Technological characteristics of wheat and non-cereal flour blends and their applicability in bread making

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SUMMARY
Alternative materials for bread production, which are used to enrich its composition, cause changes in the quality of dough and loaves that are important for bakers. We tested the applicability in bread making of four non-cereal flours: chestnut, coconut, flax and hemp at 5%, 10% and 15% of wheat flour replacement. All the flours, except for chestnut, improved dough rheology and protein content. Coconut flour decreased gelatinization maximum, while the other flours, in particular flax flour, increased it. The increasing rate of coconut flour and 15% of chestnut and hemp flours reduced the bread volume, while 10% of flax flour improved it. All the flours, except for coconut, darkened the crumb, chestnut gave it additional purple shade and hemp made it the darkest. Coconut and flax addition gave the bread high sensory acceptability, while chestnut and hemp breads were negatively scored due to a strong, strange and musty aroma, and a strange crumb colour.

Keywords
coconut flour; chestnut flour; flaxseed flour; hemp flour; bread making; wheat flour blends

High intake of bread and the growing prevalence of diet-related lifestyle diseases result in the interest in fortification of bread by valuable nutrients. For that purpose, synthetic nutrient supplements, such as calcium and iron, thiamine, riboflavin or vitamin B6 may be added to enrich bread. Natural raw materials, such as skimmed milk powder, whey, buttermilk, dried yeasts, oilseeds, non-bread cereals or non-cereal flours may be also used [1]. Wheat bread is commonly enriched in nutrients and flavour by replacing a part of the wheat flour with flours from edible parts of other plants. This implies changes in sensory and chemical composition of bread, but also changes the dough rheological characteristics [2].

The aim of using alternative raw materials in baking of bread is to improve its nutritional value and create products with functional properties. Nevertheless, before chemical and clinical analysis, their applicability in bakery should be proven and the overall quality of the product should be evaluated. In this study, four non-cereal flours with potential health benefits were selected to enrich wheat bread: coconut, chestnut, hemp and flax.

Chestnut fruits (*Castanea sativa* Mill.), fresh or processed, are highly regarded in the countries of Southern Europe, where they are a common component of the Mediterranean diet. Chestnut flour is obtained by grinding dried chestnuts, which are of lower size or broken. Chestnut flour, as a substitute for wheat flour, can improve the nutritional value of products. It has an average protein content of 6.9%, 50.6% of starch, 32.6% of saccharides, 2.0% of lipids and 4.2% fibre [3]. Although it has a lower protein content than the cereal grains, it shows beneficial nutritional characteristics. The chestnut protein has a high content of essential amino acids (4–7%), and it is rich in lysine and threonine, while methionine is the limiting aminoacid. Chestnut flour also contains significant amounts of vitamin E,vitamin B group, potassium, fluorine and magnesium [3, 4].

Coconut flour is obtained from dried and milled coconut pulp, after extracting the coconut oil [5]. Its composition depends on the retention

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of components after the extraction. Coconut flour was reported to contain 3.6% moisture, 3.1% ash, 10.9% lipids, 12.1% proteins and 60.9% dietary fibre [6, 7].

Dietary fibre is composed of non-starch polysaccharides, which are not digested in the small intestine, but can be fermented in the colon to short-chain fatty acids. It increases the volume of food without additional energy value, and enhances water absorption in the colon, which prevents from constipation. Fibrous structure and viscosity of the dietary fibre delays the absorption of cholesterol and glucose to the blood, and decreases the glycemic index of foods, thus helping to control obesity and diabetes mellitus [6].

Flaxseed is a good source of polyunsaturated fatty acids (contains 73% of total fatty acids, 18% mono-unsaturated fatty acids and 9% of saturated fatty acids), soluble fibre, α-linolenic acid and phytoestrogens. Flaxseed flour can be used for the production of bread and pastry, adding it nutty flavour. It is widely used in USA in bread, cookies, muffins and other cereal-based products [8]. Flaxseed is rich in phytochemicals, primarily lignans, however, other phytochemicals, such as saponins and phytates, are also present. Flaxseed consumption improves vascular function and has anti-arrhythmic, anti-atherogenic and anti-inflammatory properties. It was also regarded to prevent from cancer, osteoporosis and high cholesterol [9, 10].

Hemp has been grown for thousand years for use as bast fibre, food and medicine. Hemp seeds are known for their high biological value. They are rich in phytochemicals, vitamins A, B, C and E, and minerals, such as calcium, potassium, phosphorus and iron. They contain large amounts of poly–unsaturated fatty acids (linoleic and linolenic), fibre and proteins. Hemp seeds are known to reduce blood pressure, lower blood cholesterol and provide support of the immune system. Main hemp proteins, albumin and edistin, are easily digestible. It also contains essential amino acids, including high levels of arginine [11–13].

