

Chemical profile and potential for utilization of plant by-products from the canning industry

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Abstract. This study focuses on the chemical profile of pepper and eggplant stems (pedicel) with seeds obtained as plant by-products from the canning industry. The contents of proteins, carbohydrates, fats, fatty acid composition, β -carotene, mineral elements, dietary fiber (including pectin), and other components were determined. A granulometric analysis was also performed. The samples were characterized by high protein content (13.21% for pepper and 15.02% for eggplant). The dominant fatty acids in pepper stems were linoleic (68.15%), palmitic (10.41%), oleic (9.42%), and linolenic (5.55%), while in eggplant stems – linoleic (33.10%), linolenic (20.83%), palmitic (15.52%), and stearic (11.13%) acids. Among the mineral components, potassium, calcium, and magnesium predominated in both samples. Dietary fiber content was 47.57% for pepper and 56.92% for eggplant. The results show that both materials are potential sources of valuable biocomponents for the food and biotechnological industries.

1 Introduction

Fruits and vegetables play an extremely important role in human nutrition. Their production and industrial processing have increased considerably in recent years as a result of the growing world population and changing dietary habits. Losses of agricultural products and the waste generated from them represent a serious global problem and are the highest among all food categories, reaching up to 60% [1].

Europe generates approximately 89 million tons of food waste each year, a number expected to rise substantially in the coming years [2].

The food industry, especially the sector for canning fruits and vegetables, generates significant amounts (up to 50%) of plant by-products [3]. These include husks, peels, pods, seeds, stems, stalks, roots, press cakes, pulps, as well as unripe or damaged fruits and vegetables [4,5].

All these underutilized materials have for years been turning into a serious nutritional, economic and environmental problem [6].

They are usually discarded or used as animal feed, although it is well known that they contain potentially beneficial compounds.

The concept is increasingly gaining ground that plant by-products are not just waste, but a valuable

source of dietary fiber, proteins, fats, carotenoids, polyphenols, minerals, and other constituents [2,7].*

Compared to the edible parts, these materials often contain higher levels of bioactive compounds that exert beneficial biological effects, such as antioxidant and antimicrobial activity [8].

The valorization of fruit and vegetable by-products by converting them into value-added products (e.g. food or functional ingredients, feed, cosmetic raw materials) represents a key opportunity for industry. In this regard, the literature describes various approaches – conversion of plant material into energy, isolation of bioactive components, extraction of functional ingredients, development of functional foods, etc. [2,9,10].

Recently, innovations in food products using fruit and vegetable by-products have attracted considerable public attention and interest due to the low cost of raw materials and the positive impact on the environment [11].

Bulgaria has strong traditions in the processing of fruits and vegetables, with pepper and eggplant being among the main raw materials for the canning industry. In the course of processing, specific plant by-products are generated, such as pedicel, calyx, placenta and seeds. While the main edible parts of vegetables are well studied, information on the chemical composition and utilization potential of these by-products is limited in the

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scientific literature. This is especially true for Bulgarian cultivars of pepper and eggplant. The lack of detailed data on their chemical profile and content of bioactive compounds hampers their effective industrial application. In order to develop a successful utilization process, it is necessary to characterize in detail the contents of the main macro- and microcomponents.

The aim of the present study is to characterize the chemical profile of pepper and eggplant stems with seeds obtained as by-products from the canning industry. The investigation includes the determination of proteins, fats and their fatty acid composition, β -carotene, mineral substances and dietary fiber. The potential of these plant materials as promising sources of valuable biocomponents for the food and biotechnological industries is also evaluated.

2 Materials and methods

2.1 Plant materials

In the present study, plant by-products from the canning industry obtained during processing of Bulgarian cultivars of pepper (*Capsicum annuum* L.) and eggplant (*Solanum melongena* L.) cultivated in the Plovdiv region, Bulgaria, were used. The pepper cultivar was “Plovdivska kapiya”, and the eggplant cultivar – “Bulgarski 12”. The plant materials included pedicels, calyces, placentas, seeds and a small portion of tissue immediately around the calyx.

