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Assessment of the potential for use post-production residues of cruciferous vegetables within Zero Waste idea

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The aim of the study was to compare the overall total phenolic compounds content and antioxidant properties of spices (oregano, thyme and rosemary) from ecological and conventional cultivation. The antioxidant activity of the obtained spice extracts was estimated with the use of radical tests (DPPH and ABTS), binding and reduction of metal ions, accelerated Rancimat test and based on the spectrophotometric method. The obtained results indicate that spice extracts from ecological cultivation are characterized by a higher, overall total phenolic compound content compared to spice extracts grown in a conventional system. Ecological spice extracts showed better antioxidant properties than conventional spices in most tests. The results of the statistical analysis show a positive correlation between the total content of polyphenols and the antiradical activity of the extracts. The negative correlation was found between the content of polyphenols and the Rancimat test and the chelating activity. It seems that the usage of organic spice extracts in food production could be considered as natural antioxidants, reducing fat oxidation processes to a greater extent than with conventional cultivations.

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1. Introduction

The Zero Waste concept assumes the reduction of unnecessary waste throughout the product life cycle. The International Zero Waste International Alliance standards defines Zero Waste as: "An ethical, economical, effective and future-proof concept whereby people can change their lifestyles and habits to those that mimic natural cycles, where all discarded materials are designed to become resources that can be used by others. Zero Waste means the design and management of products and processes to systematically reduce the amount and toxicity of waste and materials, preserve and recover all resources, and avoid incineration or landfilling. The implementation of Zero Waste will lead to the complete elimination of harmful substances entering the soil, water and air that threaten the health of the Earth, humanity, animals and plants. Population growth, the increase in the food production rate and consumption negatively

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affect the availability of natural resources while generating large amounts of waste. Agricultural production should manage crops and residues in such a way that nothing is thrown away or wasted. Avoidable and unavoidable losses and waste occur in the food system. According to the Food and Agriculture Organization of the United Nations (FAO), waste can be classified as waste and loss. Losses occur during agricultural production and processing, while waste is generated during consumer consumption [23]. Waste reduces the availability of land for agriculture, causing health and environmental damage [24]. The circular economy radically transforms the culture and system of extraction, production and consumption towards a system of restoring and regenerating the value of natural resources, limiting the excessive consumption of raw materials and energy and avoiding unnecessary waste generation [25]. The transition to a circular economy involves various social, economic and environmental spheres that create opportunities for the regeneration, renewal and agri-food industry innovation, protecting resource scarcity [1]. It contributes to reducing the amount of residues in the food chain by improving the efficiency and technology of processing and regenerating natural resources: soil, water resources and reducing carbon dioxide emissions [2]. The problem of counteracting food waste is very difficult, especially when it is necessary to distinguish whether we are dealing with the waste of food or natural resources. Approximately 1.3 billion tons of food is lost or wasted annually from the stages of production to consumption. This limit is very fluid and depends primarily on the intended use of the raw material. In the case of vegetable management, when we talk about food waste, it is necessary to specify at what point it becomes food. According to Regulation (EC) No. 178/2002 of the European Parliament and of the Council of 28 January 2002, "food means any substance or product, whether processed, partially processed or unprocessed, intended or likely to be consumed by humans". Food losses also occur at the processing stage (peeling, cutting) or during technological processes. The industry produces over a million tons of vegetable scraps annually. They are a rich source of dietary fiber, polyphenols, carotenoids, alkaloids and saponins [3], which could be partly used for further production.

Cruciferous vegetables, including broccoli and cauliflower, are eagerly eaten all over the world. The world production of cauliflower and broccoli is estimated at around 26 million tons. The largest producers are China, India, but also the United States with a share of approx. 40.0%, 33.0% and 5.0%, respectively, of the global volume of cauliflower harvest. In Europe, the countries with the largest cauliflower and broccoli production include: Spain, Italy and France, but also Poland and Turkey. According to the data of the Central Statistical Office, in 2022 the total domestic production of field-grown vegetables was estimated at 3.9 million tons, i.e. approx. 3% higher than the production in 2021 [7]. Due to soil drought, the harvest of root and brassica vegetables decreased during the growing season. The cauliflower harvest was 2% lower and amounted to 135 thousand tons. The area of cauliflower cultivation decreases slightly in Poland from year to year. In 2022, this vegetable was cultivated on an area of 5,000 ha, which means a decrease of almost 300 ha compared to the previous year. There is also a trend of reducing the area on which broccoli is grown. In 2022, this vegetable grew in Poland on an area of nearly 4,400 ha, while a year earlier the cultivation area was 450 ha larger [8].