Characteristics of these flours indicate their high nutritional value and, therefore, they may constitute a valuable source of nutrients at bread fortification. Wheat bread is unable to fully meet the human nutritional requirements. The addition of natural raw materials rich in dietary fibre, proteins, essential fatty acids, vitamins and minerals, may lead to significant improvement in the nutritional value of bread. This could bring a positive impact on the functioning of the human body and prevent a number of diet-related diseases [14].

Enrichment in the composition of breads may result in significant changes in the properties of dough and of the final product [2]. Despite the nutritional benefits, using gluten-free non-cereal flours change the technological properties of dough as well as improve or damage the overall quality breads [15]. Non-cereal flours are also more expensive than wheat flour. Hence, there is a strong need to find a balance between the nutrient, technological and economic aspects of bread making, to encourage bakers to produce and consumers to buy bread enriched with non-cereal ingredients.

MATERIALS AND METHODS

Flour

Commercial flours were used: wheat flour type 550, (Diamant Stradunia, Stradunia, Poland), BIO chestnut flour (Clement Faugier, Privas, France), coconut flour (AmanPrana, Schoten, Belgium), flax whole meal (Młyn Bogutyn, Radzyń Podlaski, Poland) and hemp flour (Hanf & Natur, Lindlar, Germany). Wheat flour was obtained from Diamant Stradunia, and non-cereal flours from Młyn Bogutyn. Non-cereal flours were used to replace 5%, 10% and 15% of wheat flour. Blends were made on-site before each experiment.

Flour analysis

Protein content

Blends and wheat flour were analysed for total protein content by the Kjeldahl N × 5.7 method [16] with the use of Kjeltec 2400/2460 device (Foss Analytical, Höganäs, Sweden).

Wet gluten

Wet gluten quantity (wet gluten yield) was determined based on dough hand washing with tap water and weighing the obtained mass. Dough made from 25.0 g of flour and 12.5 ml of tap water was formed and soaked for 20 min in tap water at room temperature. The dough was hand-washed with tap water until the removal of all the starch (iodine test). Gluten was centrifuged to remove the excess of water. Gluten quality (spreadability) was calculated as the difference between 5 g wet gluten diameters before and after incubation for 60 min at 30 °C, 85% relative humidity (RH).

Dough rheology

Dough mixing profile was determined with the use of farinograph (Brabender, Duisburg, Germany) according to PN-ISO 5530-1:1999 [17] using 50 g mixing bowl. The following characteristics were determined: water absorption, dough development time, dough stability and dough softening measured 12 min after the end of the development time. Additionally, quality number was determined. It was expressed as the distance in millimetres from the beginning of water addition point to the point, in which the curve decreased by 30 Farinograph units (FU) relative to the peak resistance.

Viscoelastic properties

Characteristics of the starch-amylase complex were determined with the use of amylograph (Amylograph-E, Brabender) [18], with maximum gelatinization. Suspension of 80 g flour at 14% moisture and 450 ml distilled water was put into the reaction tank and was heated at 1.5 $°C \cdot min^{-1}$ from the initial temperature of 30 °C. The amylograph was stopped manually after reaching the maximum gelatinization (curve peak).

Laboratory baking

Baking

Ratios of 0:100, 5:95, 10:90 and 15:85 of non-cereal and wheat flour blends were used for laboratory baking. The dough was mixed on the farinograph for 3 min at 30 °C. An amount of 250 g of flour, 7.5 g of fresh yeast and 3.8 g of salt were used. Water addition was adjusted to gain the dough of consistency of 300 FU. The dough was put into forms and fermented at 30 °C and 85% RH in a proofing cabinet. Dough was folded twice (after 60 min and then after 30 min of fermentation) and left for proofing for approx. 30 min. Loaves were baked in a laboratory oven (Brabender No. 35506, 6 kW, 380 V; Brabender) for 30 min at a constant temperature of 230 °C. Steam obtained from 100 ml of distilled water was injected into the baking chamber right after putting the forms into the oven. After being baked, loaves were sprinkled with water and left at the room temperature to cool down. Baking experiments were performed twice and average results from them were reported in the study.

