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POSSIBILITIES OF INCORPORATION OF BY-PRODUCTS FROM MALT PRODUCTION INTO BAKERY PRODUCTS

Miriam Solgajová, Andrea Mendelová, Štefan Dráb, Anna Kolesárová, Miroslav Kročko*

Address(es): Ing. Miriam Solgajová, PhD.,
Institute of Food Sciences, Faculty of Biotechnology and Food Sciences, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic.

*Corresponding author: miriam.solgajova@uniag.sk

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ABSTRACT

The greatest attention has been paid to the utilization of plant resources resulting from the by-products of the food industry. This research was focused on the development of a fortified durable pastry where wheat flour type T-650 was replaced by homogenised spent malt rootlets in different substitution levels of 5%, 10% and 15%. Such incorporation not only minimizes waste and utilizes potentially valuable by-products of malt production but may also contribute to increasing the nutritional value of the final product. The results showed that with increasing addition of malt rootlets in the mixture with wheat flour, some technological parameters (gluten content and its quality, Zeleny's sedimentation test, Falling Number) decreased. Substitution levels of 5% and 10% gave acceptable pastry of higher contents of protein and ash. With the addition of malt rootlets, the ash content significantly ($p < 0.05$) increased (1.86% - 2.39%) as well as the crude protein content (9.12% - 10.06%) thus increasing the nutritional value of the durable pastry. Pastry with a higher proportion of malt rootlets (10% and 15%) achieved increased dry matter content, confirmed by the results of water activity, which was reduced, contributing to the prolongation of the pastry shelf-life. Based on the sensory evaluation, the replacement of wheat flour with malt rootlets up to 5 - 10% improved the sensory properties of pastry in terms of appearance, aroma, taste, and overall acceptability. This research shows the potential of using malt rootlets as a by-product in the food industry in terms of added value in the production of innovative food products

Keywords: malt, malt rootlets, durable pastry, evaluation, bakery products

INTRODUCTION

In recent years of technological advances and commitment to environmental sustainability, the importance of the food and manufacturing industry is increasingly shifting towards the use of environmentally friendly resources and the efficient use of raw materials. This trend brings with it new challenges and opportunities, as well as the need to find innovative solutions and technologies. One of these aspects is the increasing importance of secondary raw materials and their transformation into valuable commodities, which contributes to a more efficient use of resources and a reduction in waste (**Neylon *et al*., 2020**). An area that poses a challenge in this respect is the brewing and malting industry. The malting and brewing process produces by-products in the form of spent malt rootlets, sprouts, and brewers' spent grains. These by-products, which would otherwise end up as waste, represent a potential source of raw materials for other sectors of the food industry, such as the baking industry. Malting is an important technological method for processing whole grains; the main product, malt, is mainly used for brewing beer, but the process also provides by-products such as malt rootlets and sprouts (**Aborus *et al*., 2017; Koistinen *et al*., 2020**). The by-products of malting and brewing have a relatively wide range of applications in the processing industry and in animal nutrition; their biotechnological potential is quite broad. They are used to produce value-added compounds (e.g., xylitol, lactic acid), are used to culture microorganisms, as raw material for extraction of certain compounds (sugars, proteins, acids, and antioxidants), are useful in the production of enzymes, or as an adsorbent for the removal of organic matter from wastewater (**Loučka *et al*., 2018**). Malt rootlets are germs appearing during the malting process of barley, which are separated before the brewing process and treated as a by-product for animal feed. The dried malt is cooled, de-germinated, and stripped of roots and sprouts. These by-products are made up of dry roots, grain germ, and may also contain malt dust (from malt polishing), malt skins, and malt fragments up to 10%. From 100 kg of barley, 3 - 5 kg of malt rootlets with a dry matter between 92 - 96% is obtained (**Loučka *et al*., 2018; Bota *et al*., 2019**). Malt rootlets are removed after malting because they cause a bitter taste, have the ability to absorb moisture, and cause undesirable colouring of the beer (**Olivares-Galván *et al*., 2022**). The moisture content of malt rootlets is very low (4.2 - 12.9%) and contains high amounts of carbohydrates and protein. The main fibre present is insoluble and includes arabinoxylans. The main amino acids in the protein are glutamic acid, aspartic acid, isoleucine, phenylalanine, lysine, and leucine. Malt rootlets are also a source of minerals and phenolic compounds (**Agrahar-Murugkar *et al*., 2015; Mohammadi *et al*., 2021; Olivares-Galván *et al*., 2022**). The crude protein concentration of this by-product is remarkably high. Total crude protein accounts for 20 - 39% of the total weight. The fibre content has also been found to be high, accounting for more than 40% of the total weight (**Sentís-Moré *et al*., 2023**). Barley rootlets could contribute to the human diet through their valuable nutrients such as protein, essential amino acids, healthy fats, polyphenols, and minerals (**Chis *et al*., 2020**). Reducing by-products of production to a minimum or reincorporating them into the production process as raw material can help to achieve environmental sustainability. Given that some by-products derived from the malting and brewing industries are nutritious and valuable, as well as cheap and affordable, they can be incorporated into a variety of industries oriented towards food, pharmaceutical, or biotechnological production (**Cejas *et al*., 2017; Neylon *et al*., 2020; Olivares-Galván *et al*., 2022**). The application of malt rootlets to bakery products could lead to an increase in the nutritional value of these products, as the proteins contained in this by-product would replace the proteins when reduced flours are used. These specific components of by-products from the malting industry can be obtained by chemical or biological methods and subsequently biotransformed into components with high nutritional value for food, or used in animal feed or in the cosmetic and pharmaceutical industry (**Bota *et al*., 2019**).

