CHAPTER 12

Use of asparagus waste to fortify bakery products

Olesia Priss
Kateryna Kostetska
Pavlo Bulhakov

Abstract

The modern industry of food production faces constant challenges, raised by growth of population, global environmental changes and high impact of geopolitical factors on the food supply chains. Sustainability in processes of food production and distribution is crucial for food security and rational management of valuable natural resources. High losses, especially in perishable crops like asparagus (up to 50% of the total production), are serious issue, which demands development of new approaches to reduce and rationally utilize the waste.

Asparagus is a highly valuable and popular vegetable crop. However, it rapidly loses its commercial quality due to the high level of metabolism in the spears, which contributes to significant product losses during processing and storage. Up to 20% of spears are additionally wasted due to the trimming during the storage, which contributes significantly to the production losses.

The chapter of the monograph is dedicated to the possibility of utilization of waste from asparagus processing for enriching food products, namely bakery products. The basal parts of asparagus spears, which are usually utilized, were proven to contain high amount of the phenolic compounds. The elemental analysis of the freeze-dried asparagus powder showed presence of many valuable microelements and high quantities of protein, which make such powder a valuable dietary supplement. A series of bread recipes in which part of the flour was replaced with the obtained asparagus powder was tested to produce bakery products with enhanced biological value. Four types of low-carbohydrate flours were tested (whole-grain spelt and quinoa, flaxseed, and amaranth), to which asparagus powder was added in various proportions. The bread produced using these new recipes was evaluated based on its physicochemical characteristics and organoleptic properties. It was shown that

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adding asparagus powder (5–10%) to amaranth, quinoa and flaxseed flour helped retain the shape of produced bread, reduced crumb moisture and facilitated uniform porosity, though did not provide positive impact on the organoleptic properties. At the same time, bread made with whole-grain spelt flour and up to 10% replacement with asparagus powder met all requirements for each of the indicators. These experimental results thus justify the replacement of up to 10% of spelt flour with asparagus powder to enhance the nutritional value of the product.

The use of asparagus powder in the bakery, therefore, allows for the reduction of food waste, the enhancement of product nutritional value through the inclusion of micronutrients, proteins, and antioxidants, and the expansion of the range of bakery products, including options for consumers with low-carbohydrate or gluten-free dietary needs.

Keywords

Asparagus, storage waste, vegetable powder, bread, food product enrichment.

12.1 Introduction

In the face of challenges currently confronting humanity due to global environmental changes and disruptions to established food supply chains caused by geopolitical factors, the importance of optimizing models of consumption and production cannot be overstated. Pursuit of active development of sustainable food production and rationalization of all processes in its chain is reflected, e.g. in Goal 12.3 of the United Nations Sustainable Development Goals for 2030, which aims to halve per capita food waste and reduce food losses along supply chains [1].

In modern supply systems, food losses still occur at all stages, from cultivation and storage to processing and consumption. The dominance in the structure of these losses is firmly held by fruit and vegetable waste. Although the global trend of increasing fruit and vegetable consumption has boosted their production over the last decade, annual losses of these products still reach 40 to 50% of the total harvest. Such high amounts of wasted material results in financial losses for all participants in the supply chain, from producers to consumers, as well as irreversible and wasteful losses of natural resources used during production. Therefore, rationalizing the processes of storage and transportation of plant-based products as well as development of strategies of smart utilization of wasted material, are extremely important for creating stable food systems and ensuring food security.

High losses during the storage of fruits and vegetables are caused by their low resistance to mechanical damage, high moisture content (75–95%), intense gas exchange, and active post-harvest metabolism. In the case of Asparagus, a plant with high metabolic activity, waste can account for up to 50% of the total amount [2].

Asparagus (*Asparagus officinalis L.*) is one of the most popular vegetable crops in the world due to its taste, nutritional value, and high content of valuable phytonutrients. Thanks to the rapid growth in demand over the past 35 years, asparagus production worldwide has increased 5.5 times, and in Europe, it has doubled. In Ukraine, asparagus has traditionally been used rather as an ornamental plant, however, with the growing trend of healthy diets and the globalization of culinary preferences, it becomes popular among Ukrainians, stimulating farmers' interest in cultivating it.