Each of the two materials was chopped, dried in a laboratory dryer at 50 °C and ground. The resulting flours were sieved through a laboratory sieve with an aperture size of 1.0 mm. The final products represented homogeneous mixtures of the inedible parts of the two vegetables. They were packed in polyethylene bags and stored at room temperature (approximately 25 °C) for three days before the chemical analyses were carried out. Information on fertilizers and plant protection products used during cultivation was not available, as the raw materials were obtained as industrial by-products from a commercial canning facility.

In the results presented below, the two plant materials containing the individual parts (pedicels, calyces, placentas, seeds) are referred to, for brevity, simply as “pepper pedicels” and “eggplant pedicels”.

2.2 Sieve analysis

Sampling and sieve analysis of the ground products were performed according to BDS 745:1980 [12]. The study was carried out on a laboratory plansifter (model LP-200) equipped with five sieve frames with dimensions 200 × 200 mm. The sieves used had aperture sizes of 132, 200, 280, 355, 450, 560, 670, 800, and 1000 μ m. The sieving time was 5 min at a plansifter rotation frequency of 180 min⁻¹ (rpm). To facilitate sieving, two rubber balls were placed in each frame. The particle size distribution of the milled and fractionated material was expressed as mass fractions (q_i , %) of the size classes, following the terminology in DIN 9276-1 [13].

2.3 Chemical analysis

The contents of the main chemical components were determined using commonly accepted standard laboratory procedures, as follows: proteins – Kjeldahl method according to BDS ISO 1871:2014 [14]; fats – gravimetrically after extraction by the Soxhlet method [15]; fatty acid composition – according to ISO 12966-4:2015 [16]; total dietary fiber – by enzymatic-gravimetric method AOAC 985.29/2017 [17]; nitrates – according to BDS EN 12014-2:2018 [18]. Extraction and quantitative determination of β -carotene were performed using the HPLC method described by M. Hernandez-Ortega et al. [19]. Ash content was determined by dry ashing of the sample at 550 °C in a muffle furnace, and moisture content – by drying in a laboratory dryer at 103 ± 2 °C to constant mass. Pectic substances were determined titrimetrically [20], while total carbohydrates were determined using the colorimetric method of DuBois et al. [21]. The contents of glucose, fructose and sucrose were determined by the HPLC method developed by Petkova et al. [22]. Elemental composition of the samples was determined according to BDS EN 16943:2017 [23] and EN 14083:2003 [24].

3 Results and discussion

The results of the granulometric analysis of the milled plant samples from pepper and eggplant pedicels are presented in Figure 1. The particle size distribution of pepper pedicels is bimodal, with two main peaks: the first in the range of fine fractions (below 200 μ m), and the second in the coarser fraction range centered around 670 μ m. This distribution pattern may be due to differences in strength and chemical composition of the various anatomical parts of the pedicels.

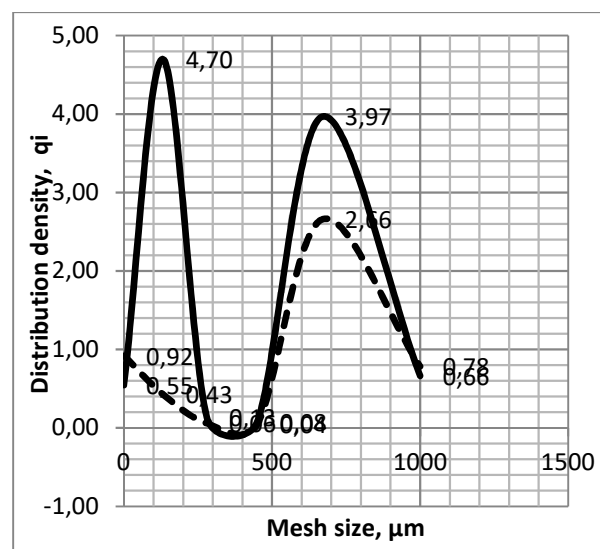


Fig. 1. Particle size distribution (sieve analysis) of ground plant material from pepper and eggplant pedicels (— pepper pedicels; - - - eggplant pedicels). q_i represents the relative amount of material corresponding to the i -th particle size fraction.

For the eggplant pedicel sample, a single main maximum is observed at about 700 μm , indicating that the predominant particle size lies in the coarser range (grits-type fraction). In this range, the distribution density of eggplant particles is lower compared to the corresponding fraction of pepper pedicels.

