Utilization of plant processing wastes for enrichment of bakery and confectionery products

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Abstract

Introduction. In this mini-review some technologies proposed by Ukrainian scientists for utilization of plant processing waste to enrich bakery and confectionery products are present.

Material and methods. The use of cereal, vegetable, fruit and oil processing wastes in the manufacturing of bakery and confectionary products was proposed. The effects of partial replacement of wheat flour with plant additives on technological parameters and sensory characteristics of food products are described.

Results and discussion. Partial replacement of wheat flour with plant additives allowed to increase nutritional value of food products. Thus, replacement of wheat flour with 5–20% of pumpkin seed flour resulted in an increase of protein content by 13.9–55.5% and fiber content by 12.07–48.7% in bread in comparison with control one without additives. Replacement of wheat flour, 5–15%, with pumpkin cellulose increased the content of protein 1.1–1.4 times and dietary fiber in 1.4–2.2 times in comparison with control bread. Bread supplemented with oat bran, 5–15% instead of wheat flour had higher by 19.5–52.2% score of lysine than bread without plant additives. Waste from grape processing containing protein, lipids, fiber, minerals and polyphenols, could be successfully used in preparation of flour-based confectionery products. Grape seed powder could serve as a substitute of cocoa powder in confectionery coatings technologies. Grape seed cake powder and grape skin powder being used for partial replacement of wheat flour in biscuits enriched the product with dietary fiber, polyphenolic compounds, minerals and vitamins. Addition of flour from extruded sunflower seed kernels in preparation of gingerbread allows to enrich it with valuable nutrients and improve its technological characteristics.

Conclusions. Wastes from the processing of plant materials contain valuable substances and can be used in the preparation of functional products. It is essential to maintain and preferentially increase the high quality of products; thus, it is necessary to replace wheat flour with a plant additive in amounts not exceeding 10%.

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Introduction

Processing of plant materials generates a large amount of waste with a high content of valuable substances, which with common improper deposition causes nowadays pollution of the environment. Meanwhile, these wastes can be a source of useful compounds such as proteins, dietary fiber, lipids, starch, minerals, vitamins and antioxidants. The Food and Agriculture Organization of the United Nations declares that reducing food waste is an important way for increasing efficiency of the food system and for contributing to environmental sustainability (FAO, 2019).

In Ukraine, the agricultural sector is quite developed and there is a wide range of plant products, the processing of which generates a significant amount of waste. This mini-review aims to describe some technologies that are being developed in Ukraine for the use of plant processing waste in food production to protect the environment from potential pollution by minimizing the waste itself, and by increasing the nutritional value of food products, supplemented with additives based on these wastes; this strategy may be useful in other regions of the world as well.

These technologies are presented in more detail in the books of the series Food Biotechnology and Engineering published by CRC Press, Taylor & Francis Group in 2022 and 2023 (Figure 1).