Asparagus owes its global popularity to its valuable dietary properties and the presence of diverse biologically active substances [3]. It contains phenolic compounds, tannins, flavonoids (e.g., rutin, kaempferol, quercetin), anthocyanins, steroidal saponins, dietary fibers, carotenoids, chlorophylls, and sterols [4]. These compounds influence metabolic and regulatory processes, contributing to asparagus's pharmacological effects, such as antioxidant, antitumor, antidiabetic, hypoglycemic, hypolipidemic, antiepileptic, and immunomodulatory activities [3]. Asparagus proteins provide majority of essential amino acids, with asparagine and glutamine dominating, accounting for 40–43% of total amino acids, and exceeding the relative content found in animal-based products [5]. The spears are also rich in vitamins, including folic acid, phylloquinone, and tocopherol. Additionally, asparagus contains high levels of minerals such as potassium, calcium, and iron [3]. Introducing into diets products with high amounts of biologically active substances and phytonutrients, such as asparagus, may help to combat so-called "hidden hunger" – multiple micronutrient deficiencies caused by consuming an energy-dense, but nutrient-poor diet [6, 7].

Asparagus is primarily consumed fresh, but processed products, including canned and frozen asparagus, are also in demand, especially in Asian markets, where they are more traditional. Due to the high nutritional value and health benefits of asparagus, there is ongoing research to develop new products based on asparagus that retain the maximum amount of biologically active substances for market introduction [8, 9]. For example, in recent years, methods for freezing asparagus with pre-blanching, canning, and producing juices, teas, wines, vinegar, yogurt, and other fermented products, as well as recipes for pasta made from dried asparagus, have been patented in China [3]. Powders made by drying asparagus spears are used as food additives due to their high content of dietary fiber and biologically active substances [2, 3]. Extracts, powders, and juices from asparagus are widely used not only in food applications but also in medicine, cosmetology, and plant tissue culture. To utilize asparagus production waste, technologies are being developed for extracting enzymes, certain biologically active substances, and even producing cellulose nanocrystals [3, 10, 11].

The asparagus growing season in Ukraine is fairly short – from the last decade of April to early June. The edible part consists of young asparagus spears measuring 15–22 cm in length and up to 2 cm in thickness. These are the young parts of the plant with a high level of respiratory metabolism, and the respiration rate increases immediately after harvest due to wound stress [12]. Consequently, harvested asparagus spoils quickly: the shelf life of cut spears is 3–5 days at room temperature and 14–15 days when stored in a refrigerator [13]. Moreover, if canned, only the upper 15 cm of the asparagus spear is used, while the rest (up to 15–18 cm) is discarded as waste. At least 20% of edible asparagus parts are thus disposed during commercial processing, storage, and post-storage preparation. During preparation for storage or sale, initial processing of asparagus spears involves trimming the lower ends of the spears to create uniform bundles of standard height. The trimmed sections (usually about 2 cm) are classified as waste, furthermore, asparagus cuts are also refreshed after storage by additional trimming the dried portion to maintain the commercial appearance. Extending the shelf life of asparagus and reducing waste in the harvested products, can contribute to improving the availability of this valuable food product, enhancing nutritional diets, and reducing the burden on ecosystems.

Fruit and vegetable waste are often composted or used as organic fertilizer for soils, as well as for animal feed. At the same time, given the significant content of antioxidants, phenolic compounds, and other biologically active substances, asparagus waste represents a promising source of biologically active compounds and raw material for the creation of value-added products.

Our recent research, focused on the evaluation of asparagus processing waste as raw material for obtaining phytonutrients, confirmed, that basal parts of spears of asparagus varieties, cultivated in Ukraine (namely, Rosalie and Prius), contain high quantities of phenolic compounds [14]. In the study, phenolic content was analyzed for the whole asparagus spears, waste that was generated during preparation for storage, whole spears after the storage period, and waste generated during preparation for sale after storage. Phenolic compounds are of particular value in asparagus processing waste, since they are natural antioxidants, valuable for tissue protection. According to our observations, in the basal parts of asparagus spears, which are considered waste, content of phenolic compounds is 20–27% lower, if compared to thus in whole spears. Nevertheless, the total phenolic content in such waste remains relatively high: 74.77 mg/100 g in the Prius variety and 67.73 mg/100 g in the Rosalie variety. Additionally, no significant differences in the basal parts of asparagus (classified as waste) were observed before and after storage [14]. Therefore, asparagus waste from both studied varieties, Prius and Rosalie, can serve as a good source for obtaining polyphenolic compounds.