Bread quality evaluation

After 24 h, bread was evaluated in terms of loaf volume, overbake, crumb porosity, colour measurement and sensory properties. Bread volume was assessed by millet seed displacement method using the SA-WY device (ZBPP, Bydgoszcz, Poland), and expressed in cubic centimetres per kilogram of flour. Overbake was calculated as bread mass to flour mass percentage ratio. Crumb porosity of each loaf was visually observed and compared with the 8 degrees Dallman scale, where 1 indicates non-uniform structure, large and irregular cells, and 8 indicates uniform compact structure, small and regular cells. Crumb colour was measured by Minolta Colorimeter CR-400/410 (Konica Minolta, Osaka, Japan). Five different points of the same slice with CIE L^*, a^* and b^* values were measured.

Sensory analysis

Bread was subjected to sensory evaluation by seven semi-trained panellists. The questionnaire included point evaluation of external appearance, crust colour, thickness and uniformity, crumb elasticity, porosity and flavour.

Statistical evaluation

The results were statistically analysed by Statistica 6.0 software package (StatSoft, Tulsa, Oklahoma, USA). Two-way ANOVA at $p = 0.95$ was calculated and homogenous groups according to Duncan's test were estimated. Interactions between non-cereal flours and their replacement level were shown in order to indicate their combined effect on flour and bread characteristics.

RESULTS AND DISCUSSION

Flour and dough characteristics

A strong effect of non-cereal flours on wheat flour characteristics was observed (Tab. 1).

The increasing share of coconut, flax or hemp flours resulted in an increase in total protein content, while chestnut flour addition caused a decrease in the protein content. Comparing to wheat flour (11.5% of protein content), coconut, flax and hemp flours contained high amounts of proteins, 20.2%, 33.1% and 31.5%, respectively, while chestnut flour contained a lower amount of proteins, 6.1% (data not shown). However, the flour replacement with non-cereal flours led to a decrease in gluten yield. Nevertheless, 5% of hemp increased the gluten yield. The most adverse effect on gluten was observed when flax flour was added. At the replacement levels of 10% and 15%, it was impossible to wash out the gluten. This was probably due to the swelling of mucous substances when preparing the dough, making it difficult to connect to the components of gluten. Addition of non-cereal flours also resulted in strengthening the gluten, the gluten ball diameters did not extend as much as those of pure wheat gluten.

Our results are in agreement with literature data that the protein content in chestnut flour is low, and gluten proteins are absent [3, 19]. Increasing the share of hemp (20%, 30% and 40%) increased the protein contents in rice–hemp blends and, when defatted hemp was used, a higher in-

Tab. 1. Protein profiles of flour blends.

Flour blend		Protein content [%]	Gluten yield [%]	Gluten quality [mm]
Wheat flour	100%	11.5 ± 0.0^{fg}	29.9 ± 0.1^{bc}	8.0 ± 1.0^{a}
Chestnut-wheat flour	5:95	11.2 ± 0.0^{gh}	29.3 ± 0.2^{bcd}	5.5 ± 0.5^{b}
	10:90	10.9 ± 0.0^{hi}	28.5 ± 0.4^{d}	3.7 ± 0.2^{cd}
	15:85	10.7 ± 0.0^{i}	24.3 ± 0.1^{f}	2.7 ± 0.1^{d}
Coconut-wheat flour	5:95	12.1 ± 0.2^{de}	30.2 ± 0.2^{b}	7.7 ± 0.3^{a}
	10:90	11.9 ± 0.0^{ef}	28.9 ± 0.8^{cd}	5.5 ± 0.5^{b}
	15:85	12.6 ± 0.1^{c}	26.0 ± 0.5^{e}	4.0 ± 0.3^{c}
Flax-wheat flour	5:95	12.4 ± 0.0^{cd}	16.2 ± 0.2^{g}	0.0 ± 0^{e}
	10:90	13.4 ± 0.1^{b}	0.0^{g}	–
	15:85	14.3 ± 0.0^{a}	0.0^{g}	–
Hemp-wheat flour	5:95	12.2 ± 0.0^{bcd}	31.6 ± 0.2^{a}	7.2 ± 0.2^{a}
	10:90	13.3 ± 0.0^{b}	29.1 ± 0.1^{bcd}	4.5 ± 0.1^{bc}
	15:85	14.1 ± 0.1^{a}	25.1 ± 0.7^{ef}	3.0 ± 0.3^{d}

Data represent the mean of two replicates ± standard deviation. Small letters denote significant groups according to Duncan's test, $p = 0.95$.

crease in the protein content was observed [12]. Although in present study rice was not evaluated, the increase in protein content was also observed.

Dough rheology

Increasing the addition of coconut and flax improved water absorption of flour, and when chestnut or hemp were added, no effects were observed (Tab. 2). The increasing share of all the flours, except for the chestnut one, improved dough development time, the most effective being coconut. At 10% and 15% of coconut, flax or hemp replacement, an increase in dough stability was observed. Interestingly, a better effect was noticed at 10% share of flax or hemp. In case of chestnut addition, only at the level of 15% a slight increase in dough stability was observed. Chestnut flour did not affect the dough softening. A slight decrease in dough softening was observed when flax was added and at lower levels of coconut or hemp replace-

Tab. 2. Dough rheology and water absorption.