The aim of the research, which is presented in this paper, was to incorporate malt rootlets as a by-product from malt production into durable pastry and to assess the effect of the addition of malt rootlets combined with T-650 wheat flour on the technological quality of the flour and thus compare chemical and sensory parameters of pastry without and with the addition of 5%, 10%, and 15% of malt rootlets.

MATERIAL AND METHODS

Material used

Commercially available wheat flour T-650 (Miroslav Grznár MLYN ZRNO, SR) was used in this study to prepare mixed flours. Wheat flour was replaced with homogenized malt rootlets obtained from the Heineken brewery (Hurbanovo, SK), in amounts of 5%, 10%, 15%. As a control only pure wheat flour was used. Other ingredients used for the bakery experiment were purchased at the local market and included: sugar, olive oil, baking powder, and salt. Combinations of evaluated mixed flours presents Table 1.

Table 1 Combinations of evaluated mixed flours

Sample	Flour (g)	Malt rootlets (g)	Sugar (g)	Olive oil (g)	Salt (g)	Baking powder (g)	Water (g)
C	250.0	0	5	92	4	5	120
S5	237.5	12.5	5	92	4	5	120
S10	225.0	25.0	5	92	4	5	120
S15	212.5	37.5	5	92	4	5	120

C (control wheat flour), S5 (sample with 5% addition of malt rootlets), S10 (sample with 10% addition of malt rootlets), S15 (sample with 15% addition of malt rootlets)

Experimental baking

During the baking experiment, four types of durable pastry without the addition of malt rootlets (as a control sample) and with the addition of 5%, 10% and 15% of malt rootlets were prepared. The basic recipe was the same, the individual samples differed by the addition of different proportions of malt rootlets. Recipe for sample composition (per 250 g of flour): sugar, olive oil, baking powder, salt, water (Table 1). Each type of durable pastry was prepared separately. All ingredients were mixed well, and the dough was rolled to a thickness of 1-3 mm. The pastry was baked at 200 °C for 7 minutes (oven MIWE condo, Germany). After cooling, pastry was evaluated for chemical and sensory characteristics.

Chemical and Sensory analysis

For chemical evaluation, to determine the technological quality of the wheat flour and individual flour mixtures used, the following parameters were determined: dry matter (ICC Standard 110/1), ash content (ICC Standard 104/1), nitrogen content according to Kjeldahl method (ICC Standard No. 105/2), amount of gluten and its properties (STN ISO 46 1011-9), Falling Number (ICC Standard 107/1), Sedimentation test according to Zeleny (ICC Standard 116/1).
For evaluation of the technological quality of durable pastry, the following parameters were determined: ash content (ICC Standard No. 104/1), crude protein content by the Kjedahl method (ICC Standard No. 105/2), by which the amount of the protein was calculated using a factor 5.7, moisture content in the dry matter (ICC Standard No. 110/1), and water activity (a_w) of the samples was determined with an apparatus for water activity measurement (LabMaster.aw, Novasina AG, Switzerland).
The sensory evaluation of bakery products according to ISO 6658 was carried out by a sensory panel consisting of a group of 15 trained evaluators. The task for the evaluators was to evaluate 9 sensory parameters of durable pastry, namely: overall appearance, aroma (overall, intensity), foreign smell, consistency, taste (overall, intensity), aftertaste, and overall acceptability. All parameters were compared with the control sample without malt rootlets addition. A 9-point hedonic scale ranging from 9 (excellent) to 1 (unacceptable) for each characteristic was used for evaluation.