In addition to biologically active substances of phenolic nature, asparagus spears (including their basal parts) can also serve as a source of other valuable compounds, such as fiber, proteins and microelements. According to literature, the powder obtained by drying asparagus retains most of the heat-stable components and is therefore considered a promising food additive [10, 11]. The possibility of using it as an additive in various food products is currently the subject of active research [2, 3]. In this chapter, let's investigate the potential of asparagus-derived powder as an additive to the bread and bakery products. It is important to note, that such an additive can be obtained from otherwise wasted material during the asparagus harvesting stage without additional investments in crop cultivation, which highlights the cost-effectiveness of the approach.

Currently, the demand for bread is shaped by various target consumer groups. While some consumers are primarily guided by the cost and organoleptic properties of the product, other categories are increasingly focused on healthy eating and choose bakery products based on their high nutritional qualities, including dietary, taste, and aesthetic characteristics. Responding to these trends and aiming to attract specific audiences, manufacturers are experimenting with innovative recipes, particularly by adding functional ingredients.

The biological value of bakery products is often enhanced by incorporating alternative flours into the dough recipe instead of wheat flour [15]. For example, spelt flour (a species of wheat) has a high protein content (about 14–15%), which is comparable to that of wheat, but it is also rich in B vitamins, magnesium, iron, and fiber, and is better digested than regular wheat flour [16]. Spelt flour has a reduced gluten content but is not suitable for people with celiac disease due to its presence. Spelt flour is well-suited for baking bread, cookies, and pies, although it may be less elastic. Flaxseed flour has a very high fiber and omega-3 fatty acid content but low carbohydrate content, making it ideal for low-carb diets. It is also rich in lignans, antioxidants, and protein (about 35%), but due to its low starch content, it does not form dough structure and can only be used as an additive to other flours (10–20%) [17].

Amaranth flour also has a relatively high protein content, is rich in the essential amino acid lysine, as well as iron, magnesium, calcium, and B vitamins. It is suitable for gluten-free diets [18], but it has a strong, specific taste that can dominate and does not hold dough structure well [19]. Quinoa flour is also high in protein (similar to amaranth flour, with a protein content of about 14–15%), contains all essential amino acids, and is rich in fiber, antioxidants, B vitamins, and minerals (magnesium, zinc). It is gluten-free, but if improperly processed, it can have a bitter taste. Due to the absence of gluten, the structures of amaranth and quinoa flours are weak, making them suitable for cookies and pancakes, but they must be mixed with other flours for bread production [20]. Compared to wheat flour, the described types of flour contain more protein (significantly more in the case of flaxseed flour) and fewer carbohydrates [15, 20]. Due to the lower gluten content or its absence, as well as insufficient starch content, these flours cannot fully replace wheat flour in bakery products and must be combined to achieve the proper dough structure [20].

Adding asparagus powder to such alternative flours, according to our assumptions, can partially compensate for the lack of gluten due to its rich protein composition. This could positively influence achieving the necessary parameters for bread baking while also enriching the bakery product with microelements, proteins, and biologically active substances. Such enrichment could be particularly valuable for consumers requiring gluten-free and low-carbohydrate diets.

12.2 Methods of research

The studies included were conducted with asparagus spears of the Prius and Rosali varieties, harvested in accordance with the requirements of CODEX STAN 225-2001 [21]. The basal parts of asparagus spears were freeze-dried to produce a powder. The raw material was pre-frozen at a temperature of –40°C. After the freezing phase was completed, the samples were placed in the chamber of a freeze dryer (model: CC-02, Sublimat, Ukraine). Drying was carried out at a chamber pressure of 15 Pa. The process consisted of two main stages. Primary drying, aimed at removing unbound moisture at a temperature of +5°C for 15 hours. Final drying, performed at +40°C for 20 hours. After the drying process was completed, the samples were ground into a fine powder using a laboratory mill (MILLER-800) and sieved through a mesh with pore size $\leq 200\ \mu$m. The resulting powder was stored in airtight containers at +4°C until further use in experiments.

12.2.1 Chemical analysis

Quantitative chemical analysis of the powder was conducted at the Sector for Microelement Studies of the State Institution "Institute for Occupational Health of the NAMS of Ukraine".

