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Effect of Wheat and Barley Malt Addition on the Quality of the Baking Blend and Wheat Bread

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Wheat grain obtained from agricultural overproduction is stored for a long time in grain warehouses, which reduces its baking value. The aim of this study was to use barley and wheat malt flours as additives to flours obtained from grain of different wheat varieties stored for 12 months under optimal conditions, to improve their baking properties. The addition of barley malt flour at a mean rate of 0.5% or wheat malt flour at a mean rate of 0.7% reduced the time needed for the wheat gel to reach its maximum viscosity by 67.2%, compared to the control sample (without malt flour added). Bread made of flour blends with malt flours added was characterised by a higher loaf volume and specific volume as well as darker crust and crumb. The addition of malt flours also led to significantly reduced hardness, gumminess, and chewiness of bread crumb. The study demonstrated that it is possible to effectively use long-stored wheat grains for bread making applying wheat malt flour or barley malt flour as enhancers.

INTRODUCTION

Consumers increasingly seek out baked products not only with specific taste and flavour but also containing natural ingredients used as additives. Given this, efforts are made to improve the quality of these products even at the stage of wheat grain milling, *e.g*., by developing flour blends, and also at the later stages by modifying production technologies. The application of improvers has been shown to affect organoleptic properties (taste, aroma), crumb texture, and loaf volume of the bread [Li Vigni *et al*., 2010].

Raw materials of natural origin which may be used to improve wheat flour include malts, malt extracts, and malt flours. When added in adequate amounts, they have been shown to positively affect technological properties and sensory characteristics of bread [Honců *et al.*, 2015; Rögner *et al.,* 2021a,b]. The production of malts involves controlled germination of caryopses in specified conditions, whereby the grain is soaked which leads to enhanced enzymatic activity and partial growth of rootlets; subsequently, the material is dried and the rootlets are removed [Farzaneh *et al*., 2017; Kleinwächter *et al*., 2014; Rögner *et al.,* 2021b; Schmitt *et al*., 2013]. Wheat and barley malts are sources of α-amylase which was found responsible for increased viscosity of wheat flour dough. During the processes of dough preparation, kneading, and baking, its activity affected CO_2 production in the dough, while its excess amount led to superfluous starch dextrinization and softening of the dough; consequently causing very high viscosity of the bread crumb produced [Zarzycki *et al.,* 2012]. In bread making, malt was usually added at a rate of approximately 1% (depending on flour quality) [Honců *et al*., 2015]. In addition to increasing the rate of the fermentation process, malt contributed to enhanced rheological properties of the dough, while the increased content of reducing sugars led to greater intensity of the Maillard reaction resulting in golden-brown colour of the bread crust [Honců *et al*., 2015; Rögner *et al.,* 2021b]. The addition of malt did not modify the taste of wheat bread but contributed to greater loaf volume, better crumb texture, and extended shelf-life of the bread [Honců *et al*., 2015].

The addition of barley or wheat malt with moderate proteolytic activity (reflected by Kolbach Index) contributed to the strengthening of the gluten network formed in the dough [Honciů *et al*., 2015; Zadeike *et al*., 2018]. Notably, however, malt with high proteolytic activity expressed as the Kolbach Index >42–45% should not be used for this purpose since it may adversely affect the properties of the gluten network in the dough, and consequently the quality and stability of the finished product [Zadeike *et al*., 2018]. The addition of germinated grains was also reported to result in increased

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bioavailability of mineral substances and dietary fibre, and in reduced contents of phytic acid and tannins in the finished products [Agrahar-Murugkar *et al*., 2015].

The purpose of this study was to determine amylographic properties of the flour produced from grains of three wheat varieties stored for one year in optimum conditions, to assess the effects of wheat and barley malt flour addition on flour quality, and to examine the breads produced for their physical and textural properties.

MATERIAL AND METHODS

Material

The material selected for the study comprised grains of three winter varieties of common wheat: Reform, Findus, and Kilimanjaro, as well as flours obtained by milling these grains. The research material was provided by Farming Cooperative SAN (Łąka, Poland). The grain was produced using conventional farming methods in 2019, in the Głuchów village (50°04'54''N; 22°16'11''E) in Łańcut District, Podkarpackie Region, Poland.

The malt flours were produced from spring barley of Irina variety and winter wheat of Elixer variety provided by Farming Cooperative SAN (Poland). The grain was produced in 2019, using conventional farming methods, in the Łąka village (50°05'10''N; 22°05'48''E), Rzeszów District, Podkarpackie Region, Poland.

Experimental design

The experimental design is presented in Figure 1. The wheat grains of tree varieties (8 kg each) were cold-stored for 12 months at a temperature of 11–12°C and relative humidity of 10%. After 8 weeks and 12 months of storage, 3 representative samples of the grains (500 g each) were taken for determinations of grain quality characteristics. Moreover, 5-kg portions of 12 month-stored grain of each wheat variety were taken for milling. They were purified in an SLN3 type separator (Pfeuffer GMBH, Kitzingen, Germany), conditioned up to the moisture content of 15 g/100 g (24 h), and milled in a Quadrumat Junior mill (Brabender GmbH & Co. KG, Duisburg, Germany).

Flour yield was calculated as follows:

$$Flour\ yield = \frac{Flour\ weight\ (g)}{Grain\ subjected\ to\ milling\ (g)} \times 100\% \quad (1)$$

Three representative samples (1.5 kg each) of flour of each wheat variety were taken for determinations of the chemical composition and quality characteristics. The flours (3.5 kg of flour made from each of the wheat varieties) were also used for baking breads. The breads were prepared with the addition of wheat and barley malt flours. Flour blends and breads containing barley malt flour (B) were marked as follows: RB (Reform variety), FB (Findus variety), and KB (Kilimanjaro variety), whereas flours and breads containing wheat malt flour (W) were marked as RW (Reform variety), FW (Findus variety), and KW (Kilimanjaro variety). Controls (C) marked as RC (Reform variety), FC (Findus variety), and KC (Kilimanjaro variety) were breads without malt flour addition. Three loaves of bread of each type were baked and their physical parameters and texture prolife were analysed.