The established particle size distribution is crucial for identifying the most suitable utilization routes for these by-products. For example, the finer fraction (below 200 μm) of pepper would be more appropriate for applications requiring high solubility or efficient extraction of bioactive compounds. Conversely, the coarser particle size of eggplant is associated with lower bulk density and specific textural characteristics, suggesting potential applications as a source of insoluble dietary fiber or as a raw material for bioenergy production. These differences in granulometry imply the need for a differentiated approach in their industrial application, taking into account the technological requirements of the final product, whether it is a food product, feed additive, or raw material for biotechnological processes.

The contents of the main chemical components (proteins, carbohydrates, fats, dietary fiber, pectin, β -carotene, nitrates, ash, and moisture) of pepper and eggplant pedicels are presented in Table 1.

Table 1. Chemical composition of pepper (*Capsicum annuum* L.) and eggplant (*Solanum melongena* L.) pedicels, in %

Component (Parameter)	Pepper pedicels	Eggplant pedicels
Proteins	13.21 \pm 0.25	15.02 \pm 0.30
Total Carbohydrate	64.74 \pm 0.45	62.80 \pm 0.40
Glucose	2.32 \pm 0.02	0.35 \pm 0.03
Fructose	3.10 \pm 0.05	0.60 \pm 0.10
Sucrose	0.12 \pm 0.01	0.21 \pm 0.05
Total Fat	4.87 \pm 0.12	4.92 \pm 0.20
Dietary Fiber	47.57 \pm 0.74	56.92 \pm 0.89
Pectin	6.8 \pm 0.4	5.4 \pm 0.2
β -carotene	0.452	–
Nitrate	0.094 \pm 0.005	2.83 \pm 0.10
Ash	8.02 \pm 0.60	9.41 \pm 0.48
Moisture	8.46 \pm 0.22	6.94 \pm 0.14

Note: Values are expressed as mean \pm expanded uncertainty at the 95% confidence level.

The data show some distinct differences in chemical composition, although both materials are plant by-products from the canning industry. Pepper pedicels are characterized by higher levels of simple sugars (glucose and fructose) as well as the presence of β -carotene (4520 $\mu\text{g/g}$). For comparison, in a study of carotenoid content in dried red peppers by Marcela Hernández-Ortega et al. [19], the highest reported values for the cultivar “Guajillo pepper 15660” were 344 $\mu\text{g/g}$ DWB (at total carotenoids of 3406 $\mu\text{g/g}$ DWB). The difference is substantial, especially considering that the plant material used in the present study includes only a small part of the fruit (the rear cap), where these natural

pigments are concentrated. This discrepancy may be due not only to differences in pepper cultivars, but also to genotype, maturity stage and drying conditions.

In all cases, the presence of carotenoids, as well as the content of phenolic compounds in *Capsicum annuum* L. [25], suggests a greater potential for extraction of antioxidant substances compared to *Solanum melongena* L. On the other hand, eggplant pedicels show higher values for total protein, dietary fiber and ash, which may indicate higher amounts of structural polymers and mineral substances.

The pectin content is similar in the two plant materials, but the slightly higher value in pepper pedicels may be important when developing extraction technologies. A markedly higher nitrate level is observed in eggplant pedicels, which is an important factor in safety assessment and further technological processing.

Fatty acid profiles of the fats extracted from pepper and eggplant pedicels are presented (Tables 2 and 3).

Table 2. Fatty acid composition of pepper pedicels.

No.	Fatty acid	Content (% of total fat)	Uncertainty
	Saturated fatty acids		
1	Butyric acid (C4:0)	< 0.01	–
2	Caproic acid (C6:0)	< 0.01	–
3	Caprylic acid (C8:0)	< 0.01	–
4	Capric acid (C10:0)	< 0.01	–
5	Lauric acid (C12:0)	0.082	0.005
6	Myristic acid (C14:0)	0.352	0.022
7	Palmitic acid (C16:0)	10.408	0.570
8	Stearic acid (C18:0)	2.893	0.155
9	Arachidic acid (C20:0)	0.452	0.016
10	Behenic acid (C22:0)	0.327	0.013
11	Lignoceric acid (C24:0)	< 0.01	–
	Unsaturated fatty acids		
12	Palmitoleic acid (C16:1)	0.389	0.024
13	Oleic acid (C18:1)	9.419	0.832
14	Linoleic acid (C18:2)	68.153	4.054
15	Linolenic acid (C18:3)	5.548	0.429
16	Erucic acid (C22:1)	< 0.01	–

Table 3. Fatty acid composition of eggplant pedicels.