A 0.2 g sample of dried asparagus was dissolved in 3.0 ml of 65% nitric acid and autoclaved for 30 minutes, followed by mineralization in a MARS-One microwave oven for 25 minutes. After cooling, the sample volume was adjusted to 10.0 ml with deionized water. Macro- and microelement content was determined using inductively coupled plasma optical emission spectroscopy (ICP-OES) on an "Optima 2100 DV" device (Perkin-Elmer, USA). Data processing was performed using the WinLab32 software for ICP-OES and statistical analysis in Microsoft Excel. Protein content in the dry sample was calculated based on nitrogen levels.

12.2.2 Laboratory baking of bread with asparagus powder

The laboratory baking of bread products with asparagus powder was conducted in the laboratory of the Department of Food Technologies at Uman National University of Horticulture.

The asparagus powder was incorporated into bread formulations for laboratory baking. Initial experiments evaluated the effect of adding 5% and 10% asparagus powder (**Fig. 12.1**) to bread mixtures made from whole-grain spelt, quinoa, amaranth, or flaxseed flour. Bread without asparagus powder served as the control. Fermentation, dough proofing, and baking conditions were optimized experimentally.

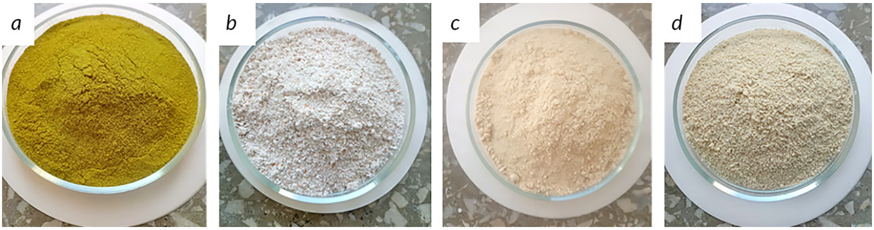

Fig. 12.1 Ingredients for the experiment: *a* – asparagus powder; *b* – whole-grain spelt flour; *c* – quinoa flour; *d* – flaxseed flour

Further studies focused on spelt flour mixtures, which yielded satisfactory results. Mixtures of asparagus powder and spelt flour were prepared in ratios of 0:100, 5:95, 10:90, 15:85, 20:80, and 30:70. The dough formulation was calculated based on 100 g of dry mixture, consisting of wholegrain spelt wheat flour and asparagus powder in a ratio of 95:5.

The formulation included the following ingredients (g):

– wholegrain spelt wheat flour – 95;
– asparagus powder – 5;
– sunflower oil – 1.5;
– table salt – 1.5;
– compressed baker's yeast – 1.5;

– sugar – 1.5;
– water – 50–55.

The dough fermented at 28–32°C for 150–180 minutes, was shaped, proofed, and baked in a steam-injected oven at 200–220°C for 15–20 minutes.

Bread was evaluated 16 hours post-baking using a previously established methodology [22]. For evaluation, next parameters were used: organoleptic properties (appearance, crust color, crumb elasticity, pore structure, taste, aroma), assessed by the group of experts, and physicochemical parameters (baking loss, specific volume, porosity, moisture, acidity). Moisture was measured with an SESh-3M device, and bread volume was determined by grain displacement using an RZ-BIO device, expressed in cm^3/kg of flour.

12.3 Results and discussion

12.3.1 Asparagus powder as a source of nutrients

Quantitative chemical analysis of the powder revealed a high content of micronutrients, in the powder obtained from the basal parts of asparagus (**Table 12.1**). The rich elemental composition of such powder allows for its potential use in enriching other products with biologically active substances.

Table 12.1 Content of chemical elements in dried asparagus

Element	λ, nm	C, (mg/kg)	Technical error, %	Detection limit, mg/kg
Mg	279.1	2564.5 ± 15.4	0.87	0.005
K	766.5	47591.7 ± 245.0	0.44	1.40
Ca	317.9	5635.6 ± 9.8	0.24	0.42
Mn	257.6	41.4 ± 0.3	0.65	0.005
Zn	206.2	110.5 ± 3.1	2.31	0.056
Fe	259.9	79.52 ± 2.5	3.12	0.042
Cu	324.7	8.71 ± 0.38	3.80	0.042
P	213.8	7317.3 ± 204.4	2.85	1.40
S	190.0	24093.87 ± 333.2	2.34	0.56

The detected microelements are essential for hematopoiesis, functioning of the nervous system and muscles, strengthening bone and cartilage tissue, supporting immunity, and regulating metabolism. The content of iron (Fe), magnesium (Mg), phosphorus (P), zinc (Zn), and manganese (Mn) in dried asparagus is twice as high as in whole-grain wheat flour, while the copper (Cu) content is at least four times higher. The asparagus powder is particularly rich in potassium (K), importance of which importance cannot be overstated when it comes to reducing the risks and severity of cardiovascular diseases, maintaining muscle tone, and regulating water-salt balance.