The wheat and barley malt flours were obtained at a laboratory of the Department of Agricultural and Food Engineering at the University of Rzeszów. Briefly, the grains were spread on metal germination plates covered with filter paper, and soaked to the moisture content of 45 g/100 g. Plates with the samples were placed in a climatic cabinet and kept therein at a relative air humidity of 90% and a temperature of 15°C. Following the defined germination time, the material was dried in a laboratory dryer and the rootlets were removed. Finally, the malted wheat and barley grains were milled (Cemotec mill, Foss, Hillerød, Denmark) into flour of particle size <2 mm. The commodity characteristics of grains and the assessment of the malting process and quality attributes of wheat and barley malt flours were presented in our previous publication [Belcar *et al.,* 2020].

Analysis of commodity characteristics of grains

The moisture content of the grain was determined using the Polish Committee for Standardization and International Organization for Standardization (PN-ISO) oven drying method [PN-EN ISO 712:2012, 2012]. The contents of total protein (expressed as g per 100 g of dry weight (d.w.) of grain), wet gluten (g/100 g), and starch (g/100 g d.w.) as well as Zeleny sedimentation value (mL) were determined using a near-infrared (NIR) DA 7200 spectrometer (Perten Instruments, Huddinge, Sweden) by passing the NIR light through the test grain placed in the chamber.

Determination of physical and chemical parameters as well as indirect baking quality indicators of the flours

The moisture content of the flour was assessed in accordance with the American Association of Cereal Chemists (AACC) method 44–15.02 [AACC, 2009]. The ash content of the flour was assessed by means of combustion method, in a muffle furnace (Nabetherm, Lilienthal, Germany), in accordance with AACC method 08–01.01 [AACC, 2009]. The contents of total protein and damaged starch (both expressed based on d.w. of grain) as well as Zeleny sedimentation value (mL) were determined using a NIR DA 7200 spectrometer (Perten Instruments). Measurements of wet gluten content and gluten index (GI) were performed in compliance with the PN-ISO method [PN-EN ISO 21415–2:2015–12, 2015] as well as International Association for Cereal Science and Technology (ICC) standard method no. 155 [ICC, 1994] using a Gluten Index System (Glutomatic 2200; centrifuge type

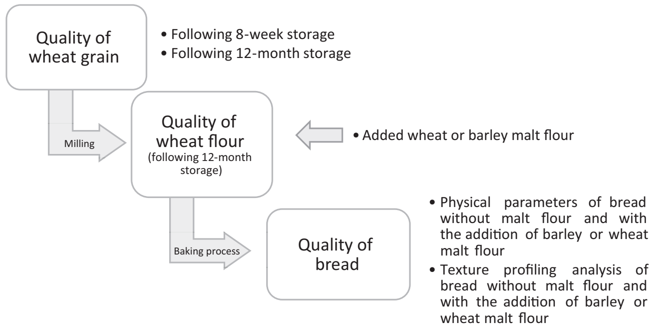

FIGURE 1. Experimental design.

2015; Perten Instruments). Flour water absorption was determined using a Farinograph-E (Brabender), in line with the ICC standard method no. 115/1 [ICC, 1992a]. The analyses were also made for dough, with a consistency of 500 farinograph units (acc. ICC [1992a]), made from flour whose weight was equivalent to the contents of dry matter in 50 g of flour with 14 g/100 g moisture content. The falling number (FN) of flour was determined based on the Hagberg-Perten ICC standard method no. 107/1 [ICC, 1995], using a Perten Falling Number 1800 apparatus (Perten Instruments). Tests were also performed to determine the proportions of malt flour and wheat flour needed to produce a baking blend with FN=250 s, which is an optimal value for wheat flour [ICC, 1995].

In order to assess starch gelatinization, amylographic analyses were performed for wheat flours and the wheat flour blends with the specified addition of wheat malt flour (RW–0.61%; FW–0.67% and KW–0.82%) or barley malt flour (RB–0.49%; FB–0.49% and KB–0.50%). The analyses were performed in accordance with the ICC standard method no. 126/1 [ICC, 1992b] using a Viscograph-E apparatus (Brabender). The flour samples with weights equivalent to the contents of dry matter in 80 g of flour with 14 g/100 g moisture content were mixed with water to achieve the final weight of 500 g. Apparent viscosity was measured at temperatures from 30 to 95°C, with intervals of 1.5°C/min. The values identified in the graph included the maximum apparent viscosity (Brabender unit, BU), gelatinization onset temperature (°C), and gelatinization peak temperature (°C).

Bread baking

Production of dough and the bread baking test were carried out in line with the direct single-phase method, in compliance with the recommendations of the Bakery Institute in Berlin [Jakubczyk & Haber, 1983]. The wheat doughs consisted of flour, yeast (at a rate of 3% relative to the weight of flour), salt (at a rate of 1% relative to the weight of flour), and water in the volume needed to achieve dough consistency of 350 FU. Corresponding samples of wheat dough were made from baking formulation consisting of flour blends with wheat malt flour or barley malt flour, mixed at specified proportions to obtain FN=250 s; the percentage of wheat malt flour was 0.61%, 0.67% and 0.82% for RW, FW, and KW, respectively, and the percentage of barley malt flour was 0.49%; 0.49%, and 0.50% for RB, FB, and KB, respectively. The ingredients were combined in a bowl of a KU2-3E multifunctional food processor (MeskoAgd, Skarżyko-Kamienna, Poland) with dough hooks attached. To achieve uniform consistency, the dough was kneaded for 2 min at 100 rpm and for 1 min at 160 rpm, and then allowed to rest for 45 s. The doughs were placed in a proofing chamber, at a temperature of 30°C and relative humidity of 80% (SvebaDahlen, Fristad, Sweden) for 60 min, with punch-down after 30 min. After the main fermentation process had been completed, the dough was weighed and divided into 250-g chunks. The chunks were manually formed into spherical shapes and inserted into greased baking pans, and placed again in the proofing chamber, to allow the dough to rise. After the proofing process had been completed, the pans with dough were placed in the baking chamber of the Classic modular electric oven (SvebaDahlen). The baking process was carried out at a temperature of 230°C for 30 min. After they had been removed from the oven, the breads were wetted with water for a shiny skin and weighed; subsequently they were left for 24 h at a room temperature.