Statistical analysis

The experiment was performed in triplicate. The data were evaluated by one-way analysis of variance (ANOVA) followed by post hoc analysis by Duncan's multiple range test (Statistica v.12, Statsoft, USA), assuming differences to be statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Evaluation of mixed flours samples

Table 2 presents the results of the characteristics of wheat control flour and mixtures of this flour with the addition of malt rootlets in amounts of 5%, 10%, and 15%.
Dry matter is an important parameter that significantly influences the shelf life of durable bakery products. The results showed that the dry matter content slightly decreased with the addition of malt rootlets. The dry matter values ranged from 86.23% to 86.49% (moisture content 13.51% - 13.77%). According to Decree No. 2/2014 of the Ministry of Agriculture and Rural Development of the Slovak Republic, the maximum moisture content for wheat flour is set at 15%. This means that all flour samples must meet this criterion to be considered of good quality and safe for consumption. The moisture content of flour is an important indicator of its quality and can affect not only its shelf life but also its baking properties and the result of the food in which the flour is used. After analyses of pure malt rootlets moisture content, authors **Chis *et al*. (2020)** reported in their study that the moisture content was 8.20%, similarly, the authors **Cejas *et al*. (2017)** also found that moisture content in malt rootlets was determined to be 7.49%.
Ash refers to the amount of minerals in the milling products. Its determination is essential for proximate analysis and subsequent nutritional evaluation. Ash content is a key element in the preparation of samples for mineral analysis, including both essential nutrients and toxic metals. The ash content of foods is also a consideration in determining their quality (**Harris and Marshall, 2017**). The value of ash of mixed flours samples increased with the gradual addition of malt rootlets. The control sample T-650 reached the lowest value of 0.60%. With the addition of malt rootlets, the ash content increased statistically significantly ($p < 0.05$) compared to the control sample (0.88% - 1.21%). **Chis *et al*. (2020**) reported in their research that the ash content in malt rootlets analyses was 7.70%. Similar findings were also reported by **Waters *et al*. (2013)** and **Neylon *et al*. (2020)**. **Wrigley *et al*. (2017)** state that flours with low ash content can be used for all baking purposes, while flours with higher ash content have a higher nutritional value and are suitable to produce dietary products (they contain more fibre, minerals).
The crude protein content of the analysed mixed flours increased statistically significantly ($p < 0.05$) with the addition of malt rootlets. The control sample showed a crude protein content of 10.37%. With the gradual addition of malt rootlets, crude protein content increased. Statistically significant ($p < 0.05$), the highest content 13.06% was detected in sample S15 (15% addition of malt rootlets). Compared to the control sample, an increase in the crude protein content up to 2.69% was observed. Similar finding was obtained by **Bota *et al*. (2019)**, who reported that the addition of malt rootlets in the amount of 5 - 10%, provided bread with high fiber and protein content.
Gluten in wheat flour forms a plastic-elastic complex composed of gliadins and glutenins. The higher the gluten content and the higher the gluten ductility, the greater the volume of the baked product, which allows better retention of gases produced by fermentation. The gluten content of mixed flours decreased with the addition of malt rootlets due to the absence of gluten-forming proteins. In sample S15 (15% addition of malt rootlets), the gluten content was 26.68%, which is statistically significantly lower ($p < 0.05$) than in the control sample (30.09%). **Both and Chloupek (2005)** reported in their work that the volume of baked goods is primarily associated with gluten content and quality. Similar conclusions were reached by **Gažar and Bojňanská (2010)**, who added different amounts of oat, buckwheat, lentil, and chickpea flour to T-650 wheat flour. Properties of gluten, such as its swelling ability, statistically significantly decresed ($p < 0.05$) as well. Gluten ductility had a slightly increasing trend with the addition of malt rootlets. **Belcar *et al*. (2022),** in their research, reported that the addition of malt flour to mixed flours increases the final volume of bread, improves its texture and colour, and makes it softer, less gummy, and chewier. Based on the values shown in Table 2, we can conclude that with the addition of malt rootlets in the mixtures, the Zeleny's sedimentation test, expressed as the hydration capacity of protein, reduced. There were significant differences among samples. Statistically significant ($p < 0.05$) the highest content was detected in control sample 34 cm^3. Zeleny's sedimentation test is an important parameter that indirectly indicates its baking quality, more precisely the quality of gluten, which as the main component of the protein complex of flour is responsible for the structure of bread (**Sobczyk *et al*., 2017**).
Falling Number is a frequently used method for the evaluation of α-amylase activity in flours of different cereals (mainly wheat and barley) (**Jukić *et al*., 2023**). A demonstrable decrease in the Falling Number was observed with the addition of malt rootlets, indicating increased enzymatic activity of α-amylase. The highest enzyme activity was observed at 15% addition of malt rootlets (239 seconds), while the lowest activity was recorded in the control sample (468 seconds). Thus, it can be concluded that as the addition of malt rootlets increases, the enzyme activity also increases. According to **Bojňanská *et al*. (2013)**, optimum values of Falling Number are in the range of 220 - 260 seconds.