The protein content in asparagus powder was also high, amounting to 5.14 ± 0.11% of the total powder mass. Adding it to food products, therefore, evidently contributes to a significant increase in their nutritional value due to the proteins, which also include essential amino acids. The high protein content, as well as the significant amounts of dietary fiber, pectins, and sugars in asparagus powder, are also noted in the literature, supporting our justification of using asparagus powder as an additive in various food products.

12.3.2 Evaluation of the feasibility of adding asparagus powder to bread recipes

To develop methods for laboratory baking of bread enriched with asparagus powder, let's experimentally determine the feasibility of replacing part of the flour in the recipe with asparagus powder. The amount of asparagus powder added to the dough was selected in a range of 5–30%, considering the requirements of the bread-making technological process. The bread was then baked, and its properties were compared with control samples baked from the corresponding flour without the addition of asparagus powder.

Bread made from whole-grain amaranth flour was characterized by a smooth surface without cracks or ruptures; the crumb quickly regained its original shape, retained moisture, and remained slightly sticky to the touch. It had developed porosity without hardening. The crumb color in all variants was brown, and the taste and smell were characteristic of this type of bread, without any off-flavors or odors. Adding asparagus powder to the bread reduced the crumb moisture, increased the uniformity of porosity, and decreased pore size (**Fig. 12.2**).

When 5% asparagus powder was added to whole-grain amaranth flour, the water absorption capacity of the dough did not change significantly. However, with an increase in the amount of powder to 10%, the dough's ability to retain moisture decreased (**Table 12.2**). Significant baking loss was observed even with the addition of 5% asparagus powder, with a value of 29.6%, which is 17% less than the control. The specific volume of the control amaranth bread was 1.08 cm^3/g, while the addition of 5% vegetable powder reduced it by 5.5%. However, the addition of 10% powder increased the specific volume of the bread to 1.19 cm^3/g.

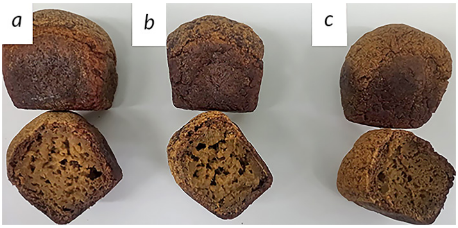

Fig. 12.2 Whole-grain amaranth flour bread: *a* – control; *b* – with addition of 5% asparagus powder; *c* – with addition of 10% asparagus powder

Table 12.2 Physicochemical indicators of bread made from whole-grain amaranth flour (control) and new recipes with the addition of asparagus powder

Indicator	Bread from whole-grain amaranth flour			
	Control	5% asparagus powder	10% asparagus powder	$LCD_{0.05}$
Specific volume of bread, cm^3/g	1.08	1.02	1.19	0.06
Baking loss, %	35.6	29.6	30.7	1.59

Bread made from defatted flaxseed flour had a smooth surface without large cracks or ruptures but was characterized by a high crumb density due to significant baking loss. The crumb regained its original shape but retained moisture, remaining slightly sticky to the touch, with low porosity and no hardening. When asparagus powder was added to defatted flaxseed flour, the crumb cracked after baking (**Fig. 12.3**).

The crumb color in all variants was dark brown, and the taste and smell were characteristic of this type of bread, without any off-flavors or odors. As shown in **Table 12.3**, increasing the amount of added asparagus powder to defatted flaxseed flour reduced the dough's water absorption capacity, significantly decreased the baking loss, and lowered the specific volume of the bread. For example, the highest percentage of baking loss was observed in the control sample, with a value of 34.1%, while the addition of 5% and 10% asparagus powder reduced this by 9–10%. The specific volume of bread made from flaxseed flour was 1.12 cm^3/g, and with the addition of 5% and 10% asparagus powder, it decreased by 2% and 9%, respectively. Thus, the addition of 10% asparagus powder to flaxseed flour had a significant impact on the specific volume of the bread.

