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Evaluation of the Possibilities of Using Oat Malt in Wheat Breadmaking

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Abstract: Malt is a natural additive to bread in amounts below 1%. However, there is a lack of research on supplementing bread with a larger dose of malt. The study aimed to evaluate the partial replacement of wheat flour with oat flour (10%) with/without the addition of malted oat flour (0.6%) and scalded malt flour (10%) on the technological and health-promoting quality of bread. At the dough preparation stage, the malted flour was scalded. The dough was prepared using the single-phase method, and laboratory baked goods were prepared using a standard baking test for pan bread. It was found that the preparation of the dough by the preliminary scalding of malt flour resulted in an improvement in the bread volume and a lower increase in crumb hardness during 2-day storage, i.e., delayed staling, compared to the control bread. Replacing wheat flour with 10% oat flour contributed to an increase in the dietary fiber content of bread and a decrease in its energy value. The measurable effect of adding 10% scalded oat malt flour to bread was a 1.5-fold increase in the total polyphenols content and an almost 2.5-fold increase in antioxidant activity compared to bread supplemented with oat flour.

Keywords: oat flour; oat malt flour; scalded malt flour; wheat bread; enriched bread quality; antioxidant potential; delayed staling

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1. Introduction

Bread is the oldest food in the world and is the basic product of the daily diet. It is mainly a source of carbohydrate that supplies the body with energy, as well as proteins, B vitamins, minerals, and compounds with bioactive properties, such as dietary fiber and polyphenols [1,2]. Growing social awareness of a healthy lifestyle and nutrition causes consumers to look for products with a positive impact on health. Industrial production of bread from refined wheat flour may contain insufficient amounts of nutritional and health-promoting ingredients [3–5]. Enriching bread with wholemeal non-bread flour, e.g., oat flour or natural plant products, allows you to obtain a product with functional properties, but not necessarily the desired textural and sensory characteristics [5–8]. In turn, the modern consumer expects fresh bread that will stay fresh for more than one day. Bread is a product with a short shelf life, which is related to the staling process, which is influenced by physico-chemical changes occurring after baking, mainly in the starch structure and the moisture loss [9–11]. Staling of bread is defined as all changes occurring after baking, which lead to loss of freshness and deterioration of the quality of the baked product. These processes intensify at different rates, increasing the hardness and brittleness of the crumb, reducing its elasticity and crispiness of the crust, and also the loss of the pleasant aroma and taste of fresh bread. Amylose recrystallization occurs within the first hours after baking, while amylopectin retrogradation takes place after a longer time. The increase in the hardness of the bread crumb during storage is not necessarily related to water losses, but results from the migration of moisture from the crumb to the crust and the interaction between starch and gluten and its movement between these ingredients. Najafabadi et al. [12] showed that baking and storage conditions of bread influence staling. The staling of bread is one of the reasons for throwing it away, and food waste is a common problem in many societies [13,14]. The demand for bread with good technological, sensory, and functional values, as well as extended shelf life, causes producers to look for various components, especially natural ones, to meet the growing expectations of consumers.

Malt is a properly prepared cereal grain by steeping to allow germination and then kilning it. Currently, almost all cereals, pseudo-cereals, and legumes can be malted. The purpose of malting is to produce sufficient amounts of enzymes in the grain, improve the bioavailability of grain components as a result of the action of these enzymes, increase the amount of bioactive substances, and acquire appropriate sensory properties for the malt [15–23]. Oat malt and other special malts differ from typical malts in terms of their use in brewing, although recently they constitute a valuable raw material addition in the production of special beers [18,19]. Compared to barley and wheat malts, non-traditional brewing malts are usually characterized by lower enzyme activity, which affects lower values of malt quality parameters such as diastatic power, extractivity, Kolbach index, free amino nitrogen, saccharification time of mash, filtration time, and wort viscosity [16,20]. For example, Salamon et al. [16] showed that the diastatic power of a typical malt determining their amylolytic activity for oat malts was on average from 45 (for hulled oat malt) to 72°WK (for naked oat malt) compared to barley malt (average 369°WK). In the study by Mäkinen and Arendt [21], the proteolytic activity of malt ranged from 8.9 for wheat malt to 11.9 U/g for oat malt. Additionally, oat malt had a high lipase activity compared to barley and wheat malts. On the other hand, the study of Gasiński et al. [17] showed that the average concentration of phenolic compounds in the analyzed oat malt samples increased by 466% compared to the oat grain from which they were obtained. For the covered oat Kozak cultivar, this increase was 325%, and for flour cultivars of naked oat grain, it ranged from 427% (for the Polar cultivar) to 527% (for the Maczo cultivar).

In bread baking, adding so-called diastatic malt is used in amounts up to approx. 1% to improve the amylolytic potential of baking mixtures and thus improve the technological and sensory characteristics of the final product [1,24–26]. Karaoğlu et al. [27] reduced the falling number of wheat flour from 539 s to the optimal value (274 $\pm$ 3 s) using the mixture of wheat flour with various types of malt (from cereals and pseudo-cereals) in amounts from 0.570 to 1.902% and commercial enzyme in the amount of 0.0115%. These researchers found that in terms of the rheological properties of the dough, the use of malt flour as a source of enzymes gave better results than the commercially available enzyme. In addition to improving the rheological characteristics of the dough, the addition of malt had a positive effect on the fermentation properties of the dough, such as increasing the fermentation speed, the ability to retain gases, and a larger volume of the bread loaf [3,27–29]. Malt also contributes to an increase in the content of reducing sugars, which may lead to a greater intensity of the Maillard reaction [25,30]. Moreover, according to Honců et al. [25], the addition of malt did not modify the taste of wheat bread but contributed to better crumb texture and extended shelf life of the bread. Because special malts, including oat malt, have lower amylolytic activity than typical brewing malts [16], they can be added in higher quantities to flour, especially those with weaker baking parameters [25,27]. The aim of the research by Mäkinen and Arendt [21] was to assess the impact of oat malt on the properties of bread and dough at a level from 0.5 to 5% compared with barley and wheat malt. Although, the oat malt weakened the extensional properties of the dough, increased bread-specific volume, and did not damage the crumb porosity, possibly because of an improvement of gas cell stability due to a high lipase activity. The results obtained by the authors showed that oat malt in an amount of up to 5% can be used in wheat baking to improve the loaf volume and nutritional quality without the detrimental effects associated with the excess amylolytic activity of barley and wheat malts, because higher doses of these malts, especially above 2.5%, produced loaves with extremely sticky crumbs and even hollow loaves.

In the production of bread, preliminary heat treatment of part of the flour added to the dough is practiced [31–34]. Scalded dough fermentation has become increasingly popular because of its positive effects on product texture, safe quality, and flavor. Based on research carried out by Klupsaite et al. [31], it was shown that the process of scalding wholemeal rye flour increased reducing sugars and maltose content and decreased the content of free amino acids in the scalded flour when compared with rye flour. These researchers also found that the addition of scalded flour had a significant influence ($p \leq 0.05$) on bread shape coefficient, mass loss after baking, and most bread color coordinates. Li et al. [33] reported that gelatinized starch resulting from the scalding process changed the dough microstructure and increased soluble sugar content, and the changed microenvironment of scalded dough affected the growth of microorganisms used for making sourdough bread.

To summarize the literature review, there is still no answer as to whether supplementation of bread with oat malt is possible in amounts above 5% without affecting the technological quality of the final product.

The aim of the study was to assess the possibility of replacing 10% wheat flour with non-bread flour to obtain good-quality bread with nutritional and health-promoting properties. Moreover, the influence of the addition of oat malt without and with scalded malt flour on delaying the staling process of wheat bread was assessed.

2. Materials and Methods

2.1. Materials

2.1.1. Chemicals

All reagents and solvents used for determinations were of reagent and analytical purity. They were produced by companies such as Avantor Performance Materials Poland (Gliwice, Poland), ChemPur (Piekary Śląskie, Poland), Megazyme (Bray, Co. Wicklow, Ireland), Merck (Darmstadt, Germany), and FOSS Analytical (Hilleroed, Danmark).