Determination of baking quality indicators and physical parameters of bread

Dough yield (DY; %) was calculated from the following formula:

$$DY = \frac{a}{m} \times 100\% \quad (2)$$

where: a – dough weight (g) and m – flour weight (g; acc. moisture content of flour – 15 g/100 g) [Sobczyk *et al.,* 2017a].

Cold bread weight (CB; g) was measured by weighing a loaf of bread 24 h after baking (Radwag, Radom, Poland), and baking yield (BY; %) was calculated as:

$$BY = \frac{CB \times DY}{a} \quad (3)$$

The volume of bread (VB; mL) was determined with the Sa-Way apparatus (bread volumeter) (Sadkiewicz Instruments, Bydgoszcz, Poland) according to the AACC method no. 10–05.01 [AACC, 2009]. The volume of bread produced from 100 g of flour (VB100; mL) was computed using the following formula:

$$VB100 = \frac{VB - DY}{a} \quad (4)$$

Specific volume (SV, mL/g) was calculated according to the formula previously used by Krochmal-Marczak *et al.* [2020]:

$$S = \frac{VB}{CB} \quad (5)$$

Crumb porosity, reflecting the relationship between the volume of pores in bread crumb and the overall volume of bread crumb, was assessed using Jakobi's method [Jakubczyk & Haber, 1983]. The determination consisted in cutting bread crumb into cubes with an edge length of 1 cm, removing the air from the crumb by kneading, and measuring the volume of the crumb. The porosity of the crumb (P; %) was calculated using the following formula:

$$P = \frac{a - b}{a} \times 100\% \quad (6)$$

where: a – volume of the bread with the crumb intact (mL), and b – volume of the crumb after pore removal (mL) [Jakubczyk & Haber, 1983].

Loaves of bread obtained from flours of three wheat varieties, both without and with the addition of wheat malt flour or barley malt flour, were cut in half and then photos of the crumb cross-section were taken using a Sony DSC – RX100 MIII digital camera (Tokyo, Japan).

The colour of bread crust and crumb was assessed in the CIELab system (*L*, a*, b**) using a spectrometer (HunterLab, Reston, VA, USA) [El-Sohaimy *et al.,* 2021]. The total colour difference (Δ*E*) between the crumb of the control bread and the bread with the addition of malt flour was also calculated [Martins & Silva, 2002; Patras *et al.,* 2011].

The texture profile of the breads was assessed 24 h after baking using a Brookfield CT3 texture analyzer (Brookfield Engineering Laboratories, Middleboro, MA, USA). The following parameters were measured or calculated: hardness (strength), cohesiveness, springiness, elasticity, gumminess, and chewiness [Sobczyk *et al*., 2017a]. During the test, the sample with a diameter of 10 mm was compressed twice with a 13.5 mm pressing device, with a moving speed of 2 mm/s, whereby deformation of the sample reached half of its height. Interval of 2 s was applied between the cycles.

Statistical analysis

All analyses were done in triplicate (n=3). The acquired results were subjected to statistical analyses using Statistica 13.3. (TIBCO Software Inc., Tulsa, OK, USA). A one-way analysis of variance (ANOVA) with completely randomized design was used with a significance level defined as α=0.05. Tukey HSD test was applied to compare the mean values.

RESULTS AND DISCUSSION

Quality changes of wheat grain during storage and quality characteristics of the flour produced from wheat grain following 12-month storage

Directly after it is harvested, wheat grain presents a low technological value (both for milling and baking), due to which the raw material is stored for 6–9 weeks (post-harvest dormancy) before the grain can be processed by milling, and its products can be used in the food industry. Processes taking place in the grain during this period lead to, *e.g*., improved gluten quality and suppressed amylolytic activity (including mainly α-amylase, which is the main enzyme responsible for the breakdown of starch in wheat grains and increased falling number of flour) [Baik & Donelson, 2018; Zarzycki *et al.,* 2012]. The rate of changes taking place in wheat grains during storage depends on the storage conditions, *i.e*., relative air humidity and temperature, as well as on the water content of the grain [Baik & Donelson, 2018]. Extended storage leads to grain weight loss, followed by moisture content decrease, and is linked with carbon dioxide excretion as well as suppressed activity of enzymes from the group of hydrolases (mainly amylases) and to a lesser extent with the suppressed activity of proteolytic enzymes [Baik & Donelson, 2018]. In our study, the characteristics of the grain of wheat varieties related to the quality of the protein-starch complex were determined, and the results achieved for the grain stored for 8 weeks and for 12 months since harvest are shown in Table 1.

The moisture content of the grain sampled 8 weeks after harvest varied significantly ($p<0.05$), ranging from 12.70 g/100 g d.w. in wheat of Reform variety to 14.90 g/100 g d.w. in wheat of Kilimanjaro variety. After one year of storage in optimum conditions, the moisture content of the grain decreased to 11.4–11.6 g/100 g d.w. (Table 1). The moisture content decrease in the stored wheat grain makes it possible to extend the storage time without compromising grain quality (under controlled storage parameters, including temperature of grain and relative air humidity in the storage facility, *e.g.*, silo). High temperature and moisture content of stored grain enhance degradation of starch contained in wheat and also increase the risk of appearance of storage pests, whose presence and activity in wheat grain significantly reduces its quality [Baik & Donelson, 2018].

The protein content of wheat grain is significantly affected by nitrogen fertilisers applied during the vegetation period, as well as by the environmental conditions and variety-related characteristics [Belcar *et al.,* 2020]. In our study, the total protein content of the Findus variety wheat grain was significantly higher ($p<0.05$) compared to the other two wheat varieties studied (Reform and Kilimanjaro), in which it was similar (Table 1).