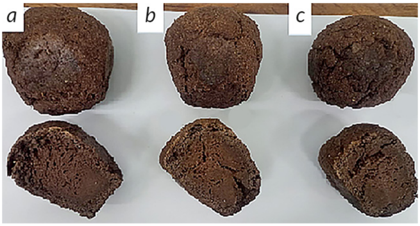

Fig. 12.3 Flaxseed flour bread: *a* – control; *b* – with addition of 5% asparagus powder; *c* – with addition of 10% asparagus powder

Table 12.3 Physicochemical indicators of bread made from defatted flaxseed flour (control) and new recipes with the addition of asparagus powder

Indicator	Bread from whole-grain amaranth flour			
	Control	5% asparagus powder	10% asparagus powder	$LCD_{0.05}$
Specific volume of bread, cm^3/g	1.12	1.10	1.02	0.05
Baking loss, %	34.1	31.1	30.7	1.9

Bread made from whole-grain quinoa flour was characterized by a smooth surface without cracks or ruptures. The crumb was dry to the touch, without hardening, and had low but uniform porosity, with small pore sizes. The crumb color in all variants was brown, and the taste and smell were characteristic of this type of bread, without any off-flavors or odors. Adding asparagus powder to the bread increased the crumb density, likely due to the significant baking loss. The pore size also decreased as the proportion of asparagus powder in the dough increased (**Fig. 12.4**).

From the data in **Table 12.4**, it is evident that adding asparagus powder to whole-grain quinoa flour significantly increases the baking loss of the bread. In the control sample, the value is 11.2%, while in the samples with 5% and 10% additions, it is 2.3 and 2.6 times higher, respectively.

Thus, unlike bread made from flaxseed flour, a positive effect of adding asparagus powder was observed in the recipe for bread made from quinoa flour, due to an increase in the dough's water absorption capacity and a significant increase in the bread's specific volume. In the control sample, this qualitative indicator of bread was 0.92 cm^3/g, while in the samples with 5% and 10% asparagus powder, it was 5% and 7% higher, respectively.

Despite some improvement in the physicochemical indicators of bread in the new recipes using asparagus powder compared to the respective control samples, their overall organoleptic evaluations remained average, which may complicate the introduction of the tested recipes to the consumer market.

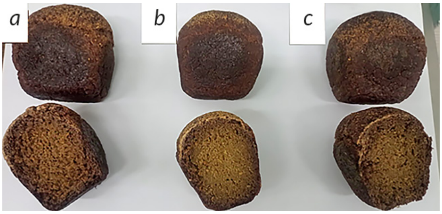

Fig. 12.4 Whole-grain quinoa flour bread: *a* – control; *b* – with addition of 5% asparagus powder; *c* – with addition of 10% asparagus powder

Table 12.4 Physicochemical indicators of bread made from whole-grain quinoa flour (control) and new recipes with the addition of asparagus powder

Indicator	Bread from whole-grain quinoa flour			
	Control	5% asparagus powder	10% asparagus powder	$LCD_{0.05}$
Specific volume of bread, cm^3/g	0.92	0.97	1.10	0.05
Baking loss, %	11.2	25.4	29.3	1.09

Fundamentally different results were obtained in the bread samples with the addition of asparagus powder to whole-grain spelt flour, which, based on our data, may have significant potential as a new bakery product. These bread samples were distinguished by better structure and appearance (**Fig. 12.5**), and therefore, to determine the optimal recipes, more variants were tested, and a broader range of quality indicators was used.

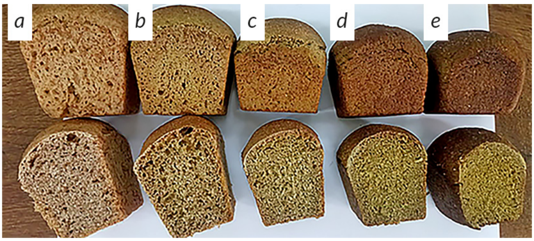

Fig. 12.5 Whole-grain spelt flour bread: *a* – control; *b* – with addition of 5% asparagus powder; *c* – with addition of 10% asparagus powder; *d* – with addition of 20% asparagus powder; *e* – with addition of 30% asparagus powder

12.3.3 Organoleptic and physicochemical indicators of bread made from whole-grain spelt flour with asparagus powder

Laboratory bread, in which a certain amount of asparagus powder was introduced with a proportional reduction in the amount of whole-grain spelt flour, was evaluated based on several organoleptic indicators (color, taste, smell) and physicochemical quality indicators. Additionally, its culinary properties (specific volume, porosity, moisture, acidity, and baking loss) were assessed. To determine the optimal recipes for laboratory baking, various proportions of asparagus powder and whole-grain spelt flour (hereafter referred to as "spelt flour") were tested. The samples contained 0%, 5%, 10%, 20%, or 30% asparagus powder in the mixtures, respectively.