2.1.2. Flours and Other Baking Materials

The basic study materials were wheat flour type 550 obtained from an industrial mill located in Poland, oat flour, and malt oat flour. The oat flour was obtained from naked oat grain. The naked oat sample for testing was made available by Strzelce Plant Breeding Ltd. PBAI Group (Strzelce, Poland). The oat grain was properly packed and met the requirements for safe grain storage, i.e., humidity below 15% [35]. To obtain the malt flour, the abovementioned naked oat grain was malting on a microtechnical scale at the Prof. Wacław Dąbrowski Institute of Agricultural and Food Biotechnology—State Research Institute using as a standard the procedure for brewing barley according to method 1.5.3 [36]. The steeping of oat grain was carried out to obtain a humidity of 45% as follows: first day—5 h submerged in water and 19 h air rest; second day—4 h submerged in water and 20 h air rest; third day—spraying water to obtain the appropriate degree of grain humidity. The steeping and germination of grain was carried out at an air temperature of 14 ± 1 °C and above 95% relative humidity. After 5 days of grain germination, the malting process was completed by drying. A kilning regime was used of 16 h at 50 °C, 1 h at 60 °C, 1 h at 70 °C, and 5 h at 80 °C. After cooling the malt, the rootlets were removed mechanically. The oat grain and oat malted grain were finely ground into flour (0.2 mm) using a DLFU disc mill (Bühner-Miag, Braunschweig, Germany). In this way, wholemeal oat flour and malted oat flour samples were obtained.

For the preparation of the dough, commercial baker's yeast in compressed form and salt were used.

2.1.3. Preparation of Flour Mixtures for Baking

Wheat flour (WF) and three flour mixtures were used for bread baking, the composition of which is presented in Table 1. All flour samples were thoroughly mixed for 30 min using a 2 L mixer (Chopin Technologies, Villeneuve-la-Garenne, France).

Table 1. The sample code and their description.

Sample Code	Sample Description
WF	wheat flour (control flour)
OF	oat flour
MF	oat malt flour
W-OF	mixture of wheat flour 90%, and oat flour 10%
W-OMF	mixture of wheat flour 90%, oat flour 10%, and oat malt flour 0.6% *
W-MF	mixture of wheat flour 90%, and oat malt flour 10% (without scalding)
WB	wheat bread (control bread)
OB	bread with 10% oat flour
OMB	bread with 10% oat flour and oat malt flour 0.6% *
SMB	bread with 10% scalded oat malt flour

Explanations: *—relative to total flour.

2.2. Methods

2.2.1. Characteristics of Quality Parameter of Basic Flours and Flour Mixtures

The baking value of wheat flour was determined by the Hagberg–Perten falling number (FN) method using an FN 1305 (Perten Instruments, Huddinge, Sweden) according to method ISO 3093 [37] and the gluten content as well as gluten index by mechanical method using a Glutomatic 2200 System (Perten Instruments, Huddinge, Sweden) according to method ISO 21415-2 [38].

In the basic flours, which were used to prepare baking mixtures, the following parameters were determined: the moisture content (M_F) by the gravimetric drying method using a SUP-65 drying oven (Wamed, Warsaw, Poland) according to method ISO 712 [39]; the total nitrogen content by the Kjeldahl method using a Kjeltec 2200 System (FOSS, Hoganas, Sweden) and calculation of the protein content (P_F) using conversion factors (5.7 for WF and 6.25 for other flours, i.e., OF and MF) according to method ISO 20483 [40]; the fat content (F_F) by the Soxhlet method using a 1043 Soxtec System (Tecator, Hoganas, Sweden) according to ISO 11085 [41]; the total ash content (A_F) by the incineration method using an L9/11/SKM muffle furnace (Nabertherm, Lilienthal/Bremen, Germany) according to method ISO 2171 [42]; the total dietary fiber content (TDF_F) including the insoluble ($IN\text{-}DF_F$) and the soluble ($S\text{-}DF_F$) fiber fractions by gravimetric method after enzymatic hydrolysis using a Total Dietary Fiber Kit (Megazyme, Bray, Co. Wicklow, Ireland) and a Fibertec E System (FOSS Tecator, Hoganas, Sweden) according to methods AACC 32-07 [43] and AOAC 991.43 [44].

The carbohydrate content (C_F) in flour samples was calculated from the formula:

$$C_F = 100 - (P_F + A_F + F_F + TDF_F) \quad (1)$$

where:

P_F—protein content of the flour sample, % d.m.;
A_F—ash content of the flour sample, % d.m.;
F_F—fat content of the flour sample, % d.m.;
TDF_F—total dietary fiber content of the flour sample, % d.m.

All test results were expressed in % of dry matter (d.m.), except for the moisture content, which was expressed in %.

The color measurement of basic flour samples was determined in the CIE L*a*b* system using a Chroma Meter CR-310 colorimeter (Minolta, Osaka, Japan). The results were expressed as color parameters L* representing lightness (L = 100 − lightness/L = 0 − darkness), a* (+a = redness/−a = greenness), and b* (+b = yellowness/−b = blueness).

In flour mixtures intended for baking were determined the falling number (FN) by the Hagberg–Perten method using an FN 1305 (Perten Instruments, Huddinge, Sweden) according to method ISO 3093 [37] and the rheological properties of the dough as a function of mixing and temperature increase using a Mixolab apparatus (Chopin Technologies, Villeneuve-la-Garenne, France) according to method ISO 17718 (Chopin+ protocol) [45].

2.2.2. Laboratory Bread Baking Trial

The wheat bread samples were obtained by a standard baking test for pan bread according to Suchowilska et al. [46]. The dough was prepared by one-stage method at 28–30 °C by mixing flour (100%), water (according to water absorption specified by Mixolab plus 3%), baker's yeast (3%), and salt (1%). In the case of oat malt flour (MF), before adding it to the dough, it was subjected to a scalding process, i.e., hydrothermal treatment consisting of mixing flour with water in a 1:2 ratio, heating to a temperature of 85 °C, and then cooling. The dough was mixed in a Heavy Duty mixer (KitchenAid, St. Joseph, MI, USA). The dough in bulk was fermented for 60 min in a proofing chamber at 30 °C/75% relative humidity. Then, after 30 min of fermentation, one kneading by hand was performed. The dough was next divided into pieces with a mass of 250 g each that were molded round and placed in baking pans in a proofing chamber for approx. 35–45 min (the time needed for optimal dough development). The loaves were baked (230 °C, 30 min) in a Piccolo oven (Winkel Wachtel, Hilden, Germany). After baking, the bread samples were cooled, stored at room temperature in polyethylene bags, and assessed after approx. 24 ± 1 h.

2.2.3. Technological Properties and Color Parameters of Bread

The bread loaves were analyzed in terms of specific bread volume (V100) using the millet seed displacement method, and the result was converted to 100 g of bread, the bread crumb moisture content (M) and hardness according to the methodology described by Stępniewska et al. [47]. The crumb hardness 24 and 72 h (H24 and H72, respectively) after baking was determined using an 1140 texture analyzer (Instron, Zurich, Switzerland). The color measurement of bread crumb samples was determined using a Chroma Meter CR-310 colorimeter (Minolta, Osaka, Japan). The bread crumb color results were reported in terms of 3-dimensional color values based on the CIE L*a*b* system. The color parameter C* (chroma) representing saturation (C = 0 − dullness/C = 60 − vividness) was calculated from the formula:

$$C* = \sqrt{(a*)^2 + (b*)^2} \tag{2}$$

where:

*a**—color parameter *a**;
*b**—color parameter *b**.

2.2.4. Chemical Composition and Energy Value of Bread

To determine the chemical composition of the bread, it was cut into slices, and after cutting off the crust, the crumb was cut into pieces 1.0–1.5 cm thick. The pieces were then dried at room temperature for 48 h and ground using a Knifetec 1095 impact mill with cooling (FOSS Tecator, Hoganas, Sweden). The bread samples prepared this way were stored in tightly closed packages at room temperature until analysis.

The assessment of the chemical composition of the obtained bread included the determination of the moisture (M), protein (P) (N × 6.25), ash (A), fat (F), and total dietary fiber (TDF) contents divided into insoluble (IN-DF) and soluble (S-DF) fiber fractions according to the methods described in Section 2.2.1. The carbohydrate content (C) in the bread samples in % of dry matter (d.m.) was calculated taking into account the content of individual bread components according to formula (1). All test results were expressed in % of dry matter (d.m.).