These vegetables are a valuable source of nutrients such as minerals, vitamins and dietary fiber, as well as phytochemicals (e.g. glucosinolates and phenolic compounds) [4, 5, 6, 9]. These vegetables have many beneficial properties, including antioxidant, anti-inflammatory, anticancer, antibacterial, regulating metabolic disorders, neuroprotective and renoprotective ones [10, 11, 12, 13, 14].

According to regulation 178/2002, plants (vegetables) before harvesting are not foodstuffs, while plants left in the fields during harvesting are natural fertilizers. Therefore, in the case of broccoli and cauliflower, all treatments in the field and losses of raw material in this area can be treated as a waste of natural resources. It is estimated that the amount of post-harvest waste is about 45-60% of the total mass of vegetables [15, 16].

The costs of cauliflower production, regardless of whether they are the early or late crops, vary depending on the purpose of the florets (for processing or as a fresh product), the place of production, weather conditions, but also the price of the planting material (seedlings or seeds) or the amount of manual work needed for harvesting and post-harvest packaging [17]. In the industry, mainly as a raw material for freezing, only the florets of broccoli and cauliflower are used. The remaining parts are identified as production waste. If the green parts and cauliflower stalk and broccoli are removed during harvesting and remain in the field, they are not classified as production waste but natural fertilizer. Before the freezing process, these vegetables must be floretized and calibrated. The smaller ones are treated as a by-product, full-fledged frozen outgrades [18]. In order to achieve economic efficiency of production, it is important to maximize the use of raw materials, reduce operating costs and the environmental footprint (carbon and water) of the production process [19]. In plants dealing with freezing vegetables, there is a problem with the formation of frozen full-fledged parts of vegetables, so-called sorting, which are small, shapeless vegetables, fragmented as a result of technological operations, etc. The aim of the study was to determine the percentage of resulting frozen vegetable sorting in relation to the amount of raw material delivered to the plant in order to identify the scale of the problem.

2. Material and methods

The gumming process is carried out in the field to protect the fresh cauliflower rose from yellowing from the sun. The process consists in covering the rose with outer leaves and it is a labor-intensive process that increases production costs. In addition, the cauliflower and broccoli were deprived of some elements (head, leaves, root) that were left in the field. The research material was broccoli and cauliflower presented in Figure 1 intended for retail trade, the so-called fresh product purchased on the Polish market in available retail chains.

Fig. 1. Cauliflower and broccoli purchased in commercial supermarket chain in Poland.

To determine the percentage share of different fractions of cauliflower and broccoli, an analysis was carried out on vegetables divided into 3 fractions. The division was performed manually using a knife for cutting vegetables. Figure 2 shows the view of a cauliflower which was divided into fractions 1 - florets, 2 - stem, 3 green parts – stem and leaves. Broccoli was similarly divided into identical fractions.

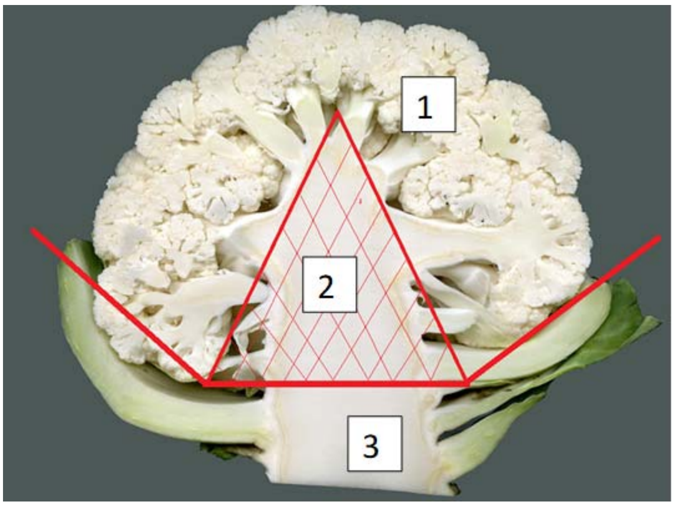

Fig. 2. View of cauliflower divided into 3 fractions

Investigations of individual vegetable mass fractions were carried out using a RADWAG PS 4500\C\2 laboratory balance with a measurement accuracy of 0.01g. The measurement was made for 10 pieces of broccoli and 10 pieces of cauliflower. On the basis of the investigation results, the percentage content of individual fractions was determined and the standard deviation (SD) of the individual masses was calculated. The results of the analyses are presented in Table 1.