Prolonged storage of wheat grain may adversely affect both the content of wet gluten (decrease in glutenin content) and Zeleny sedimentation value [Baik & Donelson, 2018]. The grain Zeleny sedimentation value is an important parameter indirectly indicating its baking quality, and more specifically the quality of gluten, which, as the main component of the flour protein complex, is responsible for bread structure formation [Sobczyk *et al.,* 2017a]. The grain of the studied wheat cultivars sampled 8 weeks after harvest was characterised by a high Zeleny sedimentation value ranging from 51.0 to even 69.0 mL, which decreased significantly ($p<0.05$) only in Findus grain after 12-month storage (Table 1). The content of wet gluten in wheat grain after 8 weeks of storage ranged from 27.20 to 35.70 g/100 g, while after one year of storage, it increased by 16.82% for the Kilimanjaro variety and did not change significantly ($p\geq0.05$) for the other varieties.

TABLE 1. Quality characteristics of grain of different wheat varieties stored for 8 weeks and 12 months after harvest.

Characteristics	Reform		Findus		Kilimanjaro	
	8 weeks	12 months	8 weeks	12 months	8 weeks	12 months
Moisture content (g/100 g)	12.70±0.36^{c}	11.50±0.40^{d}	14.10±0.30^{b}	11.40±0.35^{d}	14.90±0.10^{a}	11.60±0.20^{d}
Total protein content (g/100 g d.w.)	14.00±0.17^{b}	13.60±0.36^{b}	14.80±0.20^{a}	15.00±0.10^{a}	13.60±0.36^{b}	13.90±0.26^{b}
Wet gluten content (g/100 g)	30.60±0.56^{b}	31.80±0.66^{b}	35.70±0.80^{a}	37.00±0.53^{a}	27.20±1.50^{c}	32.70±0.96^{b}
Starch content (g/100 g d.w.)	59.60±1.32^{a}	60.20±1.65^{a}	58.80±1.15^{a}	58.50±0.44^{a}	60.10±0.53^{a}	59.60±1.59^{a}
Zeleny sedimentation value (mL)	51.0±3.6^{b}	52.0±1.7^{b}	69.0±1.0^{a}	51.0±1.7^{b}	58.0±2.7^{b}	56.0±4.0^{b}

Data are expressed as mean ± standard deviation (n=3). Values within rows with different letters are significantly different ($p<0.05$).

TABLE 2. Quality characteristics of the flours produced from grain of different wheat varieties after 12-month storage.

Characteristics	Reform	Findus	Kilimanjaro
Flour yield (%)	80.30±0.81	79.50±0.97	80.40±0.64
Moisture content (g/100 g)	11.71±0.02[a]	11.50±0.04[a]	11.74±0.12[a]
Total protein content (g/100 g d.w.)	14.60±0.35[b]	16.70±0.42[a]	15.30±0.32[b]
Zeleny sedimentation value (mL)	44.0±3.5[a]	46.0±3.0[a]	43.0±3.0[a]
Ash content (g/100 g d.w.)	0.64±0.04[ab]	0.72±0.04[a]	0.61±0.03[b]
Damaged starch content (g/100 g d.w.)	3.77±0.05[c]	4.58±0.05[a]	4.12±0.05[b]
Wet gluten content (g/100 g)	30.02±0.45[c]	36.32±0.21[a]	31.62±0.28[b]
Gluten index	98.00±0.60[a]	94.00±0.06[c]	96.00±0.35[b]
Water absorption (%)	56.30±0.40[c]	63.30±0.06[a]	57.30±0.10[b]
Falling number (s)	571.1±2.1[b]	533.3±1.9[c]	596.0±1.5[a]

Data are expressed as mean ± standard deviation ($n = 3$). Values within rows with different letters are significantly different ($p<0.05$).

The chemical and technological characteristics of the wheat flours from grain stored for 12 months were also determined and the results are shown in Table 2. The ash content of the flours obtained from wheat grains of Reform, Findus, and Kilimanjaro varieties was at a similar level (Table 2). Hrušková *et al.* [2003] analysed ash content of flours with different proportions of the outer layer of the grain (bran), and found that a high ash content was unfavourable as it slightly deteriorated rheological properties of the dough and affected bread volume.

The content of damaged starch in the flours from the investigated wheat varieties ranged from 3.77 g/100 g d.w. (Reform) to 4.58 g/100 g d.w. (Findus) (Table 2). Damage of a starch granule affects the fermentation process, bread crumb structure as well as water absorption by flour during the kneading process [Sobczyk *et al.,* 2017b]. If malt is added, highly active α-amylase contained in it attacks damaged starch and provides a substrate to baker's yeast to initiate dough fermentation (starting dose) before the hydrolytic enzymes contained in the flour provide the substrate to baker's yeast [Hrušková *et al*., 2003].

The total protein content of flour obtained from the wheat grain of the Findus variety was significantly ($p<0.05$) higher compared to the flours from the other wheat varieties analysed (Table 2). The quantity and quality of gluten affect the viscoelastic and rheological properties of the dough obtained. The high quality of gluten causes that a stable gluten network is formed in the dough, which retains carbon dioxide molecules and, as a result, contributes to a high bread loaf volume [Sobczyk *et al.,* 2017a]. In our study, the wet gluten content of the flours did not differ significantly ($p\geq0.05$) between wheat varieties and ranged between 30.02 g/100 g and 36.32 g/100 g (Table 2). The flours were also not differentiated by the Zeleny sedimentation value. The gluten index is a parameter that allows for indirect determination of bread volume and elasticity [Sobczyk *et al.,* 2017a]. Flours obtained from wheat grain stored for 12 months had a gluten index above 94 (Table 2), which proved their good baking quality. Wheat flours with a gluten index above 95 are characterised by high gluten quality and are used for bread making [Sobczyk *et al.,* 2017a].

The water absorption value of flour depends mainly on the quantity and quality of gluten and the starch content and the degree of its damage [Sobczyk *et al.,* 2017a]. The water absorption of the tested flours was significantly differentiated ($p<0.05$), including the highest value determined for the flour obtained as a result of milling wheat grain of the Findus variety (63.3%), which is associated with the high content of gluten in this sample (Table 2).