Table 2 Comparison of group averages for the chemical characteristics of the evaluated mixed flours based on Duncan's Multiple Range Test

Sample	Dry Matter (%)	Ash Content (%)	Crude protein (%)	Gluten content (%)	Gluten ductility (cm)	Gluten swelling (cm^3)	Sedimentation test (cm^3)	Falling Number (s)
C	86.49 a	0.60 a	10.37 a	30.06 b	8.33 a	21.33 d	34.00 d	468.33 c
S5	86.41 a	0.88 b	11.36 b	31.24 b	10.00 b	19.33 c	30.83 c	345.33 b
S10	86.29 a	1.14 c	12.16 c	26.65 a	10.33 b	15.67 b	25.67 b	326.67 b
S15	86.23 a	1.21 c	13.06 d	26.68 a	10.67 b	13.67 a	20.33 a	239.33 a

Notes: a-d = homogeneous groups, different letters at mean represent statistically significant differences among samples ($p < 0.05$), C (control wheat flour), S5 (sample with 5% addition of malt rootlets), S10 (sample with 10% addition of malt rootlets), S15 (sample with 15% addition of malt rootlets)

Evaluation of durable pastry

The results of water activity, dry matter content, crude protein, and ash content of durable pastry are shown in Table 3.

The dry matter content of enriched pastry statistically significantly increased with the addition of malt rootlets from 89.26% (control sample) to 91.12% (S15 - 15% addition). In their research, **Aborus *et al*. (2017)** confirmed that the dry matter content of malt rootlets is high, containing high amounts of carbohydrates and protein.

The ash content increased with the addition of malt rootlets, ranging from 1.86% (control sample) to 2.39% (S15 - 15% addition). Our results were similar to **Abdullah *et al*. (2022)**, who substituted wheat flour with germinated barley flour in their research, which significantly increased the ash content and protein content of the evaluated products compared to the control sample. **Ikuomola *et al*. (2017)** also reported similar findings, their results showed that the ash content of the biscuits in the control sample was 1.41%, and when barley bran powder was added, the ash content increased (1.81%).

The crude protein content of the analysed products statistically significantly increased ($p < 0.05$) with the addition of malt rootlets (control sample 9.12% while 15% addition 10.06%). Similar findings with an increase in protein content were reported by **Bota *et al*. (2019)**. According to authors, substitution levels of spent malt rootlets of 5% and 10% gave good bread, with high protein and fibre content. The chemical composition of malt rootlets is variable according to the variety of barley, the malting process, the conditions, and the duration of storage but always presenting a high content of fibre, protein, and minerals. According to **Peyrat-Maillard *et al*. (2001)** a level of 5% to 10% added spent malt rootlets can produce fortified products. **Hoehnel *et al*. (2020),** in their study, reported that the addition of malt rootlets to wheat bread improved the protein quality and created a better balance in the amino acid profile of wheat bread. **Salama *et al*. (1997)** reported an improvement in the nutritional profile of bread when 5% malt rootlets were added to the mixture. This addition caused an approximate increase of 1% in fibre and protein content. **Lukinac and Jukić (2022)** added malt flour to biscuits, which resulted in an increase in crude protein and fiber content of their enriched biscuits. Research by **Abdullah *et al*. (2022)** showed a significant increase in protein, fat, ash, β-glucans, and energy content in all three bakery products (bread, biscuits, and cakes) when the proportion of germinated barley flour in the mixture was incorporated.