According to the organoleptic indicators, bread made from whole-grain spelt flour met the established requirements: the surface was smooth, without large cracks or ruptures; the crumb was elastic, quickly regained its original shape, well-baked, not moist to the touch, not sticky, with developed and uniform porosity, and without hardening. The crumb color had a gray-yellow tint, and the taste and smell were characteristic of this type of bread, without any off-flavors or odors.

Table 12.5 presents the organoleptic quality indicators of bread made from spelt flour with the addition of asparagus powder in various proportions.

Bread made with the new recipes differed slightly in quality from the control sample: the crumb color was dark yellow, greenish-yellow, or greenish; the taste and smell were characteristic of asparagus. The asparagus powder contained anthocyanin pigments and had a pronounced green color.

It has been established that adding 5–10% asparagus powder to spelt flour dough is appropriate. Such bread had a uniformly colored (dark yellow) crust without ruptures or cracks, an elastic crumb (dark yellow, greenish-yellow), thin-walled porosity, a pronounced bread flavor, and a pleasant aroma of the additive.

The crumb of bread made with spelt flour and the addition of 20% and 30% asparagus powder had a greenish tint and a strongly pronounced taste and aroma of the additive, which could significantly affect consumer satisfaction. The overall sensory evaluation of the bread, based on a 9-point scale across nine characteristics, was also the highest for samples baked from mixtures containing 5–10% asparagus powder (**Table 12.6**).

All bread samples were rated 9 points for cust color and 8 points for crust surface. The glossiness of the crust in the control sample was rated 9 points, while the other bread variants scored just one point lower.

Table 12.5 Physicochemical indicators of bread made from whole-grain spelt flour (control) and new recipes with the addition of asparagus powder

Indicator	Content of asparagus powder in the baking mixture				
	0% (Control)	5%	10%	20%	30%
Appearance of the surface	surface smooth, without contaminations, cracks or ruptures			surface smooth, without contaminations, large cracks or ruptures	
Color of the surface	white-yellow	light yellow	yellow	brown	brown
Crumb appearance	Elastic, restores its original shape, baked through, not moist to the touch, not sticky, without hardening				
	with uniform porosity	with developed and uniform porosity	with uniform porosity	with not uniform porosity	
Color of the crumb	grey-yellow	dark-yellow	yellow, slightly green	greenish, particles of the enriching additive are visible	
Odor	characteristic for this type of bread			bready with a strong aroma of the additive	the aroma of the additive dominates
	without foreign odors	with the aroma of the additive			
Taste	characteristic for this type of bread			–	–
	without foreign taste	with a hint of the additive			with a strong taste of the additive

Table 12.6 Quality of bread made from whole-wheat spelt flour (control) and new recipes with the addition of asparagus powder

Indicator		Content of asparagus powder in the baking mixture				
		0% (Control)	5%	10%	20%	30%
Crust surface		8	8	8	8	8
Crust color		9	9	9	9	9
Glossiness of the surface		9	8	8	8	8
Crumb color		7	7	7	4	4
Crumb elasticity		7	8	7	4	4
Aroma		8	8	7	7	7
Taste		7	8	7	4	4
Crumb consistency during chewing		7	8	7	4	4
Pore size		8	9	5	3	1
Uniformity of pore distribution		9	7	8	8	8
Overall	score	8.8	8.9	8.1	6.5	6.3
	%	97	99	90	73	70

Bread with the addition of 5% vegetable powder was rated 8 points for crumb elasticity, crumb consistency during chewing, taste, and aroma, which is one point higher than the control sample and bread with 10% asparagus powder. The crumb condition and taste of the bread with 20% and 30% powder were rated 4 points, while the aroma of this bread received 7 points.

The bread samples differed in crumb pore size. The best pore size was observed in the sample with 5% powder and the control, which scored 9 and 8 points, respectively. As the amount of powder in the bread increased, a significant reduction in pore size was observed. However, all bread samples were characterized by high uniformity of pore distribution, scoring between 7 and 9 points.