Effect of barley malt flour or wheat malt flour addition on the falling number of the wheat flour

The falling number describes the activity of flour enzymes that affect bread crumb quality since they promote dough fermentation process. With longer storage time, the activity of α-amylase gradually decreases in wheat grains, leading to a higher falling number of the flour produced [González-Torralba *et al.*, 2013]. The rate of decrease in the activity of hydrolytic enzymes is related to the temperature at which the grain is stored. Storage of wheat grain for a certain period of time at a higher temperature (about 30°C) led to more rapid changes and decrease in the falling number compared to the grain stored for the same duration at a temperature of 15°C [González-Torralba *et al.*, 2013]. The optimum falling number of wheat flours should range from 220 to 250 s [ICC, 1995].

After 12-month storage, the flour produced from the grain had a falling number ranging from 533.3 to nearly 600 s and the value significantly ($p<0.05$) varied among the wheat varieties (Table 2). The addition of barley malt flour turned out to be more effective in reducing the falling number of wheat flour obtained 12 months after the grain harvest, compared to the flour blend with wheat malt flour (lower proportion of barley malt flour by 28.3% compared to wheat malt flour), which was noticed for all tested flours. If malt flour is added to wheat flour, the yeast uses the simple sugars contained in the malt flour in the initial stage of fermentation, and those contained in the wheat flour are used later; thanks to this, the dough fermentation process is faster, and the amount of CO_2 released increases, which significantly affects the texture and moisture content of bread crumb [Hrušková *et al*., 2003]. The addition of barley malt flour or wheat malt flour is a natural method to compensate for a decreased amount of yeast used in the dough [Honciů *et al*., 2015].

Amylograph characteristics of wheat flours with malt flour added

Amylograph may be used to examine changes in the properties of a flour suspension subjected to heating. As shown by earlier research, the addition of malt flour at a rate of 0.2––0.5% led to a decrease in the temperature at which starch gelatinisation begins, and to a decrease in the maximum viscosity compared to the gels obtained from wheat flour without malt flour addition (depending on the malt diastatic power and wheat flour quality) [Hrušková *et al*., 2003]. The results of amylographic tests applied to wheat flours as well as wheat flour blends with malt flours are shown in Figure 2. The maximum viscosity of the flour suspensions varied significantly. On average, the gelatinisation of the suspensions began in the 851th s of the test, whereas the initial temperature of gelatinisation did not differ. The maximum viscosity of the gel was observed in the 1200th s of the test on average, at a temperature of 87.9ºC (RC, FC) or 89.7°C (KC). The addition of barley malt flour reduced the time needed for achieving the maximum viscosity to 801 s and a mean temperature of 69.5ºC, decreasing the time required to achieve the maximum viscosity by 67.2% relative to the control sample (with no malt flour added). The addition of wheat malt flour slightly increased the temperature of maximum viscosity (on average 70.0ºC) compared to the gels comprising barley malt flour, with the same time needed to achieve the maximum viscosity. The maximum viscosity of the gels with wheat malt flour added was in the range from 282 BU in the case of FW to 372 BU in the case of RW sample. In a study by Hrušková *et al.* [2003], the maximum viscosity of wheat gels was found at 489 BU, and the addition of malt flour at a rate of 0.50% decreased it by 50.80% (in flour with ash content of 0.68% d.w.). These high maximum viscosity values identified in wheat gels without malt flour show that starch contained in them had good swelling power but featured suppressed activity of amylolytic enzymes, which was also confirmed by the high falling number (Table 2). The same relationship was reported by Gupta *et al.* [2009]. Amylolytic activity may be reflected by the falling number and by very high viscosity of the wheat gels produced [Zarzycki *et al.,* 2012].

Baking process of bread with malt flour added

Final proofing time of doughs with wheat malt flour added was the same ($p \geq 0.05$) as in the doughs without malt (with the exception of the dough prepared from Findus wheat), whereas the doughs enhanced with barley malt flour needed significantly ($p<0.05$) more time for proofing compared to the control doughs (Figure 3).

Dough yields of the samples obtained from flour produced from wheat grain of the Reform variety with no malt flour added were lower than those of the samples with barley or wheat malt flour added (Table 3). The differences in dough yield in the samples with barley malt flour or wheat malt flour added were statistically insignificant ($p \geq 0.05$) for Reform and Kilimanjaro varieties, whereas the baking yield of the samples with wheat malt flour added was higher than that of the samples with barley malt flour only for Kilimanjaro variety. The addition of malt flours to the wheat flour did not significantly ($p \geq 0.05$) affect the cold bread weight (Table 3).

The volume of bread with malt flour added is affected mainly by amylase activity but also by activities of other enzymes, *i.e.*, hemicelluloses, lipases, proteases, and oxidative enzymes [Mäkinen & Arendt, 2012]. The addition of malt flour at a rate of 0.2–0.5% has been shown to increase bread volume by 4.1% [Hrušková *et al*., 2003]. Based on Gupta *et al.* [2009] research on the properties of wheat and barley starch, it can be assumed that in our study bread volume was positively affected by reduced time needed to begin the gelatinisation process of wheat flour (KC, RC or FC) by the addition of malt flour. The lowest loaf volume was characteristic for bread without malt flour addition (Table 3), while the bread enriched with malt flour had a significantly higher loaf volume, regardless of the wheat flour used (except KB). The highest loaf volume in the group of breads with wheat malt flour added was found in KW sample (613.13 mL), and in the group of breads with barley malt added in FB sample (608.33 mL). The highest volume of loaf made from 100 g of flour was identified in the case of bread produced from Findus wheat flour, both in the samples with no malt added (372.27 mL) and in those with barley malt (402.66 mL) or

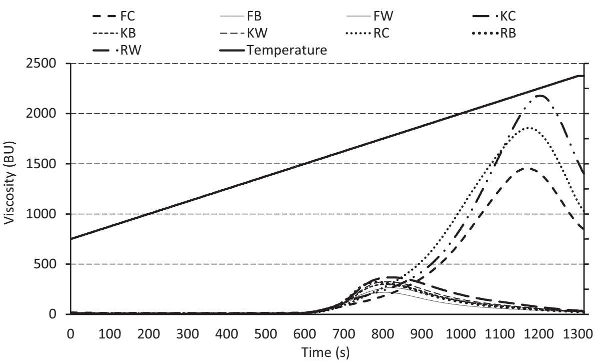

FIGURE 2. Amylogram of flours obtained from wheat of Findus variety (FC), Kilimanjaro variety (KC), Reform variety (RC), and flour blends with barley malt flour addition (B) or with wheat malt flour addition (W).