The energy value (EV) of bread was calculated based on the energy content of protein (1 g = 4 kcal), carbohydrate (1 g = 4 kcal), fat (1 g = 9 kcal), and total dietary fiber (1 g = 2 kcal) contained in them. Because the final bread contains water as a non-energy ingredient, the EV of the tested bread samples was estimated per 100 g of the product. For this purpose, the protein, fat, TDF, and carbohydrate contents were converted from % d.m. per %.

EV in kilocalories (kcal) per 100 g of bread was calculated [48] from the formula:

$$EV = (P + C)\cdot 4 + F\cdot 9 + TDF\cdot 2 \quad (3)$$

where:

P—protein content of the bread sample, %;
C—carbohydrate content of the bread sample, %;
F—fat content of the bread sample, %;
TDF—total dietary fiber content of the bread sample, %.

2.2.5. Antioxidant Potential of Bread

The total polyphenols content (TP) and the antioxidant activity as the ability to scavenge DPPH free radicals were determined in the bread samples.

Extract Preparation

The extracts of the bread samples were prepared according to the methodology described by Chlopicka et al. [49]. The powdered bread samples weighing 2.0 ± 0.0001 g were weighed on an analytical balance and extracted for 2 h with 40 mL of solvent consisting of methanol, 0.16 M of hydrochloric acid, and water, mixed in a proportion of 8:1:1, respectively. The extracts were separated by decantation, and the residues were extracted again with 40 mL of 70% (*w*/*v*) acetone for 2 h. The methanol and acetone extract mixture was subsequently centrifuged and used for analysis.

Determination of Total Polyphenols Content with the Folin–Ciocalteu Reagent

Total polyphenols (TP) content was determined by the spectrophotometric method with the Folin–Ciocalteu reagent (ChemPur, Piekary Śląskie, Poland), following the methodology described by Paśko et al. [50]. The sample with added reagents was incubated for 1 h at room temperature in the dark. The absorbance of the solution was measured using a DU-530 spectrophotometer (Beckman, Wycombe, UK) at the wavelength λ = 725 nm against a blank sample. The total polyphenols content was calculated based on the calibration curve prepared for gallic acid (POL-AURA, Zawroty, Poland). The results were expressed in mg of gallic acid equivalent (GAE) per 100 g of dry matter (d.m.).

Determination of Antioxidant Activity by DPPH Assay

The antioxidant activity was determined using the spectrophotometric method with the DPPH radical (1,1-diphenyl-2-picrylhydrazyl; TCI, Tokyo, Japan) based on the methodology described by Chlopicka et al. [49]. The absorbance of the extract was determined using a DU-530 spectrophotometer (Beckman, Wycombe, UK) at the wavelength λ = 514 nm against the blank sample. The antioxidant activity based on the DPPH free radical scavenging ability of the extract was expressed as μM Trolox (Sigma-Aldrich, Buchs, Switzerland) per 1 g of dry matter (d.m.).

2.2.6. Statistical Analysis

The analysis of variance (ANOVA) was performed to compare in the first step the quality parameters of the flour used for baking and in the second step to compare the quality parameters, nutrition value, and antioxidant potential of the obtained bread samples. Tukey's test determined the homogenous groups. All tests were performed with the significance level of $p = 0.05$. All parameters were performed at least in two replicates. Also, the principal component analysis (PCA) was performed to determine to what extent the bread samples differed and which of the study factors had the most significant influence on this. Data were analyzed using the STATISTICA 13 PL program (StatSoft, Cracow, Poland).

3. Results and Discussion

3.1. Chemical and Color Characteristics of Quality of Baking Flours

The chemical characteristics and the color measurement of three types of flour, including wheat flour (WF), and wholemeal non-bread flour samples, i.e., oat flour (OF) and oat malt flour (MF), were evaluated and are summarized in Table 2.

Table 2. Chemical composition and the color parameters of flour samples used for baking.

Indicators/Sample Codes	WF	OF	MF
		Chemical Composition	
M_F (%)	14.08 ± 0.04 ^{c}	10.42 ± 0.02 ^{b}	6.91 ± 0.03 ^{a}
P_F (% d.m.)	12.60 ± 0.06 ^{a}	13.61 ± 0.00 ^{b}	14.30 ± 0.07 ^{b}
F_F (% d.m.)	1.06 ± 0.17 ^{a}	7.42 ± 0.06 ^{b}	8.69 ± 0.17 ^{c}
A_F (% d.m.)	0.50 ± 0.03 ^{a}	2.30 ± 0.04 ^{b}	2.42 ± 0.05 ^{b}
C_F (% d.m.)	82.74 ± 0.06 ^{c}	63.62 ± 0.06 ^{a}	64.35 ± 0.03 ^{b}
TDF_F (% d.m.)	3.15 ± 0.02 ^{a}	13.05 ± 0.04 ^{c}	10.24 ± 0.02 ^{b}
including: $IN\text{-}DF_F$ (% d.m.)	1.47 ± 0.03 ^{a}	10.11 ± 0.03 ^{c}	8.44 ± 0.04 ^{b}
$S\text{-}DF_F$ (% d.m.)	1.68 ± 0.00 ^{a}	2.94 ± 0.01 ^{c}	1.80 ± 0.01 ^{b}
		Color parameters	
L*	90.48 ± 0.06 ^{c}	81.64 ± 0.02 ^{b}	75.98 ± 0.02 ^{a}
a*	−1.94 ± 0.01 ^{a}	0.32 ± 0.05 ^{c}	0.14 ± 0.01 ^{b}
b*	9.95 ± 0.06 ^{a}	10.44 ± 0.03 ^{b}	15.60 ± 0.08 ^{c}

Explanations: M_F—moisture content of flour; P_F—protein content of flour; F_F—fat content of flour; A_F—ash content of flour; C_F—carbohydrate content of flour; TDF_F—total dietary fiber content of flour; $IN\text{-}DF_F$—insoluble dietary fiber content of flour; $S\text{-}DF_F$—soluble dietary fiber content of flour; $^{a\text{–}c}$—homogenous groups at a confidence level of $p \leq 0.05$; the same letters in rows mean no statistically significant differences between the analyzed values of indicators according to Tukey's test; sample codes are described in Table 1.

The moisture content plays an important role during food packaging and transportation [5]. The lowest moisture content was in MF flour (average 6.91%) in comparison with WF and OF, the main reason for which could be found with the malting process. The assessed flour samples were characterized by moisture in the optimal range (below 15%), safe for them during storage. The tested three flour samples differed statistically significantly ($p \leq 0.05$) in all assessed chemical composition parameters (Table 2). The results showed that WF flour was characterized by statistically lower protein, fat, ash, and TDF contents (average 12.60, 1.06, 0.50, and 3.15% d.m., respectively) compared to the OF and MF flour samples (Table 2). However, the carbohydrate content was at the highest level in WF flour (average 82.74% d.m.). Compared to non-bread oat flour (OF), the MF sample had a higher content of protein, fat, ash, and carbohydrates (average 14.30, 8.69, 2.42, and 64.35% d.m., respectively). However, the statistically significant differences were found only for fat and carbohydrate content. In turn, a higher TDF content was found in OF than in MF (average 13.05 and 10.24% d.m., respectively), and in both samples, the insoluble fiber (IN-DF) fraction predominated (Table 2). Similarly, in the study by Benanti et al. [1], commercial wheat malt flour, in comparison with wheat flour, contained more protein, lipid, fiber, and ash contents, and lower carbohydrate content. Tsafrakidou et al. [51] reported that compared to other cereals, wholemeal oat flour contains the most protein and fat, but the least carbohydrates.

Differences between the quantitative composition of wholemeal flour samples obtained with naked oats and corresponding oat malt may result from the vital and biochemical changes that occur in the grain during the malting process. During germination, as the new plant develops, grain respiration is activated and metabolism occurs. At the same time, a pool of enzymes is activated and created, which are responsible for loosening the grain structure as a result of transforming high-molecular reserve substances into water-soluble low-molecular products. The course of these transformations in the grain depends on the conditions of the malting process, such as the degree of humidity, temperature, and time of germination, as well as kilning parameters [4,22,23,52]. Majzoobi et al. [15] reported that different components of the same grain may vary differently or remain unchanged under similar germination conditions. According to the authors, the protein content in sprouted grains depends on the balance between protein breakdown and its biosynthesis during germination. In turn, Hübner et al. [52] proved that extending the germination time and increasing the germination temperature of oat and barley grains contributed to a reduction in the amount of the soluble fraction of dietary fiber, which consisted mainly of beta-glucan. However, an increase in the TDF content and its insoluble fraction was observed. According to these researchers, the increase in insoluble fiber content can be explained by the loss of some components, e.g., starch as a result of grain respiration during germination and the formation of rootlets, which are removed after drying the malt. In addition, the formation of compounds such as celluloses and hemicelluloses as structural elements of growing acrospires is expected. Research by Salamon et al. [16] showed that malting of naked oat grains according to the standard scheme for brewing barley allows the obtaining of special oat malt with parameters similar to typical barley malt used for beer production. Gasiński et al. [17] stated that malting increased the content of phenolic compounds from 44.92–64.39 mg GAE/100 g of grains to 158.06–393.69 mg GAE/100 g of malts and increased the antioxidative activity of grains by 200–300%.