The overall quality assessment of the bread studied was very high for three samples: the control and those made with spelt flour mixed with 5% and 10% asparagus powder, scoring 8.1–8.9 points or 90–99% of the maximum value. Lower scores were obtained for bread samples with 20% and 30% vegetable powder added to the dough recipe, scoring 7.6–7.8 points or 70–73%, which is significantly lower than the standard but still a fairly high value.

As shown in **Fig. 12.6**, during baking, the bread sample with 5% asparagus powder outperformed the control in terms of volume increase, as the use of the additive intensifies the dough fermentation process. This is likely explained by the introduction of sugars and organic acids to the dough due to the addition of asparagus powder. These substances serve as a nutrient medium, participate in the biosynthesis of cellular metabolic components, and perform various functions in the metabolism of yeast cells.

Fig. 12.6 Bread samples during baking (from left to right): whole-grain spelt flour bread control, and bread with addition of 5%, 10%, 20%, 30% asparagus powder, respectively

A higher quantitative increase (10–30%) in the amount of asparagus powder in the dough negatively affected the gluten properties of spelt flour, leading to a reduction in the dough framework. However, significant baking loss was observed only with the addition of 30% vegetable powder to the dough recipe made from whole-grain spelt flour, where the baking loss amounted to 16.8%, which is only 8% higher than the control.

The specific volume and porosity of the control bread sample were 2.40 cm^3/g and 68%, respectively. When 5% asparagus powder was used, these indicators were almost identical to the control sample, amounting to 2.38 cm^3/g and 67%, respectively. In other samples, these indicators were lower than the control by 9–19% and 6–11%, respectively (**Table 12.7**).

Table 12.7 Physicochemical indicators of bread made from whole-wheat spelt flour (control) and new recipes with the addition of asparagus powder

Indicator	Content of asparagus powder in the baking mixture					$LSD_{0.05}$
	Control	5%	10%	20%	30%	
Moisture, %	44.2	44.8	45.6	45.4	46.0	2.26
Acidity, degree	3.7	3.9	4.0	4.1	4.1	0.20
Porosity, %	68	67	62	57	55	3.4
Specific volume of bread, cm^3/g	2.40	2.38	2.26	2.18	2.14	0.11
Baking loss, %	15.4	15.6	16.2	16.1	16.8	0.80

A decrease in the specific volume of experimental samples with the addition of vegetable powder to the dough recipe in amounts of 10–30% is associated with a significant reduction in bread porosity. In the studied samples, an increase in acidity by 5–10% was determined compared to the control samples. The more intensive acid accumulation in the dough samples of the new recipes is due to the content of organic acids in the raw material. This may be related to the intensification of lactic acid fermentation, which indicates the creation of more favorable conditions for lactic acid bacteria.

Thus, based on the obtained results, the replacement of part (5–10%) of the whole-grain spelt flour in the recipe with dried and ground asparagus during bread production has been experimentally substantiated and implemented. In the future, it is possible to determine the feasibility of using asparagus powder in the production of other food products.

12.4 Conclusions

In this chapter, the possibility of enrichment of bakery products via inclusion of asparagus powder into the dough was demonstrated. It was shown that dried powder from the basal parts of asparagus contains a high amount of protein – about 5% of its mass – as well as significant amounts of microelements. Rich chemical composition and previously demonstrated high content of antioxidants, dietary fiber and other organic compounds, thus opens up possibilities for using asparagus powder as a food additive.

The efficient introduction of the asparagus powder into the baking mixtures was experimentally proven based on tests with bread, prepared from quinoa, amaranth and flaxseed flour. Adding asparagus powder (5–10%) to gluten-free flour bread formulations helped retain the bread's shape, reduced crumb moisture, and increased pore uniformity, but also led to more significant baking loss. Despite improvements in the physicochemical properties of bread with the new recipes, their overall organoleptic evaluations remained average.

Replacement of the portion (optimally 5–10%) of whole-grain spelt flour with the asparagus powder provided excellent results, allowing to preserve high bread quality and taste (90–99% of the maximum total score), while enhancing the product nutritional value. Developed recipes thus allow to expand the range of bakery products and can be recommended for the high-scale production. Noteworthy, asparagus powder can be produced from parts of asparagus spears, currently wasted during the post-harvest treatment, without introduction of complicated additional technological processes, allowing to more rationally utilize such valuable source of nutrients.

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