Flour blend		Water absorption [%]	Dough development time [min]	Dough stability [min]	Dough softening [FU]	Quality number [mm]
Wheat flour	100%	57.6 ± 0.3^{fg}	1.5 ± 0.2^{g}	1.0 ± 0.2^{ef}	160 ± 10^{ab}	20 ± 2^{g}
Chestnut-wheat flour	5:95	58.4 ± 0.2^{ef}	2.0 ± 0.2^{g}	0.8 ± 0.1^{ef}	150 ± 10^{abc}	40 ± 1^{f}
	10:90	57.2 ± 0.1^{gh}	2.0 ± 0.3^{fg}	0.7 ± 0.05^{f}	160 ± 20^{ab}	40 ± 3^{f}
	15:85	56.7 ± 0.2^{h}	1.5 ± 0.1^{fg}	2.0 ± 0.2^{d}	170 ± 10^{a}	48 ± 2^{def}
Coconut-wheat flour	5:95	59.2 ± 0.3^{de}	3.0 ± 0.1^{g}	1.0 ± 0.25^{ef}	100 ± 5^{ef}	53 ± 1^{de}
	10:90	60.6 ± 0.1^{bc}	2.5 ± 0.3^{de}	3.3 ± 0.3^{c}	120 ± 10^{cde}	50 ± 4^{def}
	15:85	60.8 ± 0.1^{b}	5.7 ± 0.25^{a}	3.0 ± 0.2^{c}	80 ± 5^{fg}	57 ± 3^{b}
Flax-wheat flour	5:95	59.2 ± 0.2^{de}	1.8 ± 0.1^{fg}	1.0 ± 0.2^{ef}	140 ± 20^{abcd}	42 ± 2^{f}
	10:90	59.8 ± 0.4^{cd}	3.7 ± 0.2^{bc}	3.7 ± 0.4^{bc}	120 ± 5^{cde}	68 ± 2^{c}
	15:85	62.0 ± 0.5^{a}	4.3 ± 0.2^{b}	1.5 ± 0.1^{de}	130 ± 10^{bcde}	67 ± 3^{c}
Hemp-wheat flour	5:95	58.0 ± 0.3^{fg}	2.1 ± 0.3^{ef}	0.5 ± 0.2^{f}	110 ± 10^{def}	57 ± 3^{ef}
	10:90	57.3 ± 0.2^{gh}	3.5 ± 0.1^{bc}	5.5 ± 0.5^{a}	50 ± 5^{g}	125 ± 7^{a}
	15:85	57.2 ± 0.2^{gh}	3.5 ± 0.2^{bc}	4.5 ± 0.4^{b}	80 ± 5^{fg}	57 ± 3^{d}

Data represent means of two replicates ± standard deviation. Small letters denote significant groups according to Duncan's test, $p = 0.95$

ment. The lowest softening was observed at 15% of coconut, and at 10% and 15% of hemp replacement. Nevertheless, all the flours improved quality number, which expressed the rate of change of consistency after the peak. The least effect was observed at all levels of chestnut flour and 5% of flax flour, and the most beneficial was 10% addition of hemp.

It is known that chestnut flour addition strongly affects rheological properties of the rice dough [19]. The increasing rate of chestnut flour increased the yield stress, and in turn the consistency index. One of the reasons was the fibrous structure of chestnut flour and higher capacity of binding water compared to rice flour. SACCHETTI et al. [3] demonstrated that the increasing share (20%, 30% and 40%) of chestnut flour in rice-chestnut blends decreased water absorption index (*WAI*) and increased water solubility index (*WSI*) due to the higher content of saccharides. ALIANI et al. [9] found that the increasing share of coconut flour (10%, 20%, and 30%) in coconut-wheat blends reduced water absorption and improved dough development time as well as arrival time, in particular at the replacement level of 30%. Higher stability at 20% of coconut flour replacement than of wheat might have been caused by the stabilizing effect of coconut protein on gluten structure. However, at a higher level of replacement, interference with the gluten network might occur, as reflected by the unstable farinogram curve. RAJIV et al. [8] used up to 20% of flaxseed for cookies formulation. They observed a significant increase in water absorption and dough development time, and a decreasing stability with increasing the substitution level.