The water activity (a_w) of foods is a critical factor affecting its health safety. It determines whether the food contains growth of undesirable microflora or pathogenic microorganisms and whether the food contains enzymes that can degrade the product (**Linkešová and Paveleková, 2007**). The water activity of the pastry with malt rootlets has been significantly reduced, which contributes to better product shelf-life. Based on these data, we can conclude that the pastry could be considered as durable with a water activity lower than 0.6. Durable pastry is a bakery product whose water activity is less than or equal to 0.65 (**Vyhláška MPaRV SR, 2014**).

Table 3 Comparison of group averages for the chemical characteristics of the evaluated mixed flours based on Duncan's Multiple Range Test

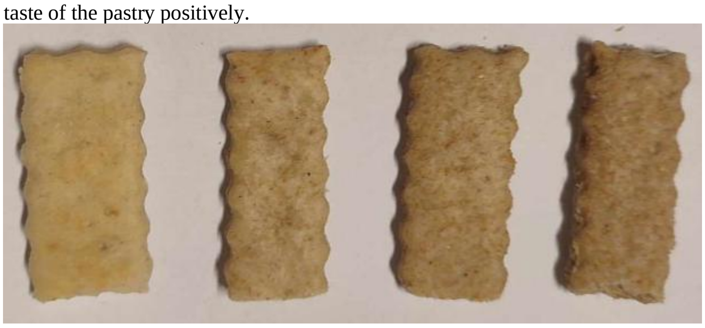
Sample	Dry Matter (%)	Ash content (%)	Crude protein (%)	A_w
C	89.26 b	1.86 a	9.12 b	0.65 c
S5	88.37 a	2.30 b	8.43 a	0.66 c
S10	90.49 c	2.17 b	9.78 c	0.58 b
S15	91.12 d	2.39 b	10.06 c	0.53 a

Notes: a-d = homogeneous groups, different letters at mean represent statistically significant differences among samples ($p < 0.05$), C (control wheat flour), S5 (sample with 5% addition of malt rootlets), S10 (sample with 10% addition of malt rootlets), S15 (sample with 15% addition of malt rootlets)

Sensory evaluation

Results of overall aroma, foreign smell, and consistency did not show any significant differences in sensory evaluations (Table 4, Figure 1). However, there were statistically significant differences ($p < 0.05$) in characteristics such as the appearance, aroma intensity, taste, aftertaste, and overall acceptability of the durable pastry.

The results of the sensory evaluation showed that the overall appearance of the pastry was best rated in samples with 5% malt rootlets addition (S5) (7.80), while the lowest rating was given to control sample C (6.87). This different rating may be due to the fact that the pastry with the addition of malt rootlets resembled whole grain products in colour. Colour is an important parameter that affects consumer acceptance of foods in general (**Spence, 2015**). The overall aroma was best rated for samples S10 (7) and S15 (6.80) as a pleasant, balanced aroma. Aroma intensity was statistically significantly ($p < 0.05$) best rated for sample S15 (6.47), while control sample C scored 4.93 and was therefore considered to be the least pronounced. The consistency of the pastry reached an average value of 6.6 for all samples. The best overall taste was recorded in sample S5 (6.93), considered very good to excellent taste. The sample S15 showed the worst taste (5.73), which may indicate that a high percentage of inappropriate addition of malt rootlets may affect the taste of the pastry negatively. Samples S5 and S10 scored high ratings, indicating that the addition of malt rootlets at levels of 5% and 10% improved the taste of the pastry positively.



C S5 S10 S15

Figure 1 Durable pastry with the addition of malt rootlets in different amounts
Legend: C-control, S5-5% addition of malt rootlets, S10-10% addition of malt rootlets, S15-15% addition of malt rootlets

