ranged from 5.3% to 7.3%, while total sugars varied from 2.8% to 3.6%. The 'Oranj kakach' variety exhibited the highest values, with 7.5% dry matter and 3.6% total sugars (Table 2).

Table 2. Contents of Dry Matter, Sugars, and Capsaicin in Chili Pepper Varieties at the Biological Ripening Stage

Variety	Dry matter content	Total sugars content	Scoville Heat Units (SHUs)
Artsiv	5.3±0,11	2.8±0,12	35000
Punj	5.4±0,13	2.6±2,1	30000
Kon	6.2±0,22	3.0±1,2	3000
Deghin kakach	7.0±0,13	3.1±0,2	3700
Oranj kakach	7.3±0,21	3.6±0,1	3200
Kaytsak	6.4±0,10	2.7±0,1	40000

Significant at 1% level

The determination of levels of carotenoids and ascorbic acid in pepper varieties highlights their potential as functional foods, as these compounds are associated with various health benefits, including antioxidant activity, immune support, and potential protective effects against chronic diseases. Incorporating these nutrient-rich varieties into diets can enhance both the nutritional quality and health-promoting properties of food products [34-36]. Vitamin C, recognized for its strong antioxidant properties, is crucial for shielding the body from oxidative stress, strengthening the immune system, and improving the absorption of iron from plant-derived foods [37]. In the current study, the carotenoid content of pepper fruits exhibited a continuous increase during the ripening process, with significant differences observed between the two ripening stages across all varieties studied (Table 3). Specifically, the carotenoid content varied significantly between the technical and mature (biological) ripening stages across the six varieties: 'Artsiv', 'Punj', 'Kon', 'Deghin kakach', 'Oranj kakach', and 'Kaytsak'. The levels of carotenoids varied as follows: 'Artsiv' (22.03 ± 2.01 and 63.05 ± 0.84 µg/g), 'Punj' (14.37 ± 5.14 and 98.24 ± 11.43 µg/g), 'Kon' (18.56 ± 4.37 and 58.70 ± 5.67 µg/g), 'Deghin kakach' (22.39 ± 2.44 and 66.05 ± 1.59 µg/g), 'Oranj kakach' (19.35 ± 7.49 and 104.2 ± 9.47 µg/g), and 'Kaytsak' (21.23 ± 6.59 and 59.49 ± 7.59 µg/g). Our experimental results are similar with other authors' results [38-39].

Spectrophotometric analysis revealed maximum reflectance between 700 and 900 nm, with a local absorption maximum observed around 960 nm in the near-infrared region. Furthermore, the ascorbic acid content in fruits at biological ripeness varied from 115.0 to 175.6 mg/100 g. The 'Punj' variety exhibited significant superiority with 175.6 mg/100 g, followed by 'Kon' and 'Oranj kakach' with 155.8 mg/100 g and 164.7 mg/100 g, respectively.

Determining the phenolic content in chili pepper varieties is essential, as these compounds are recognized for their potent antioxidant properties and their ability to combat oxidative stress, which is linked to various chronic diseases. The presence of phenolic compounds enhances the functional food potential of these peppers, making them valuable additions to diets aimed at promoting health and preventing disease [40].

The total phenolic concentrations of six varieties of chili pepper fruits at two ripening stages (technical and biological) were investigated (Table 3). The results indicated a gradual increase in phenolic concentration from green to red ripening, corroborating findings by Lahbib and Bnejdi, as well as Ye, Shang, Li et al. [39-40]. Notable differences in total phenolic content were observed among the varieties, ranging from 84 to 227 mg/100 g fresh weight (FW). Among the genotypes, 'Deghin kakach' exhibited the highest total phenolic content, with 124.43 ± 0.12 mg/100 g (technical ripening stage) and 227.9 ± 0.65 mg/100 g (biological ripening stage), while 'Kon' possessed the lowest amounts, with 85.3 ± 0.83 mg/100 g and 154.7 ± 0.56 mg/100 g at the green and red ripening stages, respectively.

Table 3. Carotenoids, Ascorbic Acid and Phenolic Content in Different Varieties of Chili Pepper

Varieties	Carotenoid content, µg/g		Content of ascorbic acid, µg/100 g		Phenolic contents (mg/100g fruit FW)	
	Technical ripening stage	Biological ripening stage	Technical ripening stage	Biological ripening stage	Technical ripening stage	Biological ripening stage
Artsiv	22.03 ± 2.01	63.05 ± 0.84	81.3 ±1.1	154.6 ±2.4	124,5±0,76	197,5±0,28
Punj	14.37 ± 5.14	98.24 ± 11.43	110.2 ±2.3	175.6 ±2.5	84,2±0,47	165,4±0,76
Kon	18.56 ± 4.37	58.70 ± 5.67	82.5 ±2.4	155.8 ±1.8	85,3±0,83	154,7±0,56
Deghin kakach	22.39 ± 2.44	66.05 ± 1.59	75.3 ±1.7	148.7 ±1.4	124,43±0,12	227,9±0,65
Oranj kakach	19.35 ± 7.49	104.2 ± 9.47	85.4 ±2.5	164.7 ±2.0	95,6±0,31	184,3±0,15
Kaytsak	21.23 ± 6.59	59.49 ± 7.59	79.4 ±1.2	151.2 ±1.5	111,8±0,78	218,4±0,23

Based on the mean phenolic contents, the varieties were classified into three categories: low (0-100 mg/100 g FW), medium (101-200 mg/100 g FW), and high (201-300 mg/100 g FW). Most of the chili peppers in the present investigation fell under the high category at the red ripening stage (Table 3). These results are supported by previous studies [41-42], which found high phenolic content in chili pepper fruits at the red ripening stage. The present study revealed that the high phenolic content was pronounced in the biological ripening stage, which may be attributed to the increased concentration of ascorbic acid [34-35]. A similar viewpoint is also shared by García-Vásquez et. al. [43]. Our results suggest that the six varieties exhibited phenolic contents ranging from 84 to 227 mg/100 g FW. In addition to their direct use in food applications, these findings can inform breeding programs aimed at producing varieties with high phenolic content, thereby enhancing their value as functional food products [44].

CONCLUSIONS

In the Argo ecological conditions of Armenia, the chili pepper varieties studied have been found to be rich in bioactive components, including phenols, ascorbic acid, carotenoids, and capsaicin. During biological ripening, key components in Armenian chili peppers—carotenoids, ascorbic acid, and phenols— increase significantly: carotenoids by up to 583.64%, ascorbic acid by 97.4%, and phenols by 96.43%. The 'Punj' variety has the highest ascorbic acid, 'Oranj kakach' has the richest carotenoid content, and 'Deghin kakach' shows the most phenols. These findings emphasize the importance of ripening in enhancing their bioactive potential, positioning them as valuable functional food ingredients.

List of abbreviations: SHUs, Scoville heat units method; LSD, least significant difference; FFPs, functional food products; FBCs, food bioactive compounds; DAT, days after transplanting; t/ha, tons per hectare; g, gram; mg, milligram; FW, fresh weight.

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

Authors' contributions: GM, AP and LT designed the research. IV, LKh and GA performed biochemical analysis. GM performed statistical analyses. LT, AA 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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