The flour samples used to prepare baking mixtures were analyzed for color parameters using the CIE L*a*b* system. For all assessed color parameters, statistically significant differences were found between the tested flours (Table 2). The L* parameter describing the lightness of color showed the highest whiteness value of 90.48 for wheat flour (WF). The darkest color, with a value of 75.98, was found in the sample of oat malt flour (MF). The a* parameter value of the WF sample was in the green range (average −1.94), and the MF and OF samples were in the red range (average 0.14 and 0.32, respectively). However, the positive values of the b* parameter of all flour samples indicate their yellowness and ranged from 9.95 (for WF) to 15.60 (for MF). The color parameters of tested flours varied, i.e., because of the flour particle size and the share of bran in wholemeal flour samples of OF and MF compared to WF, which can be directly seen in significant, almost five times higher ash content of these flours (Table 2). The color parameters of malt, and in this case malt flour (MF), are largely determined by the products of the reaction of reducing sugars with amino acids formed during drying of "green" malt, i.e., low-molecular-weight compounds of the enzymatic decomposition of starch and protein substances during germination [22,23].

3.2. Characteristics of Quality Parameters of Tested Flour Mixtures

The results of the quality characteristics of the protein and starch complex of flour samples are presented in Table 3. The sample of wheat flour (WF) type 550 was characterized by low alpha-amylase activity, as evidenced by a high falling number of 349 s on average (Table 3). The amount of wet gluten in WF was 28.1% and was suitable for using this flour for bread making. The gluten index was 91, which indicates strong gluten, which may cause difficulties in obtaining good-quality bread [53]. Flours for bread production should characterized by a gluten index value from 60 to 90. Unsuitable for baking are flours with a gluten index that exceeds 95 (too strong) and with a gluten index below 60 (too weak).

The water absorption (WA) of tested wheat flour (WF) at 57.8% indicates that it is very suitable for baking (Table 3). Flour mixture containing 10% oat flour without and with the addition of small amounts of malt flour (W-OF and W-OMF, respectively) did not cause a significant change in WA, despite the rise in dietary fiber and protein contents of the composite flours (Table 2). However, the share of 10% malted oat flour in the mixture with wheat flour (W-MF) significantly reduced the WA to 55.6%. Contrary to Aslam et al. [54] and Abdullah et al. [3], no increase in WA of flour was observed. Obtained by the authors [54], the increase in WA of wheat flour with a 10% share of malted barley flour

(58.77%) compared to wheat flour (58.03%) was only 0.74%, which, from a technological point of view, does not seem to be significant. The results obtained by Nechita et al. [55] were similar to this work. The share of malt flour in the wheat flour mixture caused a slight reduction in water absorption from 62.2 to 61.7% with the addition of only 0.25% of barley malt.

Table 3. The parameters characteristic of protein and starch complexes in tested flour mixtures.

Indicators/Sample Codes	WF	W-OF	W-OMF	W-MF
	Protein Complex Parameters			
G (%)	28.1	n.a.	n.a.	n.a.
GI	91	n.a.	n.a.	n.a.
WA (%)	57.8 ± 0.4^{b}	57.7 ± 0.1^{b}	57.2 ± 0.1^{b}	55.6 ± 0.1^{a}
T1 (min)	1.7 ± 0.0^{a}	6.6 ± 0.5^{b}	5.7 ± 0.8^{b}	2.0 ± 0.2^{a}
S (min)	10.1 ± 0.0^{c}	8.4 ± 0.0^{b}	7.4 ± 0.5^{b}	2.2 ± 0.0^{a}
C2 (N·m)	0.50 ± 0.01^{d}	0.47 ± 0.00^{c}	0.36 ± 0.01^{b}	0.12 ± 0.00^{a}
	Starch complex parameters			
FN (s)	349 ± 6^{c}	354 ± 2^{c}	238 ± 3^{b}	60 ± 1^{a}
C3 (N·m)	2.06 ± 0.02^{c}	$1.98 \pm 0.01^{b,c}$	1.86 ± 0.05^{b}	1.03 ± 0.00^{a}
C4 (N·m)	1.78 ± 0.05^{c}	1.88 ± 0.02^{c}	1.38 ± 0.09^{b}	0.22 ± 0.01^{a}
C5 (N·m)	2.73 ± 0.08^{c}	3.12 ± 0.00^{d}	1.94 ± 0.12^{b}	0.14 ± 0.01^{a}
C3-C2 (N·m)	1.56 ± 0.01^{b}	1.51 ± 0.01^{b}	1.51 ± 0.04^{b}	0.91 ± 0.00^{a}
C3-C4 (N·m)	0.28 ± 0.03^{b}	0.09 ± 0.01^{a}	0.48 ± 0.04^{c}	0.82 ± 0.01^{d}
C5-C4 (N·m)	0.95 ± 0.03^{c}	1.23 ± 0.01^{d}	0.56 ± 0.04^{b}	-0.08 ± 0.00^{a}

Explanations: G—gluten content of flour; GI—gluten index of flour; WA—water absorption of flour; T1—dough development time; S—dough stability; C2—gluten proteins weakening; FN—falling number; C3—starch gelatinization; C4—amylase activity; C5—starch retrogradation; C3-C2—starch gelatinization speed; C3-C4—the enzymatic (α-amylase) degradation speed; C5-C4—starch retrogradation rate; n.a.—not applicable; $^{a-d}$—homogeneous groups when the confidence level was $p \leq 0.05$; the same letters in rows mean no statistically significant differences between the analyzed values of indicators according to Tukey's test; sample codes are described in Table 1.

Stability tested with Mixolab and torque at C2 point are related to gluten quality [56]. The partial replacement of wheat flour with oat flour (W-OF) and the addition of malted flour (W-OMF) strengthened the structure of the dough in the first phase of its creation and significantly extended the development time (time T1) from 1.7 for WF to 6.6 min for W-OF, and 5.7 min for W-OMF, which was consistent with the results of Honců et al. [25] and Zadeike et al. [57]. The 10% share of oat malt in this mixture had no significant effect on time T1. However, the change in dough stability (S) was significantly reduced, which was due to the presence of oat flour (W-OF) and oat flour with malt flour (W-OMF). The greatest reduction was found for W-MF (from 10.1 to 2.2 min), which might have occurred due to disturbance in the natural wheat gluten network. Similar observations were made by El-Hadary et al. [58], who employed both naked and hulled barley malt to produce cookies and found that the dough stability was much lower than that of the control dough made with 100% WF. During the Mixolab test, the dough and the mixer are kept at 30 °C for 8 min. After this time, there is a gradual temperature rise with a gradient of 4 °C/minute. As the temperature increased, the consistency of the dough decreased with excessive mixing, indicating a weakening of the protein [59]. The low values of torque in points C2 indicate that dough is at risk of becoming less stable and weaker during processing. The reduction in C2 after replacing 10% of wheat flour with oat flour (W-OF) was slightly compared to WF. However, the addition to the W-OF mixture of just 0.6% oat malt flour (W-OMF) resulted in a reduction in C2 to 0.36 N·m, indicating that the dough may be inappropriate because of the sticky crumb during mechanical processing. The supplementation of wheat flour with 10% oat malt flour (W-MF) caused a reduction in C2 up to 0.12 N·m, which disqualifies such a dough from processing due to its significant stickiness. In the research of Nechita et al. [55], a small addition of malt (0.25%) also caused a significant reduction to 0.27 N·m compared to the control wheat flour (0.47 N·m).