Viscoelastic properties

Coconut flour did not affect falling number, and slight increase was observed when chestnut flour was added, regardless from its share (Tab. 3). The strongest effect on falling number was observed at the increasing share of flax flour. Interestingly, at 5% of hemp replacement, the increase in falling number was observed and, at higher levels, the falling number decreased to the wheat result. However, distribution of amylograph viscosity results was quite different. The increasing share of coconut flour, in particular the highest addition, slightly decreased gelatinization maximum. Chestnut flour and flax flour caused a significant increase in gelatinization maximum, and the effect of the latter was much stronger. Hemp addition caused a moderate increase in gelatinization maximum, regardless from the replacement level. Non-cereal flours also affected pasting temperatures. Flax significantly decreased the beginning of gelatinization, and chestnut significantly decreased the gelatinization temperature. However, the highest values of both temperatures were registered at the 15% chestnut flour replacement.

Chestnut flour is rich in saccharides, which are known to retard starch gelatinization by reducing the water activity and stabilizing the amorphous regions of the starch granule [19]. Saccharose has a restrictive effect on the gelatinization process

Tab. 3. Viscoelastic properties of flour blends.

Flour blend		Faling number [s]	Maximum gelatinization [AU]	Temperature at start of gelatinization [°C]	Gelatinization temperature [°C]
Wheat flour	100%	280 ± 4^{gh}	440 ± 10^{h}	57.0 ± 0.2^{e}	78.6 ± 0.6^{ef}
Chestnut-wheat flour	5:95	302 ± 2^{de}	470 ± 5^{g}	58.5 ± 0.2^{bc}	83.4 ± 0.4^{c}
	10:90	315 ± 5^{c}	540 ± 5^{de}	59.1 ± 0.2^{b}	86.1 ± 0.1^{b}
	15:85	311 ± 3^{cd}	560 ± 10^{d}	60.0 ± 0.3^{a}	88.8 ± 0.2^{a}
Coconut-wheat flour	5:95	294 ± 6^{ef}	400 ± 20^{h}	56.1 ± 0.1^{f}	79.8 ± 0.2^{de}
	10:90	288 ± 2^{fg}	415 ± 5^{j}	56.8 ± 0.2^{i}	78.1 ± 0.1^{f}
	15:85	285 ± 4^{fg}	370 ± 10^{i}	59.1 ± 0.1^{b}	80.7 ± 0.7^{d}
Flax-wheat flour	5:95	302 ± 2^{de}	680 ± 5^{c}	50.1 ± 0.1^{h}	78.6 ± 0.4^{ef}
	10:90	337 ± 1^{b}	835 ± 5^{b}	53.0 ± 0.4^{g}	79.5 ± 0.5^{def}
	15:85	362 ± 2^{a}	990 ± 10^{a}	52.7 ± 0.3^{g}	79.8 ± 0.8^{de}
Hemp-wheat flour	5:95	314 ± 4^{c}	500 ± 10^{f}	57.6 ± 0.2^{de}	78.6 ± 0.6^{ef}
	10:90	289 ± 1^{fg}	510 ± 5^{ef}	57.6 ± 0.3^{de}	83.4 ± 0.4^{c}
	15:85	274 ± 4^{h}	510 ± 10^{f}	58.2 ± 0.2^{cd}	85.2 ± 0.2^{b}

Data represent means of two replicates ± standard deviation. Small letters denote significant groups according to Duncan's test, $p = 0.95$.

Tab. 4. Bread characteristics depending on flour blends used.