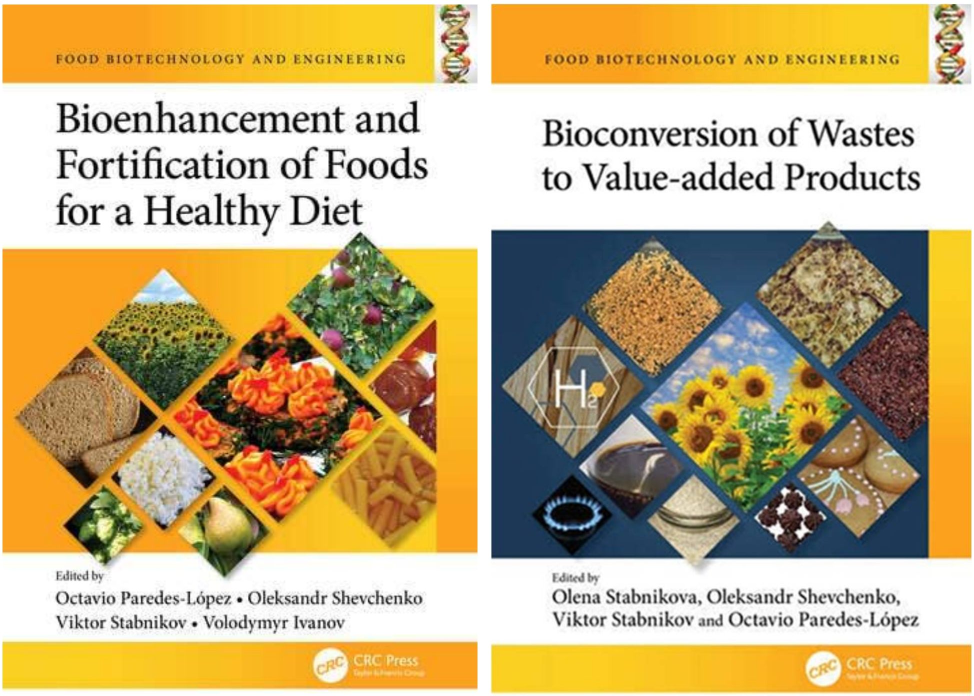

Figure 1. Books "Bioenhancement and fortification of foods for a healthy diet" (https://doi.org/10.1201/9781003225287) and "Bioconversion of wastes to value-added products" (https://doi.org/10.1201/9781003329671).

Utilization of plant processing wastes in bakery products

Ukraine ranks third in the world in growing pumpkins with 1 346 160 tons of production per year (Atlas Big, 2023). Processing of pumpkin (*Cucurbita pepo*) generates a large amount of waste including seeds and peels. Pumpkin seeds could serve as a source of proteins, carotenoids, minerals, dietary fiber, omega 3 and omega 6 fatty acids, and polyphenols, and all these substances turn into seed flour, which is characterized by high biochemical, nutritional, and functional properties (Stabnikova et al, 2021; Vinayashre et al., 2021). Pumpkin seed flour contains 3.8 times more protein and 3.5 times more fiber than wheat flour (Figure 2, Table 1).

Replacement of wheat flour with 5–20% of pumpkin seed flour resulted in an improvement of nutritional value of final bakery products due to increase of protein content by 13.9–55.5% and fiber content by 12.07–48.7% as compared with control bread without additive (Shevchenko et al., 2022). However, as the size of particles in pumpkin seed flour is much larger than wheat ones, the change of the structural and mechanical properties of dough and bread prepared from the flour mixture is predictable. Pumpkin seed flour has 1.5-fold higher water absorption capacity than wheat flour, and the viscosity of the dough prepared with replacement of 5-20% of wheat flour with pumpkin seed flour increased by 3.8—15.3%, respectively. The gas forming capacity of dough with pumpkin seed flour added to replace wheat flour from 5 to 20% decreased by 1.9–7.4%, which can be explained by the formation of protein complexes of pumpkin seed flour with wheat flour starch, which reduces its availability to amylolysis and resulted in a decrease of fermentation activity of yeast and decrease of the amount of formed sugars by 7.6–16.2% depending on the amounts of pumpkin seed flour. Finished product had crumbs with slightly increased acidity, specific volume decreased by 3.6–38.4% whereas porosity decreased by 1.4–4.1%; changes likely due to swelling of pumpkin fiber (Pereira et al., 2018). However, the bread did not change its shape. Sensorial analysis showed improvement of taste and smell of bread, which acquired a pleasant pumpkin hue. The bread crumb was elastic and well fluffed. Authors recommended 10% replacement of wheat flour with pumpkin seed flour, as this percentage does not cause any technological changes but provides an increase in the nutritional value and sensory properties acceptable to consumers of bread (Table 2).

Pumpkin cellulose is obtained after oil extraction from pumpkin seed flour (Atuonwu and Akobundu, 2010). The defatted mass is ground, sieved, and dried. The final product is a greenish flake with an average size of 0.67 mm, which contains 4.0 times more protein and 9.1 times more dietary fiber than wheat flour (Figure 1). The content of amino acid lysine in pumpkin cellulose is 1.35 g/100 g, meanwhile in wheat flour it is only 0.23 g/100 g (Shevchenko et al., 2023). Replacement of wheat flour, 5–15%, with pumpkin cellulose allowed to increase the content of protein 1.1-1.4 times and dietary fiber in 1.4–2.2 times in comparison with control bread prepared from wheat flour only (Table 2). A portion of 277 g of wheat bread represents a recommended daily intake, for the Ukrainian population (Stabnikova et al., 2023), 29% of the need for dietary fiber, but bread with 15% replacement of wheat flour with pumpkin cellulose increases this percentage to 65. Meanwhile, bakery products enriched with fibers are useful in the diet for people with diseases of gastrointestinal tract, especially irritable bowel syndrome (Loponen and Gänzle, 2018). Replacement of 5–15% of wheat flour with pumpkin cellulose reduced gas forming capacity of dough by 10.5–12.5% and the specific volume of bread by 7.7–41.0%, porosity and shape stability were also negatively affected, and at the end caused the greenish shade of the crumb and crust of the bread as well as pumpkin taste and aroma. So, to produce bread with high quality, replacement of wheat flour with pumpkin cellulose should not exceed 7%.