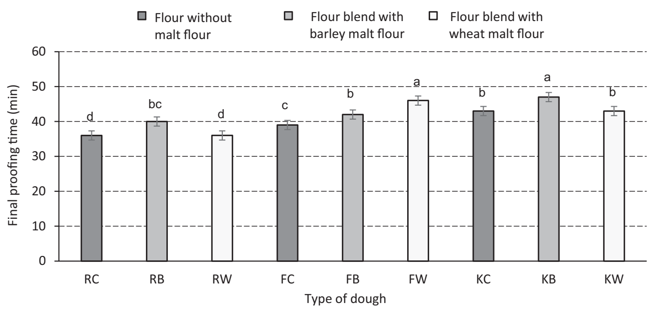

FIGURE 3. Final proofing time of dough obtained from flour of wheat of Findus variety (FC), Kilimanjaro variety (KC), Reform variety (RC), and of dough produced from flour blends with barley malt flour addition (B); or with wheat malt flour addition (W). Different letters above the bars indicate significant differences between the values ($p<0.05$).

TABLE 3. Dough yield, baking yield, and physical parameters of bread made from flours of various wheat varieties and from flour blends with the addition of barley and wheat malt flours.

Bread	Dough yield (%)	Baking yield (%)	Cold bread weight (g)	Loaf volume (mL)	Volume of bread from 100 g flour (mL)	Specific volume (mL/g)	Porosity (%)
RC	159.2±2.8^{e}	133.8±0.2^{cd}	210.4±0.4^{a}	548.3±2.9^{c}	348.7±1.9^{c}	2.61±0.02^{c}	75.20±1.35^{ab}
RB	161.6±1.4^{c}	135.1±1.1^{bc}	209.5±1.7^{abc}	593.3±32.2^{ab}	382.7±20.3^{b}	2.83±0.16^{abc}	64.40±1.55^{f}
RW	161.5±2.1^{c}	134.8±0.1^{c}	209.1±0.2$^{a\text{-}d}$	570.0±13.2^{b}	367.5±8.5^{bc}	2.72±0.06^{bc}	68.70±1.48^{def}
FC	167.0±3.0^{a}	138.0±0.7^{a}	207.0±1.0$^{b\text{-}e}$	558.3±18.9^{b}	372.3±12.3^{bc}	2.70±0.10^{bc}	79.30±1.17^{a}
FB	165.8±2.9^{b}	136.7±0.7^{ab}	206.7±0.7^{de}	608.3±2.9^{a}	402.7±2.4^{a}	2.95±0.10^{a}	66.30±1.50^{ef}
FW	166.5±2.0^{a}	137.4±0.7^{a}	206.5±1.0^{bcd}	608.3±5.8^{a}	404.3±3.8^{a}	2.94±0.02^{ab}	69.60±1.19^{bc}
KC	161.0±2.9^{c}	134.8±0.7^{c}	209.9±1.2^{ab}	568.3±17.6^{b}	365.2±11.2^{bc}	2.71±0.08^{bc}	72.20±1.62^{bcd}
KB	160.5±1.8^{d}	132.0±0.8^{d}	206.0±1.1^{e}	580.0±26.5^{ab}	371.8±16.9^{bc}	2.81±0.12^{abc}	67.10±1.40^{ef}
KW	160.6±2.0^{d}	133.9±0.6^{c}	208.8±1.1$^{a\text{-}e}$	613.3±10.4^{a}	393.2±7.4^{ab}	2.94±0.06^{ab}	73.90±1.66^{bc}

Data are expressed as mean ± standard deviation (n=3). Values within columns with different letters are significantly different ($p<0.05$).
RC, Reform variety without malt; RB, Reform variety with barley malt; RW, Reform variety with wheat malt; FC, Findus variety without malt; FB, Findus variety with barley malt; FW, Findus variety with wheat malt; KC, Kilimanjaro variety without malt; KB, Kilimanjaro variety with barley malt; KW, Kilimanjaro variety with wheat malt.

wheat malt flour (404.28 mL). Hrušková *et al.* [2003] reported the mean volume of loaf made from 100 g of flour with 0.50% addition of malt flour at 359 mL (in the case of flour with mean ash content of 0.55%) and at 345 mL (in the case of flours with a higher mean ash content of 0.68%). On the other hand, Mäkinen & Arendt [2012] reported a slightly lower volume of loaf from 100 g of flour in the case of breads with barley (313 mL) and wheat malt flour (308 mL) added.

Bread crumb should have fine cellular structure (fine pores evenly arranged across the bread crumb), that is a group of interconnected small pores characterised by thin walls and an empty space between these pores; gluten network in the dough should have sufficient elasticity, and the rate of dough growth (release of CO_2) should be moderate so that the cell walls are not disrupted [Mäkinen & Arendt, 2012].

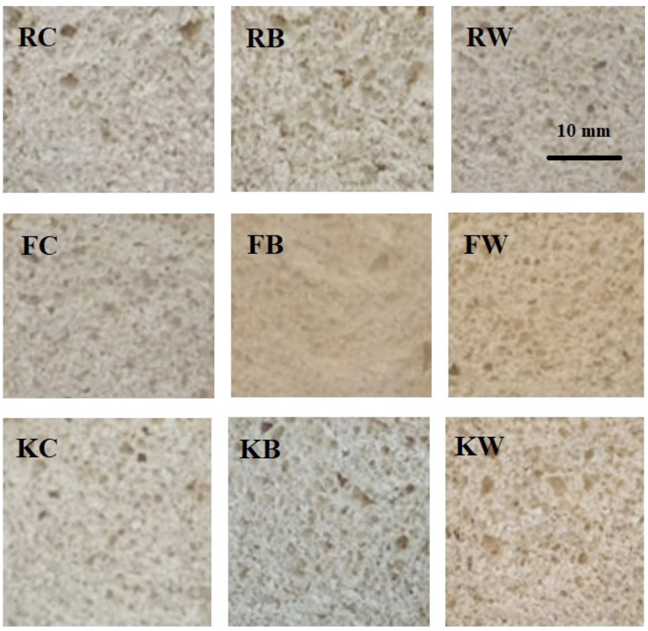

FIGURE 4. Crumb cross section of bread made from flour of wheat of Findus variety (FC), Kilimanjaro variety (KC), Reform variety (RC) and bread made from flour blends with barley malt flour (B) or with wheat malt flour (W).