No.	Fatty acid	Content (% of total fat)	Uncertainty
Saturated fatty acids			
1	Butyric acid (C4:0)	< 0.01	–
2	Caproic acid (C6:0)	0.09	0.03
3	Caprylic acid (C8:0)	< 0.01	–
4	Capric acid (C10:0)	< 0.01	–
5	Lauric acid (C12:0)	< 0.01	–
6	Myristic acid (C14:0)	0.12	0.02
7	Palmitic acid (C16:0)	15.52	0.98
8	Stearic acid (C18:0)	11.13	0.90
9	Arachidic acid (C20:0)	< 0.01	–
10	Behenic acid (C22:0)	2.89	0.28
11	Lignoceric acid (C24:0)	1.14	0.19
Unsaturated fatty acids			
12	Palmitoleic acid (C16:1)	< 0.01	–
13	Oleic acid (C18:1)	6.01	0.34
14	Linoleic acid (C18:2)	33.10	2.48
15	Linolenic acid (C18:3)	20.83	2.42
16	Erucic acid (C22:1)	< 0.01	–

Note: Fatty acid contents in Tables 2 and 3 are expressed as % of total fat and reported as mean values with expanded uncertainty ($k = 2$, $\approx 95\%$ confidence). Values “<0.01” indicate concentrations below the detection limit.

In pepper pedicels, linoleic acid (C18:2) is dominant, representing about 68% of total fatty acids. Oleic (C18:1) and linolenic (C18:3) acids show lower but still substantial shares ($\sim 9\%$ and $\sim 6\%$, respectively). Among saturated fatty acids, palmitic acid (C16:0) predominates at about 10.4%. This leads to a very high overall proportion of unsaturated fatty acids, typical for the lipid profile of seeds and other non-edible components of *Capsicum annuum* L. A similar fatty acid profile has been reported for seeds of hot peppers and other *Capsicum* species, confirming the dominant omega-6 character of the genus [26,27].

Eggplant pedicels exhibit a more balanced distribution of unsaturated fatty acids. The dominant polyunsaturated fatty acid is linoleic (C18:2), representing about 33% of total fatty acids. Linolenic acid (C18:3) ranks second with approximately 21%, and

oleic acid (C18:1) is about 6%. Compared to pepper pedicels, the relative share of linolenic (omega-3) acid in eggplant is significantly higher ($\sim 21\%$ vs. $\sim 6\%$), resulting in a lower omega-6/omega-3 ratio, although the profile still remains dominated by omega-6 acids. At the same time, eggplant pedicels are characterized by higher levels of saturated fatty acids, mainly palmitic and stearic, contributing to a higher degree of saturation of the lipid fraction.

In summary, the two plant by-products have valuable but different fatty acid characteristics. Pepper pedicels are characterized by a very high overall share of unsaturated fatty acids (over 80% of total fatty acids) and a clearly pronounced dominance of linoleic acid (omega-6). Eggplant pedicels also contain predominantly unsaturated fatty acids, but with a higher relative proportion of linolenic (omega-3) acid and a higher content of saturated fatty acids, resulting in a different, more balanced omega-6/omega-3 profile compared to pepper pedicels. These features highlight the need for differentiated utilization of the two by-products according to their specific biochemical profiles. The high relative share of unsaturated fatty acids, especially in pepper pedicels, as well as the significant contribution of linolenic acid in eggplant pedicels, suggests that these usually discarded by-products from the canning industry may be a valuable resource for the production of vegetable oils, biocomponents and other products with potential applications in the food, cosmetic and biotechnological industries.

Table 4. Content of chemical elements in plant by-products from peppers and eggplants processing.