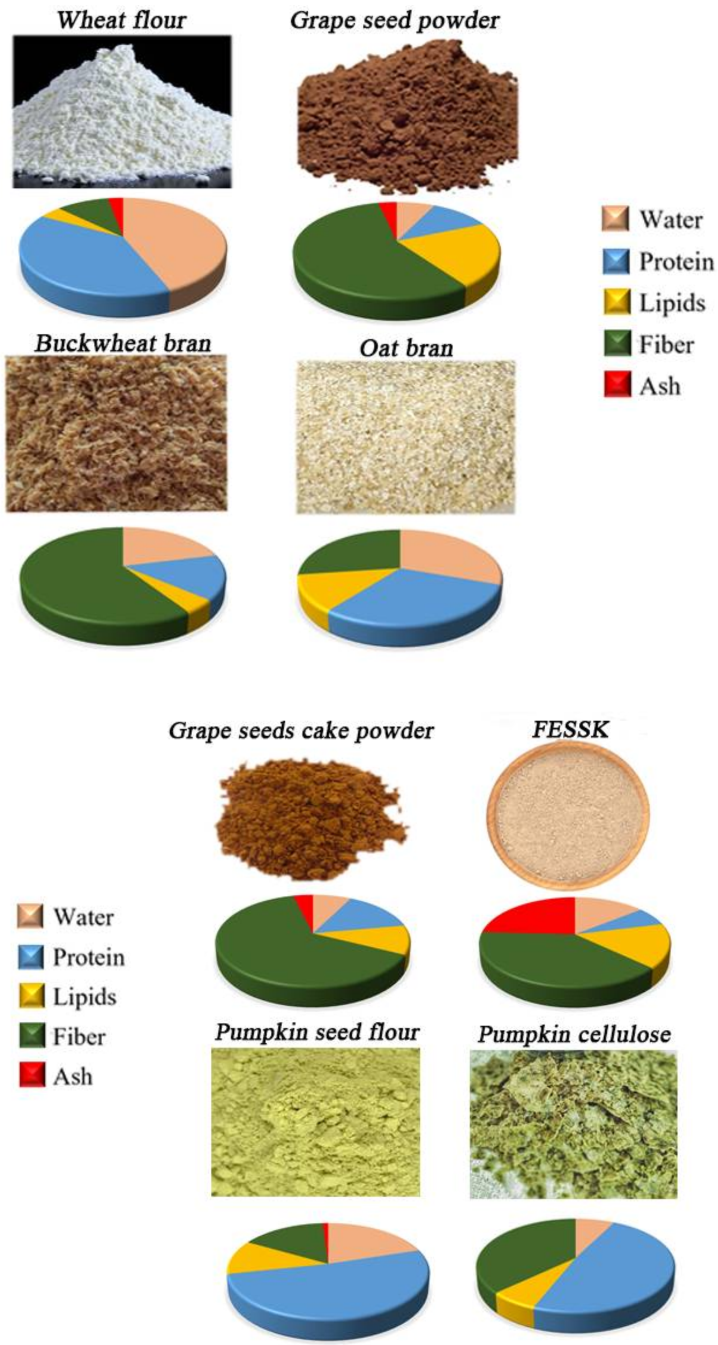

Figure 2. Chemical composition of plant processing wastes, g/100 g (wet basis)
(Grevtseva et al., 2023; Shevchenko, 2023; Shevchenko et al., 2022; Tsykhanovska et al., 2023).