Porosity of the crumb in breads without malt flour addition was better compared to the porosity of the crumb in the breads with malts added, except for KW (Table 3, Figure 4). The addition of malt leads to an increase in the number of large pores in bread crumb because of the increased activity of amylases which affect the process of fermentation and result in relatively high content of CO_2 in the dough. Amylolytic enzymes contained in malts produce such effects as gas retention in the dough, dough viscosity decrease, and product volume increase [Zadeike *et al*., 2018]. Wheat bread with the addition of barley β-glucan was characterised by a higher loaf volume, a thick-walled crumb with reduced elasticity compared to the control sample [Skendi *et al*., 2010]. Comparative assessment of breads enhanced with malt flour (Table 3, Figure 4) shows that the addition of wheat malt to a lesser degree impaired bread crumb porosity (on average decrease by 6.30% compared to the control sample), relative to barley malt (a decrease by 12.61%).

Bread colour parameters

The colour parameters of the bread crust changed under the influence of malt flour addition to the baking blend, both in the case of wheat and barley malt flours (Table 4). The addition of barley malt flour darkened the crusts of the bread obtained from the flour of each wheat variety (Findus, Kilimajaro, Reform), as did the addition of wheat malt flour, except for KW. The colour of the crust of the bread obtained from blends of flour from two wheat varieties with both malt flours (RB, RW, FB, FW) showed a significantly ($p<0.05$) higher value of the a^* parameter compared to the control samples. In the case of Kilimanjaro variety, the addition of malt (KB, KW) caused no significant ($p \geq 0.05$) change in a^* parameter value. On the other hand, only the b^* value of Kilimanjaro bread crust with the addition of barley malt flour (KB) was

TABLE 4. Colour parameters of crust and crumb of breads made from flours of various wheat varieties and from flour blends with the addition of barley and wheat malt flours.

Bread	Crust				Crumb			
	*L**	*a**	*b**	Δ*E*	*L**	*a**	*b**	Δ*E*
RC	60.33±2.01[a]	12.34±0.99[d]	32.20±0.58[bc]	–	69.58±1.78[ab]	2.62±0.17[a]	20.46±0.51[c]	–
RB	52.86±2.82[bcd]	14.93±1.13[bc]	30.62±0.97[c]	8.12±1.59[a]	67.43±1.46[b]	2.87±0.18[a]	20.53±0.54[c]	2.18±0.65[ab]
RW	52.53±1.58[bcd]	15.37±0.50[ab]	31.03±0.75[c]	8.47±1.05[a]	68.13±1.60[b]	2.83±0.18[a]	20.61±0.49[bc]	1.53±0.96[b]
KC	55.20±1.85[bc]	16.07±0.89[ab]	34.50±1.13[a]	–	71.51±1.64[a]	2.61±0.37[a]	21.06±0.89[a]	–
KB	51.38±1.93[cd]	15.90±0.54[ab]	30.96±0.83[c]	5.41±1.30[b]	68.78±1.23[ab]	2.72±0.31[a]	21.60±0.52[ab]	2.80±2.07[a]
KW	55.63±2.24[b]	15.69±0.56[ab]	33.97±1.02[ab]	2.73±0.52[c]	69.51±1.30[ab]	2.65±0.19[a]	20.82±0.53[abc]	2.79±1.22[a]
FC	56.52±1.62[ab]	13.77±0.89[cd]	31.66±0.72[c]	–	68.57±2.16[ab]	2.72±0.21[a]	20.54±0.34[c]	–
FB	51.43±2.28[cd]	16.48±0.99[a]	31.85±0.62[c]	5.80±2.03[b]	68.44±1.44[b]	2.61±0.27[a]	20.58±0.62[c]	1.10±0.61[b]
FW	49.95±2.59[d]	16.43±0.53[a]	30.77±1.69[c]	7.23±3.35[ab]	67.77±1.28[b]	2.71±0.18[a]	20.34±0.41[c]	1.90±0.30[ab]

Data are expressed as mean ± standard deviation (n=3). Values within columns with different letters are significantly different (p<0.05).
RC, Reform variety without malt; RB, Reform variety with barley malt; RW, Reform variety with wheat malt; FC, Findus variety without malt; FB, Findus variety with barley malt; FW, Findus variety with wheat malt; KC, Kilimanjaro variety without malt; KB, Kilimanjaro variety with barley malt; KW, Kilimanjaro variety with wheat malt.

significantly lower compared to the control sample. The total colour difference Δ*E* of the crust of breads with barley malt flour added ranged from 5.41 to 8.12 (Table 4). These values were high, reflecting the fact that the colour of bread crusts in this case was quite different than in the control samples. In the case of the crust of breads enhanced with wheat malt flour, values of the total colour difference were within a similar range except for the KW sample, where the Δ*E* was low (2.73) but noticeable by individuals with no related expertise. These differences in the colour parameters of bread crust could be due to the Maillard reaction between fermenting sugars derived from the malts and amino acids [Rögner *et al.,* 2021b]. In our previous study, we found that both malt flours were rich sources of reducing sugars, accounting for 1.10% in wheat malt and 1.55% in barley malt (expressed as glucose equivalents), as well as soluble proteins with contents at 3.83% d.w. in wheat malt and 3.97% d.w. in barley malt [Belcar *et al.*, 2020]. Another reason for colour differences could be the more intense caramelisation occurring at a high temperature during the baking process of breads with malts [Yang *et al*., 2020]. Moreover, the higher content of β-glucan in barley malt (456 mg/L) as compared to wheat malt (86 mg/L) [Belcar *et al.*, 2020] could result in a lighter crust and, at the same time, a slight reduction in the colour of the crumb of bread enriched with barley malt flour compared to the control product. Similar results were obtained by Hager *et al.* [2011] for wheat bread with the addition of oat β-glucan.