Flour blend		Overbake [%]	Specific volume [$cm^3 \cdot kg^{-1}$]	Porosity	Colour of bread crumb		
					L^*	a^*	b^*
Wheat flour	100%	146.9 ± 0.1^{a}	4800 ± 10^{ab}	7.0 ± 0^{a}	67.02 ± 0.36^{ab}	1.74 ± 0.13^{i}	17.77 ± 0.19^{d}
Chestnut-wheat flour	5:95	149.3 ± 0.3^{a}	4800 ± 5^{ab}	6.0 ± 1^{ab}	50.20 ± 0.55^{ef}	8.31 ± 0.07^{b}	8.74 ± 0.38^{g}
	10:90	146.9 ± 0.3^{a}	4720 ± 8^{b}	5.0 ± 1^{b}	49.65 ± 0.85^{f}	8.26 ± 0.52^{b}	8.43 ± 0.87^{g}
	15:85	147.3 ± 0.3^{a}	4160 ± 6^{c}	4.0 ± 1^{ab}	51.18 ± 0.39^{e}	8.77 ± 0.02^{a}	11.01 ± 0.25^{ef}
Coconut-wheat flour	5:95	150.5 ± 0.5^{a}	4440 ± 4^{bc}	6.0 ± 1^{ab}	68.21 ± 0.93^{a}	2.33 ± 0.21^{h}	19.23 ± 0.21^{c}
	10:90	156.9 ± 0.3^{a}	3540 ± 3^{d}	7.0 ± 0^{a}	68.12 ± 0.19^{a}	2.82 ± 0.06^{g}	19.64 ± 0.27^{b}
	15:85	157.9 ± 0.1^{a}	3000 ± 10^{e}	7.0 ± 0^{a}	66.64 ± 0.26^{b}	3.37 ± 0.07^{f}	20.23 ± 0.07^{a}
Flax-wheat flour	5:95	148.0 ± 0.4^{a}	4880 ± 3^{ab}	6.0 ± 1^{ab}	57.52 ± 1.01^{c}	3.62 ± 0.06^{ef}	11.37 ± 0.34^{e}
	10:90	152.4 ± 0.4^{a}	5180 ± 8^{a}	6.0 ± 1^{ab}	52.64 ± 0.99^{d}	4.73 ± 0.10^{d}	9.99 ± 0.20^{g}
	15:85	156.3 ± 0.3^{a}	4760 ± 2^{b}	7.0 ± 0^{a}	50.63 ± 0.66^{ef}	5.25 ± 0.06^{c}	8.78 ± 0.18^{h}
Hemp-wheat flour	5:95	149.2 ± 0.2^{a}	4840 ± 4^{a}	5.0 ± 0^{ab}	49.65 ± 0.29^{f}	2.91 ± 0.03^{g}	10.85 ± 0.15^{f}
	10:90	149.7 ± 0.1^{a}	4580 ± 5^{bc}	5.0 ± 1^{ab}	43.88 ± 0.13^{g}	3.41 ± 0.05^{f}	8.54 ± 0.10^{h}
	15:85	145.9 ± 0.9^{a}	4160 ± 10^{c}	4.0 ± 1^{b}	39.24 ± 0.22^{h}	3.68 ± 0.03^{e}	6.90 ± 0.15^{i}

Data represent means of two (for overbake and porosity) or five (for colour parameters) replicates ± standard deviation. Small letters denote significant groups according to Duncan's test, $p = 0.95$. Porosity is expressed in units of Dallman scale from 1 to 8 (1 – large and irregular cells, thick-walled structure of the crumb, 8 – small and uniform cells, thin-walled structure of the crumb).

due to the competition for water with starch, inhibition of granular starch hydration and saccharose-starch interaction. When starch cannot gelatinize due to thermal reaction, a physical mixture of caramel with starch and starch-saccharide complexes are formed [3]. That might explain the higher pasting temperatures of wheat–chestnut blends. Wang et al. [20] in studies on hemp-rice blends observed a decrease in peak viscosity with the increase in the hemp share. Also, in studies of Rajiv et al. [8], a decrease in peak viscosity was observed with increasing the share of flaxseed in blends with wheat. However, flaxseed gum was shown to enhance viscosity similarly to Arabic gum.

Baking results

Non-cereal flours had an impact on bread characteristics (Tab. 4). Bread overbake and crumb porosity were not affected by the addition of non-cereal flours. However, despite the lack of statistical differences, the increasing share of chestnut and hemp resulted in higher non-uniformity and bigger cells (lower Dallman scores). Loaves baked with the addition of chestnut and hemp flours were characterized by a reduced specific volume, and coconut flour caused the most severe decrease. The decrease in volume was proportional to the increase in non-cereal flour share.

Although chestnut has good nutritional value and aroma, it may affect the quality of baked products, namely, lower volume and unacceptable dark colour, which may be a result of inadequate gelatinization caused by the high contents of saccharides and fibre. Chestnut flour addition in rice bread resulted in harder structure and lower volume due to the rigid and compact structure of the chestnut dough. Another reason might be a higher content of saccharides in the chestnut flour, which delayed starch gelatinization during baking [19]. Dall'Asta et al. [21] explained the volume reduction of wheat-chestnut bread by a high content of dietary fibre. Fibre reduces the volume of bread by interacting with gluten, which decreases the gas retention capacity in dough. In the present study, bread baked with the increasing chestnut flour addition was also characterized by the decreasing loaf volume.

Norajit et al. [12] found that hemp addition reduced the expansion ratio of rice extrudates. It might have been caused by the effect of fatty acids on starch structure or cell wall disruption by fibre present in hemp. In this study, extrudates were not evaluated, however, the decrease in volume of the final product (bread) with the increase in hemp share could be observed.