Table 1

Chemical composition of plant processing wastes, g/100 g (wet basis)

Component	High grade wheat flour	Bran		Pumpkin		Grape powder		FESSK*
		buckwheat	oat	seed flour	cellulose	seed	cake	
Water	11.5-14.3	15.0±0.1	17.3±0.1	15.6±0.1	6.4±0.1	6.0±0.4	6.0±0.4	4.7±0.2
Protein	10.3±0.1	10.8±0.1	17.0±0.1	40.0±0.3	42.0±0.2	9.5±0.5	11.80±0.5	2.3±2.1
Lipids	1.1±0.1	3.2±0.05	7.0±0.1	9.0±0.1	6.0±0.2	18.1±0.9	8.26±0.3	5.3±0.3
Fiber	2.6-3.5	42.1±0.1	15.4±0.1	12.2±0.1	32.0±0.1	47.1±2.2	51.3±2.5	12.9±0.7
Ash	0.75	N.D.**	N.D.	0.8±0.0		2.9±0.1	3.10±0.1	8.0±0.4

*FESSK is flour from extruded sunflower seed kernels, **N.D., not determined.

Table 2

Production of food products using plant processing wastes

Food product	**Plant waste**	**Amount and technological stage, effects**	**Reference**
Bakery products			
Wheat bread	Pumpkin seed flour	Replacement of wheat flour, 10%, increased protein content by 27.8%, fiber content by 12.5% and improved taste and aroma	Shevchenko et al., 2022
	Pumpkin cellulose from defatted pumpkin seeds	Replacement of wheat flour, 7%, increased protein content by 20.7%, fiber content by 57.0% and allowed to obtain high quality bread	Shevchenko et al., 2023
	Oat bran, waste from oat milling	Replacement of wheat flour, 7%, increased protein content by 4.4%, fiber content by 23.8% and allowed to obtain high quality bread	
Bakery product with fructose	Buckwheat bran, waste from buck wheat milling	Addition in the amount of 7.3% to the wheat flour increased fiber content by 14.0% and allowed to obtain high quality bread	Shevchenko, 2022
Flour confectionary			
Cookies, gingerbread, and waffles	Grape seed powder from grape pomace, waste of winemaking	Replacement of cocoa powder, 20%, in coating helps better preservation of test and aroma, an increase of shelf life from 8 to 12 months	Grevtseva et al., 2023
Butter biscuits	Grape skin powder, waste of winemaking	Replacement of wheat flour, 16%, increased content of dietary fiber in 81.7, vitamin PP in 2.4, magnesium by 3.4, iron by 4.2 times and allowed to better shape preservation	
Gingerbread	Flour from defatted (in an extruder) sunflower seed kernels	Replacement of wheat flour, 10%, reduced the time of formation of gingerbread dough by 1.8 min, heat treatment losses by 1.15 times, increased protein content by 84.3%, decrease carbohydrate content by 11.6%	Tsykhanovska et al., 2023

Wastes from the cereal processing industry are often underestimated, but they contain valuable chemical compounds, in particular a high content of proteins and dietary fibers (Ivanov et al., 2021; Safaripour et al., 2021). Cereal bran, a main by-product from grain milling, has often been used as animal feed, but more often is discharged. For example, wheat bran consists form 14.5 to 25% of wheat (*Triticum aestivum* L.) grain, but only 10% of it is used in bakery and in breakfast cereals (Safaripour et al., 2021). One of the reasons that such wastes still remains underutilized is the lack of easy-to-use techniques for processing and application.

Oat bran, which is obtained as waste after processing oat (*Avena sativa* L.) into flour, has a creamy color, and consists of small particles with an average size of 0.44 mm (Figure 1). It contains 1.6 times more protein and 4.4 times more dietary fiber than wheat flour, and a significant amount of the amino acid lysine, 0.76 g/100 g (Shevchenko et al., 2023). The replacement of wheat flour with oat bran, 5–15%, allowed to increase the amino acid score of lysine in bread by 19.5–52.2%.

A portion of 277 g of bread with 15% replacement of wheat flour with oat bran ensured consumption of 44.4% of the daily need for dietary fiber. However, a high amount of soluble dietary fibers and β-glucan in the composition of oat bran may lead to an increase of effective viscosity of aqueous solutions. The infrared spectra of the dough at a wavelength of 2100 nm showed that the presence of the dietary fiber of oat bran delays the development of the gluten network, and the structure of the protein matrix of the dough with bran will be less stable and more weakened than that of the control sample (Shevchenko and Litvynchuk, 2022). This is in agreement with Wang et al. (2017) results, who showed that an excess of oat bran caused a decrease of processing characteristics of dough and reduced its stability.