The importance of level of alpha-amylase activity is crucial for the dough fermentation process and obtaining high-quality bread. The tested control wheat flour (WF) sample was characterized by low alpha-amylase activity (FN average 349 s) (Table 3). The addition of oat flour (OF) caused a slight increase in the falling number value; however, it was not statistically significant. On the other hand, the addition of 0.6% malt flour (MF) to wheat flour with 10% oat flour (W-OMF) caused the reduction in the falling number (average 238 s) to the optimal level for breadmaking. However, the use of 10% of oat malt flour to wheat flour (W-MF) resulted in a significant increase in alpha-amylase activity, to a level that was unacceptable from a technological point of view. Bread made from this mixture would have an incorrect appearance, with loose and sticky crumb, and dark crust.

The tested wheat flour (WF) was characterized by typical starch characteristics measured by Mixolab as C3 (starch gelatinization), C4 (amylolytic activity), and C5 (starch retrogradation) (Table 3) for wheat flour produced in Poland [60]. Compared to control flour (WF), the addition of 10% oat flour to wheat flour (W-OF) caused a slight increase in C4 (average from 1.78 to 1.88 N·m, respectively), and a significant increase in the C5 parameter (average from 2.73 to 3.12 N·m, respectively), which indicates that starch retrogradation in the obtained bread will occur faster. The share of oat flour and oat malt (W-OMF) resulted in a significant reduction in the C3, C4, and C5 parameters (average 1.86, 1.38, and 1.94 N·m, respectively) to the levels optimal for breadmaking. Nevertheless, replacing 10% of wheat flour with oat malt flour (W-MF) caused a sharp reduction in these parameters. It may be the effect of the high availability of water already at the stage of gelatinization of starch, released by gluten proteins as a result of weakening their structure by proteolytic enzymes present in malt. The decrease in C3 values is higher (2-fold) in W-MF (average 1.03 N·m) as compared to the control sample (average 2.06 N·m), probably also due to starch dilution and the high content of fat and polysaccharides in oat malt. In addition, the starch gelatinization process is influenced by the amylase–lipid complex formation, the amount of amylose leaching, the competition for free water between leached amylose and remaining non-gelatinized granules [2,61].

In the test conducted in Mixolab, the recording of the pasting properties of dough begins after the temperature of the dough is above 60 °C—then the C3 torque and the difference C3-C2 are calculated, associated with the starch gelatinization process [2]. The composition of W-OF and W-OMF flour mixtures compared to WF (average 1.51 and 1.56 N·m, respectively) did not cause significant differences between the C3 and C2 parameters (Table 3). However, the smallest reduction was found in W-MF (average 0.91 N·m), which was characterized by an almost 2-fold lower C3 value than WF.

The difference between the C3 and C4 (C3-C4) parameters, which corresponds to amylase activity and is linked to falling number, varies significantly between tested mixture flours (Table 3). The lowest difference in the C3-C4 value was found for W-OF compared to WF (average 0.09 and 0.28 N·m, respectively), which might be explained by the fact that gelatinized starch with the W-OF mixture was not susceptible to the action of amylases in the dough (as it was seen from the FN values). It was stable during the hot starch stability paste phase. The higher differences in the C3-C4 value were found for W-OMF (with 0.6% addition of diastatic malt flour; average 0.48 N·m), while almost three times higher in the mixture of wheat flour with 10% addition of malt flour (W-MF).

The C5 torque and the differences between the C5 and C4 (C5-C4) parameters represent the starch retrogradation during the cooling period and correspond to the anti-staling effects [2]. Compared to wheat flour (WF), the C5-C4 value increased after replacing it with 10% oat flour (W-OF) (average from 0.95 to 1.23 N·m, respectively) and decreased after adding 0.6% malted oat flour to the W-OF (in W-OMF mixture to average 0.56 N·m) (Table 3). A negative value of the difference of the C5-C4 (average, −0.08 N·m) determined for the mixture with 10% malt flour (W-MF) indicates that the retrogradation process may not occur because the dough contains too many amylases, released water, and is too sticky.

Taking into account the results discussed above and the research on wheat flour with 10% addition of oat malt flour (W-MF), it was decided to use preliminary thermal treatment of malt flour (MF) in the further part of the research. The process of scalding malt flour at the stage of bread dough preparation is aimed at reducing its enzymatic activity, mainly amylases and proteolytic, lipolytic, and cytolytic enzymes, while introducing starch and protein degradation products generated during oat grain germination into the dough. Moreover, as reported by Klupsaite et al. [31], the use of brewer's malt flour may contribute to increasing the content of reducing sugars and maltose.

3.3. Characteristics of Technological Properties and Color Parameters of Bread

The results of the technological quality and color parameters of the tested bread are shown in Table 4.

Table 4. The technological value and color parameters of control and enriched bread.

Indicators/Sample Codes		WB	OB	OMB	SMB
		Technological Value			
V100 ($cm^3/100$ g)		357 ± 1 ᵇ	274 ± 2 ᵃ	289 ± 4 ᵃ	365 ± 3 ᵇ
M (%)		41.8 ± 0.1 ᵃ	43.6 ± 0.1 ᶜ	42.8 ± 0.0 ᵇ	42.6 ± 0.1 ᵇ
H24 (N)		7.6 ± 0.3 ᵃ	13.0 ± 0.3 ᶜ	11.3 ± 0.3 ᵇ	6.6 ± 0.3 ᵃ
H72 (N)		11.8 ± 0.7 ᵇ	19.6 ± 1.4 ᶜ	14.3 ± 0.6 ᵇ	8.1 ± 0.3 ᵃ
H72-H24 (N)		4.2 ± 0.3 ᵃ,ᵇ	6.6 ± 1.7 ᵇ	3.0 ± 0.2 ᵃ,ᵇ	1.5 ± 0.0 ᵃ
		Color parameters			
Crumb	L*	74.87 ± 0.17 ᵈ	72.33 ± 0.37 ᶜ	70.56 ± 0.13 ᵇ	67.37 ± 0.21 ᵃ
	a*	-0.75 ± 0.03 ᵃ	0.44 ± 0.04 ᵈ	0.21 ± 0.01 ᶜ	0.07 ± 0.03 ᵇ
	b*	17.76 ± 0.29 ᵃ	19.81 ± 0.03 ᵇ	20.26 ± 0.09 ᵇ	24.01 ± 0.11 ᶜ
	C*	17.8 ± 0.3 ᵃ	19.8 ± 1.6 ᵇ	20.3 ± 0.0 ᵇ	24.0 ± 0.3 ᶜ

Explanations: V100—specific bread volume; M—bread crumb moisture content; H24—bread crumb hardness after 24 h; H72—bread crumb hardness after 72 h; H72-H24—increase the bread crumb hardness during two days of storage; a–d—homogeneous groups when the confidence level was $p \leq 0.05$; the same letters in rows mean no statistically significant differences between the analyzed values of indicators according to Tukey's test; sample codes are described in Table 1.

The specific volume (V100) of the assessed bread samples ranged from 274 to 365 $cm^3/100$ g (Table 4). The control bread (WB) and the bread made from dough with scalded oat malt flour (SMB) were characterized by a significantly higher V100 (average 357 and 365 $cm^3/100$ g, respectively) compared to OB and OMB (average 274 and 289 $cm^3/100$ g, respectively). In accordance with the requirements of the Polish standard [62] for the specific volume (V100) of wheat bread, the WB and SMB bread samples obtained a very good rating (not less than 321 $cm^3/100$ g). However, the V100 of bread enriched with 10% oat flour, i.e., OB and OMB samples, was assessed sufficiently (V100 in the range of 290–200 $cm^3/100$ g). The replacement of 10% wheat flour with OF flour led to a decrease in V100 by an average of 23.2% compared to the control bread (WB). Also, in many studies [21,63–65], the bread made from wheat flour with the addition of oat flour was characterized by significantly lower volume. The replacement of wheat flour with oat flour reduced the amount of gluten proteins, i.e., gliadin and glutenin in flour, which caused a diminishing in the quantity of gluten and a deterioration of bread volume. The study revealed that, unlike oat flour, the addition of scalded malted oat flour had a positive impact on the bread volume. The specific volume of SMB bread was higher by approx. 2.2% compared to WB and amounted to an average of 365 $cm^3/100$ g. The difference was not statistically significant ($p > 0.05$). In this case, the 10% share of scalded MF in the mixture with WF did not interfere with the formation of the gluten matrix in the dough, because the high-molecular-weight polymers of non-starch carbohydrates originating from oats were mostly decomposed into simple compounds during malting, and the remaining ones in the malt were released during the scalding process and did not compete for water while creating the gluten network. In addition, the introduction into the dough of low-molecular protein breakdown products (in malting), such as amino acids and polypeptides, did not contribute to the weakening of the structure of the gluten network. The high content of simple sugars in the malt intensified the fermentation of the dough and gas formation; however, the intact gluten network contributed to the retaining of them in the dough, which increased the volume of the bread. Very similar observations were made by Klupsaite et al. [31], who used scalded rye flour to produce semi-wheat–rye bread.