Conforti and Davis [10] observed that 15% of flaxseed addition decreased wheat bread volume and increased crumb hardness. They explained the volume decrease by the gluten dilution by whole grains. In the present work, bread baked with 5% or 15% flaxseed flour addition had the same volume as the control (wheat) bread. However, the 10% addition of flaxseed flour resulted in the biggest loaf volume. On the other hand, Rajiv et al. [8] prepared cookies enriched with roasted and ground flaxseed, and the increasing level of flax caused a decrease in diameter and an increase in hardness of cookies. Bread volume may be affected by the high content of lipids in flaxseed. A slight increase in flax content in the fat-free formula could increase bread volume [22], but larger amounts of lipids in the dough resulted in a decrease in bread volume [23]. That could explain the biggest loaf volume at 10% flax replacement, and the lack of effect at the other replacement levels in this study. Improved properties of breads with 10% of flax flour share may indicate the optimal for bread making composition of fibre and mucilage in such blend. Crumb colour was significantly altered by the addition of non-cereal flours (Tab. 4). Wheat bread crumb was bright and typical for wheat bread. The increasing share of coconut flour gave the crumb gentle yellow and red shade. Chestnut flour, regardless from the level of replacement, made the crumb darker and red. Similar effect, but not as strong, was observed at flax flour addition, the crumb became slightly red. Bread baked with hemp flour addition was characterized by the darkest and greyest crumb.

Demirkesen et al. [19] found that the increasing share of chestnut flour in rice bread recipe resulted in a decrease in L^*, an increase in a^* and a slight increase in b^*, i. e. the crumb became darker and reddish. The browning effect of chestnut on bread colour was the effect of the high content of saccharides and their reactions during baking (Maillard reaction and caramelization). Also in work of Sacchetti et al. [3], the increasing chestnut share decreased the rice extrudate's lightness, as the chestnut flour had a darken-

Tab. 5. Results of sensory analysis of breads.

Flour blend		Appearance	Crust			Crumb			Flavour	Overall
			Colour	Thickness	Uniformity	Elasticity	Porosity	Colour		
Wheat flour	100%	2.29^{ab}	2.86^{a}	2.00^{ab}	2.71^{a}	2.71^{a}	2.86^{a}	2.57^{a}	2.43^{a}	20.43^{a}
Chestnut-wheat flour	5:95	2.29^{ab}	1.86^{ab}	2.43^{ab}	2.71^{a}	2.43^{a}	1.86^{bcd}	1.14^{c}	1.57^{abcd}	16.29^{bc}
	10:90	1.86^{ab}	1.43^{b}	2.29^{ab}	2.43^{ab}	2.29^{a}	2.00^{abcd}	1.29^{bc}	1.29^{bcd}	14.86^{c}
	15:85	1.86^{ab}	2.00^{ab}	2.29^{ab}	2.14^{ab}	2.43^{a}	1.71^{cd}	1.86^{abc}	1.00^{cd}	15.28^{bc}
Coconut-wheat flour	5:95	2.43^{a}	2.57^{a}	2.14^{ab}	2.57^{ab}	2.29^{a}	2.43^{abc}	1.71^{abc}	2.29^{ab}	18.43^{ab}
	10:90	2.14^{ab}	2.43^{a}	2.14^{ab}	2.71^{a}	2.00^{a}	2.71^{ab}	2.14^{ab}	1.57^{abcd}	17.86^{abc}
	15:85	1.71^{ab}	2.00^{ab}	1.43^{b}	2.29^{ab}	2.14^{a}	2.86^{a}	2.29^{a}	1.86^{abc}	16.57^{bc}
Flax-wheat flour	5:95	2.14^{ab}	2.14^{ab}	2.57^{a}	2.29^{ab}	2.43^{a}	2.57^{abc}	1.86^{abc}	1.14^{cd}	17.14^{bc}
	10:90	2.00^{ab}	2.14^{ab}	2.29^{ab}	2.14^{ab}	2.43^{a}	2.57^{abc}	2.00^{abc}	2.00^{abc}	17.57^{abc}
	15:85	1.43^{b}	1.86^{ab}	2.00^{ab}	1.86^{b}	2.29^{a}	2.29^{abcd}	2.00^{abc}	1.86^{abc}	15.57^{bc}
Hemp-wheat flour	5:95	2.00^{ab}	2.29^{ab}	2.57^{a}	2.43^{ab}	2.43^{a}	2.14^{abcd}	1.86^{abc}	0.57^{d}	16.29^{bc}
	10:90	2.14^{ab}	2.57^{a}	2.43^{ab}	2.86^{a}	2.29^{a}	1.43^{d}	1.71^{abc}	0.71^{d}	16.00^{bc}
	15:85	2.86^{ab}	2.57^{a}	2.14^{ab}	2.71^{a}	2.43^{a}	2.14^{abcd}	1.86^{abc}	0.71^{d}	15.71^{bc}
Relative standard deviation [%]		16.3	16.9	13.1	11.6	7.0	18.9	19.3	40.4	8.7