In the same time, replacement of 5–15% of wheat flour by oat bran led to a decrease in gas forming capacity of dough compared to the control by 1.8–10.2%, and a decrease of specific volume of bread by 0.0–25%, and porosity by 4–14%. Meanwhile, sensorial properties of bread assessed on a scale of 0 to 100, with 100 being the best quality, showed that bread with wheat flour replacement by 5 and 7% with oat bran had 97.4 and 96.2 points, which is almost the same as for control, 97.2 points. These observations are consistent with those obtained by Astiz et al. (2023), who used oat bran as supplement to wheat flour up to 25% of weight and produced breads of good technological quality.

Buckwheat bran, a byproduct of buckwheat (*Fagopyrum esculentum*) milling, shows brown particles with an average size of 0.53 mm (Figure 1). The content of fiber in buckwheat bran is 16 times higher than that in wheat flour. Addition of buckwheat bran to wheat flour, in quantities of 7.3, 10.9 and 14.6% provides 20, 30 and 40% of the recommended daily amount for dietary fiber by consuming 277 g of bread (Shevchenko et al., 2022).

Introduction of buckwheat bran in the recipe of wheat bread resulted in an increase of total gas formation during fermentation from 1276 to 1334 cm^3 of CO_2/100 g of dough in comparison with 1192 cm^3 of CO_2/100 g of dough in the control, which indicates an intensification of the fermentation activity of yeast.

Meanwhile, addition of buckwheat bran led to change of structural and mechanical properties of dough, which augmented its water absorption capacity, duration of formation, springiness and extensibility, and decreased elasticity and stability. Interestingly, at the dosage of buckwheat bran of 7%, related to weight of wheat flour, all parameters were almost the same as for control. Thus, addition of buckwheat bran in an amount of 7% to wheat flour allowed to increase nutritional value of bread while keeping its high quality.

Utilization of plant processing wastes in confectionery products

Grapes (*Vitis vinifera*) are one of the world's largest fruit crops with production of 73.5 million tons in 2021 (Statista, 2023a). Approximately 75% of produced grapes is used in wine-making, and 25 – 30% of this amount is waste (Beres et al., 2017). This waste called grape or wine pomace includes seeds, skins, pulp residues and stalks (Antonićet al., 2020). Waste from wine production is used as fertilizer or animal feed, but very often it is left in open fields causing environmental pollution (Dwyer et al., 2014). Meanwhile, grape pomace has valuable chemical composition and in recent years there is a lot of research considering its application as an ingredient in the food production (García-Lomillo et al., 2017).

Flour-based products, the most popular and the most frequently consumed ones among the confectionery, have high energy value due to containing ~~of~~ wheat flour, sugar, and fat, meanwhile their nutritional value is low (Oručević Žuljević and Akagić, 2021). Thus, these products are needed to be enriched with ingredients that have high biological value. In Ukraine 124.2×10^3 tons of grapes were used for production of wine in 2019 generating 3.7 x10^3 tons of seeds, and 12.1×10^3 tons of skins (Osipova et al., 2021). Application of grape seeds and skin, containing protein, lipids, fiber, minerals and polyphenols, in preparation of flour-based confectionery products, were proposed (Grevtseva et al., 2023). Three value-added products from grape seeds and skin were produced. Grape seeds and skin were separated, then dried at temperature of 60 ºC and then grinding to obtain grape seed powder (particles with size 20–30 µm), and grape skin powder (particles with size 30–50 µm). A third byproduct, grape seed cake powder, was obtained from grape seed powder by cold pressing to produce grape oil followed by grinding to particles with a 20–30 µm size.

Grape seed powder was proposed as a substitute of cocoa powder, which is traditionally used in confectionery coatings technologies. Confectionary coating is made from sugar, fat, cocoa powder, emulsifiers (lecithin), stabilizers, flavoring substances (vanillin), and powder milk, which largely determines the appearance of the flour confectionery products. Altogether, coating reduces the rate of fat oxidation, could improve the product flavor and taste, and enhances product nutritional value. It was shown that chemical compositions of grape seed powders are richer with polyphenols, dietary fiber, minerals, and vitamins than cocoa powder. Thus, grape seed and grape seed cake powders contained total phenols 1.8 and 2.0 times, fiber 1.1 and 1.2, and vitamin PP 1.5 times higher than cocoa powder, respectively. Amounts of B-group vitamins (thiamine, riboflavin, and pyridoxine) were also higher in grape powders. In addition, they contain vitamin B12 (cobalamin), which is completely absent in cocoa powder. It has been shown that the replacement of 20% cocoa powder with grape seed powder increases the stability of the finished product during storage by suppressing fat oxidation and microbial activity due to the increased content of polyphenols in the coating. Cookies, gingerbread and waffles with coating with grape seed powders crumbled less and were characterized by better preservation of taste and aroma, as well as an increased shelf life due to inhibition of oxidation and hydrolysis of fats.