Element	Pepper pedicels	Eggplant pedicels
Na (mg/kg)	75.96 ± 2.13	870 ± 12
K (g/kg)	8.00 ± 0.51	10.55 ± 0.51
Mg (g/kg)	2.57 ± 0.30	2.27 ± 0.30
Ca (g/kg)	5.10 ± 0.42	7.91 ± 0.42
Fe (mg/kg)	58.06 ± 0.18	63.04 ± 0.26
Cu (mg/kg)	9.62 ± 0.28	8.35 ± 0.28
Zn (mg/kg)	19.45 ± 0.18	32.78 ± 0.18
Cr (mg/kg)	250 ± 5.0	4.00 ± 0.68

Results are presented as mean ± expanded uncertainty (95% confidence level).

The results show that both types of pedicels are rich sources of macro- and microelements, with potassium having the highest content (10.55 g/kg in eggplant and 8.00 g/kg in pepper). High potassium levels are typical for plant raw materials, as this element is critical for many basic physiological and biochemical processes in plant cells, without which the plant cannot survive or grow optimally [28]. The next two prevalent elements are calcium and magnesium. Magnesium content is similar in both products (2.57 and 2.27 g/kg, respectively), reflecting its role in cellular structures and

its relatively stable presence in plant tissues regardless of species differences. Iron values are also close in the two materials (about 58 and 63 mg/kg, respectively), while zinc is substantially higher in eggplant pedicels (32.78 mg/kg) than in pepper (19.45 mg/kg). Copper is present in comparable concentrations (9.62 and 8.35 mg/kg, respectively), whereas sodium shows very large differences. Eggplant pedicels have approximately eleven times higher sodium content (870 mg/kg) than pepper pedicels (75.96 mg/kg), which is likely related to species-specific physiological differences, environment, soil and irrigation conditions and other factors.

Among the studied elements, the difference in chromium content is particularly indicative – 250 mg/kg in pepper pedicels versus only 4.00 mg/kg in eggplant. Chromium has a dual nature in biological systems. On the one hand, it is classified as a heavy metal and is widely recognized as a potential environmental pollutant, with increasing levels in soil due to industrial and anthropogenic activities. Depending on its oxidation state, it exists in different forms, with Cr(VI) being highly toxic and carcinogenic to living organisms, including plants and humans. On the other hand, Cr(III) is considered an essential trace element for carbohydrate and lipid metabolism in humans and animals, although its role in plant physiology remains debated and is not fully elucidated. It is generally believed that chromium is non-essential and toxic for plants [29].

The high levels observed here (250 mg/kg in pepper) may serve as a bioindicator of potential local soil contamination. Chromium concentration is a key parameter when assessing the safety of these plant wastes for possible recycling or reuse (e.g. as feed, compost or a source of bioactive compounds) to ensure that they do not pose a risk to the food chain or the environment. The results emphasize the need for further studies on the speciation (trivalent, hexavalent), bioavailability and origin of chromium in the plant materials.

In summary, pepper and eggplant pedicels are plant by-products rich in mineral substances, with significant amounts of potassium, calcium, magnesium and other bioelements. The results demonstrate their potential for integration into biotechnological, agrochemical and food processes where mineral profile is a key factor.

4 Conclusion

The present study provides a detailed chemical profile of two important plant by-products from the Bulgarian canning industry: pepper (*Capsicum annuum* L.) and eggplant (*Solanum melongena* L.) pedicels with seeds. The results demonstrate that these materials represent rich and underutilized sources of valuable biocomponents.

The main findings can be summarized as follows:

- Both products are characterized by high contents of proteins (above 13%) and dietary fiber (above 47%), which makes them

potential raw materials for food enrichment or feed purposes.

- Significant differences in fatty acid composition were established. Pepper pedicels exhibit a dominant omega-6 profile with a high share of linoleic acid (~68%), whereas eggplant pedicels offer a more balanced omega-6/omega-3 ratio.
- The pepper sample shows extremely high β -carotene content (4520 $\mu\text{g/g}$), suggesting potential for extraction of natural antioxidants and colorants.
- The mineral profile is rich in macroelements (K, Ca, Mg), and a pronounced difference in chromium levels between the two types of samples was observed.

Overall, the results highlight the need to change the paradigm regarding these by-products – from “waste” to “valuable resource”. Their utilization through the development of innovative food ingredients, functional additives or cosmetic raw materials could simultaneously contribute to reducing food waste, increasing the economic efficiency of the canning industry and creating value-added products.

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