Waters *et al*. (2013), in their work on sensory analysis of bread enriched with malt rootlets, reported that the main sensory difference between the control and test bread was in terms of sour aroma and taste, both of which increased in line with increasing levels of malt rootlets addition. Regarding taste intensity, the addition of malt rootlets increased the taste intensity of the pastry in all cases. The intensity of the aftertaste increased with increasing proportion of malt rootlets. The worst aftertaste (4) was achieved by sample S15 (15% addition). From the evaluators' notes, the high presence of aftertaste was most reported as straw, hay, grassy, bitter, or malty. According to the data obtained, sensory panel participants rated the overall acceptability of the pastry enriched with the malt rootlets as follows: the worst - control sample (5.47) and the best - S5 (7.07) as very good impression. This suggests that the addition of malt rootlets up to 10% may positively affect the overall impression, but higher additions of more than 15% may affect the overall acceptability negatively. **Chis *et al*. (2020)** noted that in terms of biscuit taste and aroma, sensory panel participants described an intense aftertaste of whisky and alcohol, which was attributable in part to the amount of 3-methylbutan-1-ol with the addition of malt rootlets. In the case of samples with more than 15% addition, the evaluators also reported an unpleasant aldehydic taste attributable to the amount of hexanal. **Smotraeva *et al*. (2020),** in their study, assessed the effect of the addition of malt sprouts powder on the quality of muesli bars through laboratory tests. They added three different concentrations: 1%, 5%, and 10% addition of malt sprouts powder to the bar recipe. The addition of 1% malt sprouts powder did not induce any apparent changes in the appearance, taste, or aroma of the final product. However, with a 5% addition of malt sprouts, an improvement in the combination of taste, colour, and aroma of the muesli bars was observed, which increased the overall organoleptic characteristics of the product. Conversely, the addition of 10% malt sprouts powder resulted in a pronounced grassy taste and intensification of the aroma of the bars. Therefore, the optimum dose of malt sprouts powder for the muesli bars was set at 5%. **Mohammadi *et al*. (2021),** in their work, developed a new symbiotic beverage using rye, millet, and alfalfa germ, along with a combination of *L. casei* and *L. plantarum*. These beverages demonstrated satisfactory sensory properties, and the recently introduced fermented beverage met the standards for a favorable food matrix in terms of probiotic viability, gastric tolerance, and sensory properties.

Table 4 Comparison of group averages for the sensory characteristics of evaluated durable pastry based on Duncan's Multiple Range Test

Sample	Apperance	Aroma (overall)	Aroma (intensity)	Foreign smell	Consistency	Taste (overall)	Taste (intensity)	Aftertaste	Overall acceptability
C	6.87 a	6.07 a	4.93 a	7.67 a	6.80 a	4.80 a	4.93 a	6.67 b	5.47 a
S5	7.80 b	6.53 a	5.47 ab	7.80 a	6.80 a	6.93 b	6.47 ab	5.67 ab	7.07 b
S10	7.67 ab	7.0 a	5.80 ab	7.60 a	6.87 a	6.33 b	6.13 ab	5.93 b	6.60 ab
S15	7.33 ab	6.80 a	6.47 b	7.47 a	6.0 a	5.73 ab	6.67 b	4.0 a	5.93 ab

Notes: a-d = homogeneous groups, different letters at mean represent statistically significant differences among samples ($p < 0.05$), C (control wheat flour), S5 (sample with 5% addition of malt rootlets), S10 (sample with 10% addition of malt rootlets), S15 (sample with 15% addition of malt rootlets)

CONCLUSION

In conclusion, with increasing addition of malt rootlets (5, 10, and 15%) in the mixture with wheat flour, some technological parameters (gluten content and its quality, Zeleny's sedimentation test, Falling Number) decreased, but the incorporation of malt rootlets into durable pastry had a statistically significant effect on the various chemical and sensory properties of this bakery product. An increase in the ash content of the pastry was measured with a gradual increase of the malt rootlets addition (from 1.86% to 2.39%) as well as the crude protein (9.12% to 10.06%). This increase may indicate a higher nutritional value and an effect on the overall quality of the products. On the other hand, with the addition of malt rootlets, the dry matter content increased, and water activity decreased, which may have an impact on the shelf-life of these bakery products. Sensory evaluation showed that the replacement of up to 5-10% of wheat flour with malt rootlets can positively affect the appearance, aroma, taste, and overall acceptability of the durable pastry. However, higher percentage additions (15%) may have a negative effect on some sensory properties such as taste. Overall, it can be concluded that the addition of malt rootlets to bakery products can have an improving effect on their nutritional value and sensory properties. Moreover, it is important to find the optimum concentration of the addition to minimise negative effects on the quality of the products. It is also necessary to consider the environmental and social implications of integrating these products into the food system. In today's context, where it is important to strengthen environmental sustainability and resource efficiency, this topic is timely and offers scope for further research and innovation in the food industry. The integration of by-products from brewing and malting into the bakery sector is therefore a promising direction that can contribute to the overall sustainability and quality of the food industry.

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