Grape seed and grape skin powders were used in preparation of butter biscuits, which have as main components wheat flour, butter, and sugar; thus, they contain a lot of fat and carbohydrates and few bioactive compounds. Partial replacement of wheat flour with grape seed cake powder, 20%, or grape skin powder, 16%, enriches the product with dietary fiber, polyphenolic compounds, minerals and vitamins (Table 2) (Grevtseva et al., 2023). Plant additives were added during the emulsification step with oil as antioxidants. Addition of plant supplements did not change physicochemical and sensorial properties except the colors, which changed from golden to chocolate in case of grape seed cake powder, and chocolate with a purple tint in case of grape skin powder applications. Meanwhile, the content of the dietary fiber with the addition of grape seed powder increases from 0.3 to 31.2%, and grape skin powder from 0.3 to 24.5%. Incorporation of grape powders in dough ensured its texture; strengthening resulted in increased stability during the formation of biscuits and a better preservation of their shape.

Ukraine is the world's leading exporter of sunflower (*Helianthus annuus*) oil, which produced 4.08 million tons of sunflower oil in 2022/2023 (Statista, 2023b). After extracting oil from sunflower seed kernels in an extruder, the remaining cake is grinded to obtain a fraction with a particle size of 350–400 microns, used as animal feed, and a fraction with a particle size of 90–110 microns can be used in flour confectionery (Tsykhanovska et al., 2023). This fraction, flour from extruded sunflower seed kernels (FESSK), has low moisture content, 4.7%, which will protect it from rapid mold development during storage. It contains 4 times more protein, 5 times more fat and fiber than wheat flour. The content of unsaturated acids in FESSK fat is 84.78±4.18% from total fatty acids, and the main acids are linoleic, C18:2(ω-6), 65.05%, and oleic, C18:1(ω-9), 19.32%. FESSK could be used in flour confectionery for partial replacement of wheat flour. High soluble protein content, 32.31 g/100 g of FESSK, ensures its emulsions properties and helps in foam stabilization. Thus, replacing 10% of wheat flour with FESSK in the recipe of traditional gingerbread resulted in improving technological parameters, for instance by increasing viscosity and improving emulsification and gelation of the four systems. The amount of bound water in gingerbread with FESSK increased by 20% which allows improving wetting by 20%, chewing by 11%, crumbling by 33% and prolonging the shelf life of the final product. Incorporation of FESSK in wheat flour resulted in activation of biochemical processes that leads to decrease density, increase porosity, and improvement of texture of the gingerbread. Altogether with higher quality properties, gingerbread enriched with FESSK had higher contents of protein, minerals and fiber (Table 2). Thus, the use of secondary products from the sunflower oilseed industry in preparation of flour confectionery allowed to convert waste to value-added products increasing their nutritional and sensory characteristics and it is in line with an eco-friendly strategy for organic waste minimization.

Conclusions

Food waste is a big global challenge and its reduction is a way to a better preservation of food resources, protection of the natural environment, and at the same time increasing the productivity of the food system. Meanwhile, plant processing waste, which is usually disposed of or partially used for animal feeding, contains valuable substances that can be involved in preparation of different food products, particularly in bakery and confectionery. This strategy is especially relevant for regions of the world with developed agriculture systems.

It was shown that different wastes from cereal, fruit, and vegetable processing such as oat and buckwheat brans, pumpkin flour, and pumpkin cellulose could be successfully used in production of bakery goods by increasing their nutritional value and functionality; meanwhile waste from winery and oilseed could find their application in confectionary. It is essential to maintain and preferentially increase the high quality of products; thus, based in different previous studies, it is necessary to replace wheat flour with a plant additive in amounts not exceeding 10%.

In brief, future research should involve the importance of increasing the level of plant wastes while producing new food products of high quality and high level of acceptability.

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