The tested bread samples significantly differed in bread crumb moisture (Table 4). The crumb of control bread had statistically lower moisture content (average 41.8%). Among the tested bread samples, the bread with 10% oat flour (OB) had the highest moisture content (average 43.6%). The higher moisture content in OB compared to the control bread (WB) may result from binding larger amounts of water by oats beta-glucan, which constitutes the soluble fraction of dietary fiber. In the studies by Krochmal-Marczak et al. [64], the moisture content of the control wheat bread was 41.3%, while the moisture content of oat–wheat bread, with 30% oat flour content, was 44.5%. According to a study conducted by Sobczyk et al. [66], the increase in oat flakes addition caused an increase in the moisture content of the finished product. In turn, the addition of only 0.6% of malt flour (MF) to the W-OF mixture probably contributed to the partial enzymatic hydrolysis of beta-glucan during dough fermentation, which resulted in lower crumb moisture (average 42.8%) and a higher specific volume of the OMB sample (Table 4). Generally, the bread samples with the addition of malt flour (MF), i.e., OMB and SMB, were characterized by significantly higher bread crumb moisture content (average 42.8% and 42.6%, respectively) compared to wheat bread (WB).

The tested bread samples differed significantly in terms of bread crumb hardness determined 24 and 72 h after baking (H24 and H72, respectively). These studies revealed that compared to the other evaluated bread samples, the 10% addition of scalded MF to the wheat dough contributed to the greatest reduction in the bread crumb hardness 24 and 72 h after baking (average 6.6 and 8.1 N, respectively) (Table 4). Similar results were demonstrated by Murniece et al. [32], who studied the impact of scalded rye flour on the technological quality of rye bread. The above studies revealed that rye bread samples prepared with scalded rye flour were characterized by a softer crumb compared to control rye bread (without scalded flour). Compared to the SMB bread sample, both WB and OMB were characterized by higher bread crumb hardness values at H24 and H72 (for WB on average 7.6 and 11.8 N, respectively, and for OMB on average 11.3 and 14.3 N, respectively). Replacing 10% of WF with OF flour samples resulted in a 71.1% increase in the H24 of the OB compared to the WB bread samples, while the addition of the same amount of scalded MF flour to the wheat flour resulted in a 13.2% decrease in the H24 of the SMB bread crumb. In the case of SMB and control bread (WB) samples, no statistically significant differences were found in terms of crumb hardness after 24 h (H24), while these differences were significant in samples stored for 72 h (H72). Compared to all tested bread samples, the crumb hardness with 10% oat flour (OF) was characterized by the highest values of H24 and H72 (average 13.0 and 19.6 N, respectively). The OMB bread compared to OB was characterized by slightly lower hardness because the enrichment of OF flour with the addition of 0.6% MF without its scalding enabled better loosening of the bread crumb. Similarly, in the study conducted by Mäkinen and Arendt [21], the bread samples with the addition of 0.5 to 5.0% oat, barley, and wheat malt flour were characterized by lower hardness compared to the control bread (without malt flour addition). However, bread samples supplemented with oat malt showed higher crumb hardness (average in the range of 4.6–5.3 N) than those supplemented with wheat and barley malts (average in the range of 2.5–4.5 N and 2.7–5.1 N, respectively). According to Yang et al. [67], the reduction in cookie crumb hardness caused by the addition of wheat malt flour was associated with enhanced degradation of protein and starch by enzymes such as amylases and proteinases. Whereas, Goesaert et al. [68] noticed that malt flour reduces bread crumb hardness by the action of exoamylases that split amylopectins and the action of endoamylases that reduce the starch strength.

Among all tested bread samples, the SMB bread was characterized by the lowest statistical increase in bread crumb hardness during two days of storage on average, 1.5 N (calculated from the difference in hardness H72-H24) compared to the OMB, WB, and OB (with average 3.0, 4.2 and 6.6 N, respectively) (Table 4). Generally, bread with the addition of MF (without and with scalded) to the baking mixture led to a slowdown of the staling process. The anti-staling properties of SMB and OMB were probably related to the interactions of low-molecular-weight dextrins from malt with starch and gluten from wheat flour. Klupsaite et al. [31] revealed that scalded flour reduced the staling process because the crumb bread prepared with wheat flour mixed with scalded rye flour was characterized by lower hardness after 72 h of storage compared to control bread. In turn, in a study by Mäkinen and Arendt [21], the increase in the bread crumb hardness with the addition of malt flour after 5 days (120 h) of storage was much lower than that of the control sample and decreased with the increase in the addition of malt flours in the bread samples. Extending the shelf life (delaying staling) of bread seems to be important for reducing food waste. According to respondents, the most frequently thrown-away products included fruit and vegetables, followed by bread [13,14]. Reducing the problem of food waste should lead to decisive actions aimed at educating consumers according to the idea of "Don't waste food", because bread and bakery products account for more than 50% of total food waste [69]. Undoubtedly, stale bread can have a positive impact on health because, compared to fresh bread, it contains larger amounts of resistant starch (RS), which is part of soluble dietary fiber [9,10]. The results of the study by Amaral et al. [9] indicate that it is possible to increase the RS content in wheat bread by modifying the processing conditions. Keeping the bread at room temperature for 3 days contributed to increasing the RS content by over 26%, and at a temperature of 4 °C by almost 13% compared to fresh bread (without storage).

The color is one of the most important distinguishing features that, in the opinion of consumers, may reflect the final quality of the product. The value of the L* parameter of bread crumb ranged on average from 74.87 to 67.37 (for WB and SMB, respectively), which seems to correspond to the L* parameter determining the lightness/darkness of flour samples used for baking bread (Table 2). The a* parameter of the crumb of the analyzed bread samples ranged from green, on average −0.75 for WB, to red, with average values ranging from 0.07 to 0.44 for SMB and OB, respectively. The tested bread samples differed statistically significantly in terms of the L* and a* parameters. The value of the color parameter b* for all tested bread samples ranged from yellow on average from 17.76 to 24.01 (for WF and SMB, respectively). Similar relationships were observed by Belcar et al. [24] when assessing the color parameters of the crumb of bread with the addition of barley or wheat malt flour. The color parameter C* indicates the purity of the color. The value of the color parameter C* of the tested bread samples ranged from 17.8 (for WB) to 24.0 (for SMB), which allows for the assessment of the saturation and brightness of the crumb color of the tested bread samples to define them as very pale to pale. Bread samples with added malt (i.e., OMB and SMB) showed significantly higher saturation values than the control sample (WB).

Compared to the control bread (WB), the bread enriched with MF was rated as having the highest technological quality, both with a 10% addition of non-bread oat flour (OMB) and with the addition of scalded malt flour to the dough (SMB). An increase in the degree of rising of the bread, an improvement in the porosity of the crumb, as well as an enrichment of the aroma and taste of the bread with the abovementioned ingredient were found. OB bread with 10% wholemeal oat flour was rated the lowest. Partial replacement of WF with oat flour OF, which does not belong to bread flour, harmed the crumb characteristics and aroma of the bread. The bread was less risen, the crumb had slightly reduced elasticity, less uniform porosity, and a tendency to crumble, and there was a noticeable bitter aftertaste. Similar observations were made by Wójcik et al. [7], who proved that the addition of black oat flour higher than 15% caused the bread crumb to crumble and become less elastic, and its taste was slightly bitter. Salehifar and Shahedi [70] found that the bitter aftertaste of bread supplemented with oat flour may come from non-volatile, bitter components that are products of lipid oxidation by lipoxygenases. Moreover, the bitterness of stored oat flour is attributed to the formation of specific hydromonoglycerides.