Table 1. Percentage share of individual fractions in broccoli and cauliflower

Vegetable	**Fraction 1**	**Fraction 2**	**Fraction 3**
	[%]	[%]	[%]
Broccoli	51 ± 0.02	20 ± 0.02	29 ± 0.01
Cauliflowers	52 ± 0.04	11 ± 0.02	37 ± 0.02

As a result of broccoli and cauliflower division, it was shown that Fraction 1, i.e. florets, accounted for 51% and 52% of the vegetable mass. Fraction 2, i.e. broccoli and cauliflower stalk, was 20% and 11%, and Fraction 3 – green elements was 29% and 37%.

In the refrigeration industry, only broccoli and cauliflower florets (Fraction 1) are frozen and delivered in such a form directly from the grower's field. Data were obtained from a domestic production plant dealing with freezing vegetables on the amount of raw material received, the amount of produced frozen finished product and the amount of produced frozen vegetable outgrades. The data was obtained from the 2017-2022 growing seasons, based on the actual production lists. In the industry, the time of harvesting and processing one type of vegetables is called a "campaign", which for broccoli and cauliflower lasts from September to November. On the basis of the obtained data, the technological loss was additionally calculated using the Formula 1, which is not suitable for further processing and constitutes production waste sent for disposal.

$$U_t = M_p - (M_g + M_p) \quad (1)$$

U_t – technological loss [kg],
M_p – the mass of raw material delivery to the plant [kg],
M_g – the mass of produced frozen broccoli or cauliflower [kg],
M_p – the mass of resulting frozen vegetable outgrades [kg].

The obtained data were expressed in kilograms, but for the purpose of further research, the percentage of the frozen finished product - broccoli or cauliflower, frozen vegetable outgrades and technological loss was determined. The frozen finished product at the processing plant was broccoli florets or cauliflower meeting the quality standards in terms of size. The assorted vegetables are wholesome vegetables, which, due to their shape and size, cannot be used for the production of one-ingredient frozen foods. Technological loss is the total post-production waste, including elements that fell to the ground during the process or were mechanically damaged and cannot be used for food purposes.

3. Results and discussion

Table 2 summarizes the fresh broccoli and cauliflower mass delivered to the processing plant and the percentage of frozen broccoli and cauliflower, frozen vegetables outgrades, technological loss for the years 2017-2022. The raw material mass delivered to the processing plant is in the form of broccoli and cauliflower florets, Fraction 1 (Fig. 1), which is respectively 51% and 52%.

Table 2. Summary of broccoli and cauliflower production data in 2018-2022

Vegetable	**Year of production**	**Mass of raw material delivered to plant**	**Percentage of finished product**	**Percentage of frozen vegetables outgrades**	**Percentage of technological loss**
		[kg]	[%]	[%]	[%]
Broccoli	2018	1 450 114	92.98	5.91	1.11

Vegetable	Year of production	Mass of raw material delivered to plant	Percentage of finished product	Percentage of frozen vegetables outgrades	Percentage of technological loss
Cauliflower		1 635 052	82.7	13.28	4.02
Broccoli	2019	1 492 285	95.62	5.05	0.67
Cauliflower		1 460 960	83.26	11.21	5.53
Broccoli	2020	1 083 166	95.2	5.46	0.58
Cauliflowers		1 443 276	83.37	12.45	4.18
Broccoli	2021	1 216 184	94.54	5.31	0.15
Cauliflower		1 315 318	80.73	17.56	1.72
Broccoli	2022	1 315 318	92.78	5.05	2.17
Cauliflower		1 508 029	83.69	13.03	3.28