The values of the crumb colour parameters of the tested breads with the addition of barley and wheat malt flours and the control bread were not significantly differentiated (Table 4). Adekunte *et al.* [2010] classified differences in perceivable colour as: very distinct ($\Delta E>3$), distinct ($1.5<\Delta E<3$), and small difference ($\Delta E<1.5$). In the case of the breads enriched with malt wheat flour, the difference in their crust color (except KW) was very distinct compared to the crust colour of the control breads ($\Delta E>3$), whereas the difference in crumb colour of the breads (except for FB) was distinct compared to the control bread crumb ($1.5<\Delta E<3$). The Δ*E* value for FB was 1.10, indicating a little perceivable colour difference.

Analysis of crumb texture in the investigated breads

Results related to the texture profile of bread crumb made from flours of different wheat varieties and from baking blends with malts are presented in Table 5. Generally, the breads with both barley malt flour and wheat malt flour added presented lower values of texture parameters compared to the breads without malt flour addition. On the other hand, the value of any texture parameter of the crumb of the breads enriched with wheat malt flour did not differ significantly from that of the breads with barley malt flour. The addition of wheat malt flour and barley malt flour led a decrease in bread crumb hardness by on average 26.19% and 27.46%, respectively, compared to the control samples. In a study conducted by Zadeike *et al*. [2018], wheat malt flour was added at a rate of 2% in the process of ciabatta production, leading to 20.5% decrease in its hardness and to 12.6% decrease in its cohesiveness, compared to the control sample. Yang *et al*. [2020] reported that with an increasing amount of malt in the cookies, their hardness decreased (compared to the control sample) and they turned less brittle. The decrease in these parameters was associated with enhanced degradation of starch and protein by enzymes from the group of amylases and proteinases in the doughs with malt added. In turn, Goesaert *et al*. [2009] found that malt flour added to bread delayed the process of crumb hardening owing to both the activity of endoamylases reducing the strength of starch networks and the activity of exoamylases which cause splitting of amylopectins. In a study by Mäkinen & Arendt [2012], the hardness of breads with the addition of malt flour was found to increase with longer duration of storage (0–5 days). The increased wheat malt flour content in the baked products was

TABLE 5. Texture parameters of the crumb of breads made from flours of various wheat varieties and from flour blends with the addition of barley and wheat malt flours.

Bread	Hardness (N)	Cohesiveness	Elasticity	Springiness	Gumminess (N)	Chewiness (N)
RC	16.40±3.32^{a}	0.48±0.03^{cde}	0.25±0.02^{b-e}	11.29±0.25^{b}	7.83±1.59^{a}	6.54±1.36^{ab}
RB	11.85±2.65^{bc}	0.45±0.03^{e}	0.21±0.01^{f}	10.67±0.28^{cd}	5.25±1.04^{b}	4.15±0.84^{cd}
RW	11.57±2.37^{bc}	0.47±0.04^{de}	0.23±0.02^{ef}	10.52±0.33^{d}	5.30±1.05^{b}	4.07±0.94^{cd}
KC	14.68±3.02^{ab}	0.53±0.04^{bc}	0.28±0.02^{b}	11.47±0.34^{ab}	7.74±1.35^{a}	6.58±1.16^{a}
KB	10.33±2.26^{c}	0.51±0.06^{bcd}	0.24±0.02^{cde}	10.75±0.38^{cd}	5.26±1.09^{b}	4.20±0.94^{cd}
KW	10.89±3.72^{bc}	0.51±0.06^{bcd}	0.24±0.04^{def}	11.12±0.31^{bc}	5.60±2.52^{ab}	4.63±2.19^{bcd}
FC	10.88±2.41^{bc}	0.60±0.04^{a}	0.34±0.02^{a}	11.80±0.19^{a}	6.54±1.28^{ab}	5.71±1.12^{abc}
FB	8.16±1.78^{c}	0.55±0.05^{b}	0.27±0.03^{bcd}	11.02±0.40^{bc}	4.43±0.85^{b}	3.64±0.79^{d}
FW	8.35±1.40^{c}	0.56±0.03^{ab}	0.28±0.02^{bc}	11.29±0.27^{b}	4.68±0.81^{b}	3.92±0.71^{cd}

Data are expressed as mean ± standard deviation (n=3). Values within columns with different letters are significantly different (p<0.05)
RC, Reform variety without malt; RB, Reform variety with barley malt; RW, Reform variety with wheat malt; FC, Findus variety without malt; FB, Findus variety with barley malt; FW, Findus variety with wheat malt; KC, Kilimanjaro variety without malt; KB, Kilimanjaro variety with barley malt; KW, Kilimanjaro variety with wheat malt.

associated with a decrease in hardness, compared to the control sample and baked products enhanced with barley malt. Furthermore, these authors found that even a small addition of malts (0.5%) extended the shelf-life of the baked products even with longer storage time. In the present study, the addition of wheat malt flour led to a decrease in the gumminess and chewiness on average by 29.47% and 32.92%, respectively, and the addition of barley malt flour resulted in a mean decrease by 32.42% and 36.32%, respectively, compared to the control samples (Table 5). The values of cohesiveness, springiness, and elasticity also slightly decreased in the baked products with malt flour added, compared to the control samples, which shows that both wheat malt and barley malt flour added to the baking blend in the right proportion positively affects the texture properties of the crumb, which increases attractiveness of the finished product.

CONCLUSION

Long-term storage of surplus wheat grain (*e.g.*, resulting from abundant harvests or high wheat yield) leads to a gradual deterioration of its quality. Wheat and barley malt flours can be added as technological improvers to wheat flour made from long-stored grain. Breads with a small amount of barley malt flour (0.5% on average) or wheat malt flour (0.7% on average) featured higher values of physical parameters, such as loaf volume and specific volume compared to the control breads (without malt flour). The use of malt flour darkened the colour of bread crust and crumb and positively affected the texture profile of the bread produced. Malts are products available all year round, but are slightly more expensive than wheat grain due to the technological processes (malting and drying) used in their production. However, they are added to bread in small amounts, which should not increase the economic costs of the bread making. Wheat grain surplus stored in warehouses can be successfully used for the production of bread enriched with malts flour.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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