3.4. Characteristics of Nutritional Value and Antioxidant Potential of Bread

The results of nutritional and energy value as well as the antioxidant potential of the tested bread are shown in Table 5.

Table 5. The nutritional value and the antioxidant potential of control and enriched bread.

Indicators/Sample Codes	WB	OB	OMB	SMB
	Nutritional Value			
P (% d.m.)	12.82 ± 0.04 ^{a}	12.92 ± 0.05 ^{a,b}	13.08 ± 0.05 ^{b}	13.11 ± 0.07 ^{b}
F (% d.m.)	0.16 ± 0.00 ^{a}	0.25 ± 0.03 ^{b}	0.22 ± 0.01 ^{a,b}	0.28 ± 0.01 ^{b}
C (% d.m.)	82.18 ± 0.09 ^{c}	81.44 ± 0.00 ^{b}	81.30 ± 0.08 ^{a,b}	81.18 ± 0.04 ^{a}
TDF (%)	1.91 ± 0.01 ^{a}	2.19 ± 0.01 ^{b}	2.18 ± 0.01 ^{b}	2.28 ± 0.03 ^{c}
TDF (% d.m.)	3.29 ± 0.03 ^{a}	3.88 ± 0.03 ^{b}	3.80 ± 0.02 ^{b}	3.78 ± 0.04 ^{b}
including: IN-DF (% d.m.)	2.49 ± 0.01 ^{a}	2.79 ± 0.00 ^{b}	2.81 ± 0.01 ^{b}	2.91 ± 0.01 ^{c}
S-DF (% d.m.)	0.80 ± 0.05 ^{a}	1.09 ± 0.03 ^{c}	1.00 ± 0.04 ^{b,c}	0.88 ± 0.05 ^{a,b}
EV (kcal/100 g)	226 ± 1 ^{c}	219 ± 1 ^{a}	221 ± 0 ^{b}	222 ± 0 ^{b}
	Antioxidant potential			
TP (mg GAE/100 g d.m.)	49.3 ± 2.2 ^{a}	60.2 ± 3.8 ^{a}	60.6 ± 5.0 ^{a}	89.8 ± 1.8 ^{b}
DPPH (µM Trolox/g d.m.)	0.54 ± 0.00 ^{a}	0.67 ± 0.04 ^{a,b}	0.76 ± 0.03 ^{b}	1.63 ± 0.04 ^{c}

Explanations: P—protein content of bread; F—fat content of bread; C—carbohydrate content of bread; TDF—total dietary fiber content of bread; IN-DF—insoluble dietary fiber of bread; S-DF—soluble dietary fiber of bread; EV—energy value of bread; TP—total polyphenol content of bread; DPPH—antioxidant activity by DPPH assay of bread; $^{a–c}$—homogeneous groups when the confidence level was $p \leq 0.05$; the same letters in rows mean no statistically significant differences between the analyzed values of indicators according to Tukey's test; sample codes are described in Table 1.

The control bread (WB) was characterized by statistically lower protein, fat, and TDF contents (average 12.82, 0.16, and 3.29% d.m., respectively), as well as statistically higher carbohydrate content (average 82.18% d.m.) compared to the other tested bread samples (Table 5). Meanwhile, the total dietary fiber (TDF) content ranged on average from 3.29 to 3.88% d.m. (for WB and OB, respectively). Considering that the dietary fiber content in 100 g of bread supplemented with 10% non-bread flour ranged from 2.18 to 2.28 g (for OMB and SMB, respectively) (Table 5), in light of EU legislation [71], these products could not be included in the criteria for using a nutrition and health claim. The data obtained for the bread samples seem to be consistent with the results of the TDF content in the flour samples used in this study (Table 2). The statistically higher contents of insoluble dietary fiber (IN-DF) were found in SMB (average 2.91% d.m.), and the lowest in the control wheat bread (average 2.49% d.m.). The share of the soluble dietary fiber fraction (S-DF) in the bread samples (Table 5) constituted approx. ¼ of total dietary fiber content (TDF). The highest soluble dietary fiber (S-DF) was found in bread samples supplemented with oat flour, i.e., OB and OMB (about 1.0% d.m.). Oat flour and other oat products are a rich source of beta-glucan, which constitutes the soluble fiber fraction (S-DF) and thus substances with health-promoting properties [22,72–74]. Research by Krochmal-Marczak et al. [64] proved that replacing part of wheat flour in the recipe with a 30% addition of oat flour resulted in a significant increase in the beta-glucan content (almost 3-fold) and the TDF content (over 4-fold) compared to wheat bread (control sample). Redaelli et al. [75] reported that the total beta-glucan content in the assessed European oat genotypes ranged from 2.85 to 6.77% d.m., and the soluble fraction from 2.05 to 5.29% d.m., which constituted 50.7–87.0% of their total content. During the malting process, the beta-glucan present in the grain is broken down by cytolytic enzymes (mainly beta-glucanases) [15,22,23]. Hübner et al. [52] observed a decrease in the beta-glucan and the S-DF contents in oat malt as the germination time was extended and the germination temperature was increased. In the study by Salamon et al. [16], the beta-glucan content in the obtained oat malt samples used as a standard scheme for brewing barley ranged from 0.04 to 0.10% d.m., and in barley malt sample was 0.42% d.m. Therefore, lower beta-glucan content was expected in oat malt flour (MF). It should be mentioned that from a health point of view, the soluble dietary fiber (S-DF) fraction is more desirable, as it has a beneficial effect on the intestinal microbiome, regulates glucose levels, and lowers blood cholesterol levels. On the other hand, the insoluble fiber fraction (IN-DF) increases the feeling of satiety and binds bile acids, thus inhibiting their transformation into carcinogenic compounds [63,72,73,76].

The results of the energy value (EV) of the tested bread, presented in Table 5, indicate that the EV ranged from 219 kcal/100 g (for OB) to 226 kcal/100 g (for WB). The bread samples supplemented with MF flour, i.e., OMB and SMB, showed lower EV than control bread (WB). The EV of the tested bread samples consisted of energy coming mainly from carbohydrates, which provide the body with approx. 84% of energy, and to a lesser extent proteins, whose share was approx. 13.5%. Wyka et al. [10] showed an increase in the energy value of bread during its storage. The observed changes were caused by processes occurring during the staling of bread. On the one hand, changes in the starch structure, including through slow retrogradation of amylopectin to resistant starch, reduce the energy value of bread, because RS is part of the dietary fiber [9]. However, the loss of water, including migration from the crumb to the crust of bread, resulted in a decrease in the weight of the bread and, consequently, an increase in the percentage of ingredients remaining in the bread concerning the entire tested sample.

The results of the total polyphenols (TP) content in the tested bread samples and their antioxidant capacity measured by DPPH radical scavenging are shown in Table 5. The TP content in bread samples ranged from 49.3 to 89.8 mg GAE/100 g d.m. (WB and SMB, respectively). Chlopicka et al. [49] observed a reduction in the total phenolic and total flavonoid contents in bread compared to the flour used for baking. According to the authors, the antioxidant compounds present in flour may be damaged or degraded as a result of the thermal processes during baking, although losses of these substances probably also occur during the mixing and kneading of the dough. Replacing wheat flour (WF) with 10% OF contributed to an increase in the content of total polyphenols in OB bread, on average by approx. 22% (i.e., average from 49.3 to 60.2 mg GAE/100 g d.m.) compared to the control bread (WB). When the same dose of scalded malt flour (MF) was added to the dough, the amount of polyphenols in SMB bread increased on average by 40.5 mg GAE/100 g d.m., which in percentage terms increased by approx. 82%. These data indicate that malts are a rich source of compounds with bioactive properties, as previously reported by other researchers [15,77–79]. Antioxidants produced during the malting process of grains have numerous documented health benefits, including anticancer, blood cholesterol and blood pressure lowering, antidepressants, and prevention of type 2 diabetes and its complications [80]. Majzoobi et al. [15] reported that the bioactive compounds and antioxidant activity in grains often increase during germination. According to the authors, the increase in the polyphenols content may be due to the activation of an enzyme supporting the biosynthesis of polyphenols and enzymatic hydrolysis of polyphenol components bound carbohydrates and proteins in cell walls. Leitao et al. [78] found that during the malting process, the total polyphenols content in malt increased 4-fold compared to barley, and this difference was mainly due to higher concentration of *p*-coumaric, ferulic, and sinapic acids in the malt. In a previous study by Salamon et al. [16], the total polyphenols content determined in hulled oat malts ranged from 215 to 245 mg GAE/100 g d.m., and in naked oat malt and barley malt samples, the values were 305 and 342 mg GAE/100 g d.m., respectively.