The broccoli was delivered to the plant in the amount of 1 450 114 kg and 1 492 285 kg, respectively in 2018-2019. In 2020, the amount of this raw material dropped significantly to 1 083 166 kg. In 2021-2022, the amount of delivered broccoli increased to 1 216 184 and 1 315 318 kg. In 2018-2019, cauliflower was delivered to the plant in the amount of 1 635 052 kg and 1 460 960 kg. In 2020, the amount of this raw material decreased significantly to 1 443 276 kg. In 2021-2022, the quantities of cauliflower delivered were 1 315 318 kg and 1 508 029 kg, respectively. Broccoli and cauliflower delivered to the plant are identified as the raw material used for the further freezing processes. In addition, broccoli and cauliflower as raw materials entering the plant account for 51% and 52% of the mass of fresh vegetables intended for the retail market. The remaining green parts and stalk, which accounts for almost 50%, remain on the field as natural fertilizer. It should be noted that the percentage of parts that remain in the field is definitely higher because fraction division studies were carried out on vegetables available for retail sale. Waste (loss) generated at the harvesting stage was omitted. Research by Liu et al. (2018) showed that the whole mature broccoli mass of the fresh plant is mainly leaves, which accounts for 47%, followed by stems (21%), roots (17%) and florets (15%) [20]. According to the authors [21], broccoli leaves and stems make up about 60%-75% of the vegetable mass and are usually wasted during harvesting. The potential use of stems and leaves would increase the productivity of the world's broccoli crops from 15% to as much as 83%. The authors [20,22] estimated that the amount of post-harvest waste is about 45-60% of the total weight of the vegetables. Table 3 presents the calculated average mass of vegetable losses (waste) from 5 seasons that is generated during the harvesting of broccoli and cauliflower, depending on the percentage of florets in the vegetables.

Table 3. Average mass of losses in field during broccoli and cauliflower harvesting in 2018-2022 depending on percentage of vegetables florets

Vegetable	Mass of raw material delivered to plant	Content of mass loss of vegetables after harvest assuming 50% of florets	Content of mass loss of vegetables after harvest assuming 40% of florets
	[kg]	[kg]	[kg]
Broccoli	1 311 413	668 821	524 565
Cauliflowers	1 472 527	765 714	589 011

The average amount of losses generated in the field is up to 50% (the share of florets is 50%), the mass of these losses after harvest is 668 821 kg and 765 714 kg, respectively, for broccoli and cauliflower.

Assuming, that the amount of losses remaining in the field is up to 60% (the share of florets is 40%), the mass of these losses after harvest is 524 565 kg and 589 011 kg for broccoli and cauliflower. The parts of vegetables remaining in the field could be partly used in the food industry because they contain a large amount of nutrients and bioactive compounds such as vitamins, minerals, fiber and others. When they are produced in the field, they are only a natural fertilizer for future crops.

Table 4. Average value of broccoli and cauliflower products share from frozen food production in 2018-2022.

Vegetable	Percentage of frozen finished product	Percentage of frozen vegetable outgrades	Percentage of technological loss
	[%]	[%]	[%]
Broccoli	93.76	5.31	0.94
Cauliflowers	82.75	13.51	3.75

Table 4 summarizes the average values of the produced frozen broccoli and cauliflower florets, frozen outgrades and technological loss from 5 years of production. On the basis of the research results, it was observed that the broccoli delivered to the plant yields on average 93.76% of the frozen finished product and 5.31% of frozen vegetable outgrades. The technological loss did not exceed one percent. The cauliflower delivered to the plant yields on average:82.75% of the frozen finished product and 13.51% of frozen vegetable outgrades. In the case of this vegetable, the technological loss is much greater and amounts to 3.75%. Analyzing the use of the raw material supplied to the plant, the higher efficiency of the broccoli freezing process and the amount of frozen sort is 5.31%, whereas for cauliflower this value is 2.5 times higher. While these values seem to be small in percentage terms, when compared to the production volume, it occurs that entrepreneurs struggle with tons of vegetables that are wholesome, but due to their size they are classified as outgrades. The high nutritional quality of outgrades was demonstrated in the authors' studies [18, 19].