The antioxidant activity in bread was closely correlated with the content of total polyphenols content (TP), as reported by researchers [16,49,73,77,81]. The rate of scavenging the DPPH free radical (Table 5) determined in bread with 10% of scalded oat malt flour (SMB) was an average of 1.63 µM Trolox/g d.m., and the antioxidant activity was approx. 3-fold higher than that in the control bread (WB). The result of supplementing wheat flour (WF) with oat flour (OF) was an increase of approx. 24% in the antioxidant activity of OB bread (average 0.67 µM Trolox/g d.m.) compared to the control WB sample (average 0.54 µM Trolox/g d.m.).

3.5. Comprehensive Assessment of the Quality Parameters, Nutritional Value, and Antioxidant Potential of Bread Samples Using Principal Component Analysis (PCA)

A comprehensive assessment of the quality parameters, nutritional value, and antioxidant potential of the tested bread samples was presented using Principal Component Analysis (PCA), as illustrated in Figure 1.

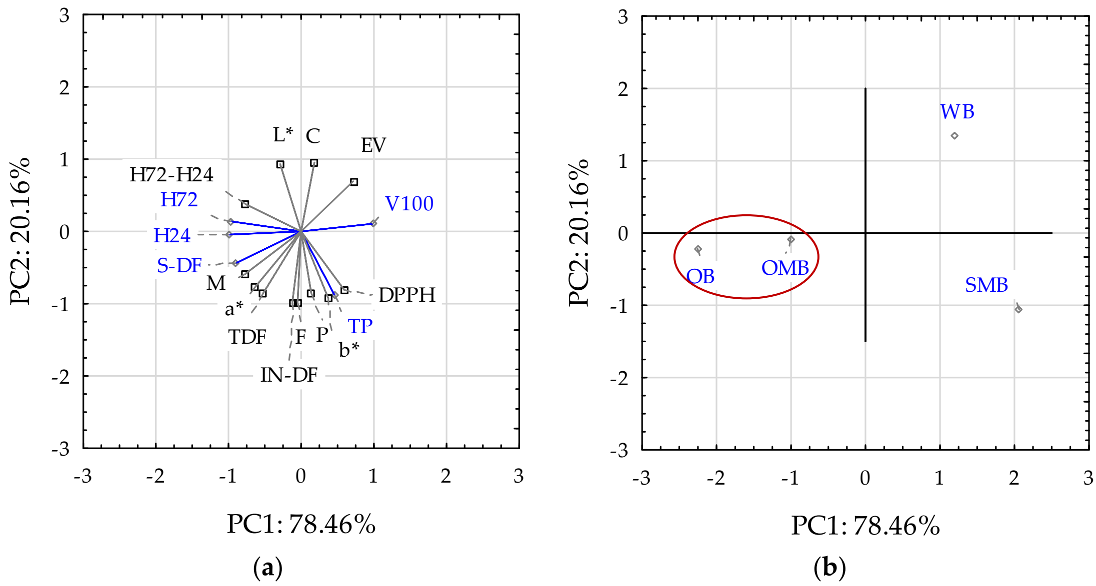

Figure 1. PCA analysis of similarities and differences in quality parameters, nutritional value, and antioxidant potential of bread samples: (**a**) PCA loading plot of the two main components, PC1 and PC2; (**b**) score plot presenting bread samples in terms of PC1 vs. PC2. Code explanations: sample codes as in Table 1. The blue lines in Figure 1a indicate the active data included in the PCA analysis, while the red loop concerns similar indicator values of the analyzed bread samples.

The first two principal components (PC1 and PC2) explained 98.62% of the variability (Figure 1a). The PC1 accounted for 78.46% of the variability with the major parameters, such as the specific volume (V100), crumb hardness twenty-four (H24) and seventy-two (H72) hours after baking, bread moisture (M), as well as soluble dietary fiber content (S-DF). Exploration of quality indicators of bread samples (Figure 1a) indicated that bread samples with higher hardness (H24, H72), crumb moisture (M), and soluble fiber (S-DF) contents were characterized by a smaller bread-specific volume (V100), which confirms the previously discussed results presented in Tables 4 and 5. PC2 explained 20.16% of the variability and was strongly positively related to the carbohydrate content (C) and color parameter L*, while negatively associated with contents of fat (F), protein (P), total polyphenols (TP), total dietary fiber and its insoluble fraction (TDF and IN-DF, respectively), color parameters a* and b*, as well as antioxidant activity (DPPH). Moreover, it was shown that bread with higher crumb moisture (M) and total dietary fiber (TDF) contents had a lower energy value (EV), which was confirmed by the results presented in Table 5.

The distribution of bread samples is shown in the PC1 and PC2 graph (Figure 1b). It was shown that in the positive part of PC1, at a considerable distance from each other, there were both samples of control bread (WB) and with the addition of scalded malt flour (SMB). However, in the case of PC2, the SMB sample was located in the negative part, and the WB was in the positive part. This indicates significant differences between these bread samples. Compared to the control wheat bread (WB), the SMB bread sample showed higher contents of protein, fat, total polyphenol, and total dietary fiber, including its insoluble fraction (P, F, TP, TDF, IN-DF, respectively), as well as higher values of antioxidant activity (DPPH) and color parameters a* and b*. In the case of the carbohydrate content (C) and color lightness L*, the SMB sample had lower values. Moreover, taking into account the distribution of the tested bread samples along the PC1 axis, it was found that bread samples with the 10% addition of oat flour, i.e., OB and OMB (without and with 0.6% oat malt flour, respectively), were on the negative side of PC1. These relationships confirm previous observations that bread samples OB and OMB showed smaller specific volume (V100), higher crumb hardness after 24 and 72 h (H24 and H72), and contents of crumb moisture (M) and soluble dietary fiber (S-DF), compared to WB and SMB.

4. Conclusions

Commercially available bread with health-promoting properties and a proper diet can contribute to improving the health of society. Malted cereal grains contain valuable nutrients and biologically active ingredients and are a source of enzymes activated and created during grain germination. Oat malt is characterized by lower activity of amylolytic enzymes than typical brewing malts, so it can be successfully used as a natural additive in the production of bread to improve its technological and health-promoting properties and delay the staling process. The addition of malt in the form of flour used for baking bread is possible in very small amounts, i.e., up to 1%. However, the use of malt flour subjected to the scalding process allows the use of oat malt in a much larger proportion compared to wheat flour. The hydrothermal treatment (scalding) of oat malt flour used in this study allowed the use of a higher (10%) addition of oat malt to wheat bread.

Compared to the control bread (wheat bread), replacing 10% of wheat flour with malted scalded oat flour allowed to obtain bread with a higher specific volume by approx. 2% and lower crumb hardness, by approx. 13 and 31% (24 and 72 h after baking, respectively). This bread was also characterized by a higher content of total dietary fiber, including its insoluble and soluble fractions, by approx. 15, 17, and 10%, respectively. The measurable effect was also a 1.5-fold increase in the total polyphenols content and an almost 2.5-fold increase in antioxidant activity compared to bread supplemented with oat flour. However, compared to bread obtained with the addition of 10% oat flour, the addition of 0.6% oat malt flour to the mixture of wheat flour with 10% oat flour resulted in an increase in the specific volume of the bread by approx. 5% and a reduction in crumb hardness by approx. 13 and 27% (24 and 72 h after baking, respectively). The obtained research results regarding bread with the addition of oat malt (with and without scalded malt flour) may constitute the basis for further research on reformulating food dedicated to people who prefer to consume products with properties that positively influence a healthy lifestyle. This direction should also be of interest to producers looking for new solutions to respond to the changing needs of the food market.

The need to conduct research in a broader scope should be emphasized, regarding analytical tests (chemical composition, nutritional value, especially the content of ingredients with health-promoting properties) and sensory evaluation (consumer evaluation), as well as their practical use (technological and market indicators). This is due to changes in nutritional trends regarding the global need to limit the consumption of animal products as well as the need to produce nutritious food with health-promoting properties that ensure the well-being and health of consumers.

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