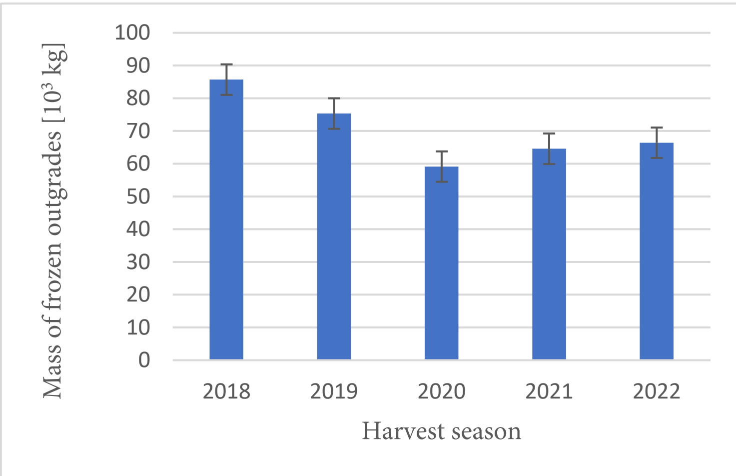

Fig. 3. Mass of frozen broccoli outgrades depending on year for autumn harvest season

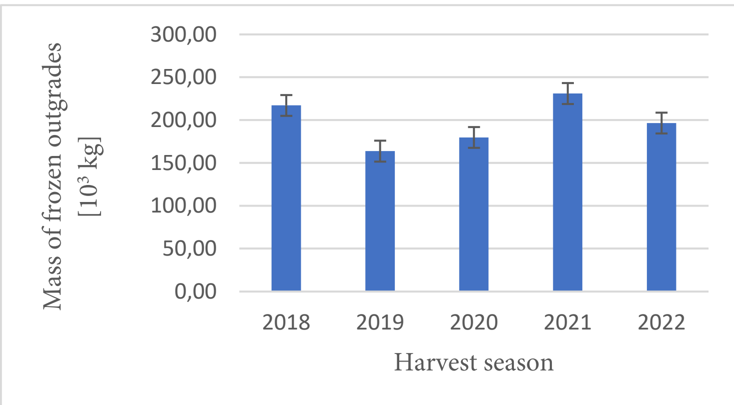

Fig. 4. Mass of frozen broccoli outgrades depending on year for autumn harvest season

Figures 3 and 4 show the average weight of frozen vegetables from the autumn harvest. It should be noted that in the case of cauliflower, the sort obtained is an average of 197.6 tons, and in the case of broccoli, it is an average of 70 tons. These are significant quantities for which entrepreneurs are willing to look for new applications. The lack of alternatives for its management will be associated with increasing the production costs and its profitability (including environmental costs), and for the consumer with a relative increase in the price of the finished product.

4. Conclusions

Agriculture and the food sector face numerous economic, social and environmental challenges. They are not only an expression of social pressure resulting from the general need for sustainable development, but also respond to specific expectations, e.g. in the field of ensuring food security, the use of agricultural raw materials for industrial and energy needs, waste management or preserving the natural environment. Food waste can occur during processing, packaging, shipping and retailing. The production of cauliflower and broccoli for industrial purposes is mechanized and the floretization of cauliflower and broccoli takes place in the field, which reduces the unit production costs.

Morphologically, broccoli and cauliflower can be divided into 3 parts, including the rose, stem and green parts. Currently, the most desired part of these vegetables are the florets. Broccoli florets or broccoli sprouts are usually used for consumption, while other parts such as the stems and leaves are wasted during harvesting. The potential ingestion of the stems and leaves would increase the productivity of the process. Although they are used, information on the nutritional benefits and compounds promoting human health is still limited; nevertheless, new trends in their use in cooking can be observed in recent years.

The frozen vegetable assortment created in the freezing broccoli and cauliflower process is an enormous technological problem for plants. This raw material is partly used for the production of mixed vegetables, but the demand for such products is limited. Production plants are looking for new solutions for their development. One of them is the use of vegetables for producing vegetarian burgers, vegetable spreads or freeze-dried bars. Responding to the needs of industry, the project developed technologies for vegetable outgrades development and a prototype line for burger production. The work was carried out as part of the project entitled: "Development of an innovative method for calculating the carbon footprint for the basic basket of food products" Agreement No. BIOSTRATEG3/343817/17/NCBR/2018, co-financed by the National Center for Research and Development under the program BIOSTRATEG III.

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