Data represent means of seven replicates. Small letters denote significant groups according to Duncan's test, $p = 0.95$.

ing effect on the blend. The colour of blends became darker, and a^* and b^* values increased compared to rice flour, which was almost white. On the other hand, Conforti and Davis [10] found that crumb became darker under the influence of flax addition. It was caused by the darker colour of flax flour, not Maillard reaction, as crumb did not undergo it. Norajit et al. [12] observed the effect of hemp on the colour of rice extrudates, which also became darker, and had higher a^* and b^* values, and lower L^* value than control (rice). The same trends were observed by Wang et al. [20] in crumb colour of rice–hemp bread.

Bread sensory analysis

Sensory profile of bread was strongly affected by the non-cereal additives (Tab. 5). Loaves were characterized by uniform external appearance, crust colour, thickness and texture (uniformity). However, bread baked with 15% share of flax flour had slightly irregular crust, which affected its external appearance.

Crumb of all breads was equally elastic, but it slightly varied in terms of porosity, colour uniformity and stickiness. Wheat (control) and coconut bread had the most desirable crumb porosity. However, the acceptability of coconut bread was slightly lower at 5% replacement and was increasing with the increase in flour replacement. Flax bread crumb porosity was also given a high score. But on the contrary to the coconut, it was the most irregular at the maximum replacement level. Chestnut and hemp breads were characterized by a worse crumb porosity, and the least desirable was bread with the addition of 10% hemp flour. Wheat bread and 10% and 15% coconut bread had the brightest and most uniform crumb colour. On the other hand, loaves baked with 5% and 10% share of chestnut flour had red crumb with dark grey streaks, which gave them the lowest score.

Wheat bread had the most desirable flavour, and the 5% coconut flour and 10% flax flour breads were also highly acceptable. Coconut bread had a pleasant mild coconut aroma, however, at 15% the aroma was too strong, and the crumb was little dry, which was less acceptable in bread. On the other hand, flavour of flax bread was described by the panellists as “fishy”. Breads with 15% chestnut flour and 5% flax flour were not acceptable, being bitter and sour. Flavour of wheat-hemp bread was definitely unsatisfactory, regardless from the replacement level. It was musty and had a very strong bitter aftertaste.

In sensory analysis, the highest overall score got the wheat (control) bread. Satisfactory results were obtained for 5% and 10% coconut and 10% flax bread. The worst one was the 10% chestnut bread, due to the strange and irregular colour. The quite high score of hemp breads was the effect of good external appearance, even if the flavour was disqualifying.

Changes in flavour of bread baked with non-cereal flours were reported. On the basis of the colour analysis results, bitter taste of rice–chestnut bread might have been a result of the Maillard reaction [3]. Gunathilake and Abeyrathne [6] showed that noodles with up to 20% coconut flour substitution were a desirable product. Due to the high content of alpha linolenic acid in flaxseed, flaxseed products were more susceptible to lipid oxidation. However, at low levels of addition, this need not be a problem. Different cereal products, such as bagel or yeast bread, containing low flaxseed addition (up to 15%), had acceptable flavour and overall score compared to the wheat control. The musty flavour could be reduced by the addition of antioxidants and flavourings [9]. On the other hand, Conforti and Davis [10] found that bread baked with 15% share of flaxseed had slightly higher musty aroma, stronger aftertaste, stale and grainy taste. Rajiv et al. [8] reported significant deterioration of cookies surface colour, surface characteristics, texture, flavour and mouth feel beyond 15% level of flaxseed substitution. Additionally, texture and crumb softness were better in flax bread than in control bread. In studies of Norajit et al. [12] on rice–hemp energy bars, with increasing share of hemp, panellists gave higher ratings regarding colour and flavour, but lower regarding the taste. They also pointed out that the high content of hemp in the product caused too strong flavour. Novak et al. [13] described the essential oils present in hemp, which were α-pinene, myrcene, trans-β-ocimene, α-terpinolene, *trans*-caryophyllene and α-humulene. These oils are related to oils of hop (*Humulus lupulus* L.).

CONCLUSIONS

Our study showed a different effect of non-cereal flours on bread making properties of wheat flour, as well as on acceptance of the final product. We observed a good effect of 10% flax addition on dough rheology, which resulted in the best bread characteristics and high sensory acceptability. Good results were also observed at the replacement with coconut flour. Although loaves were slightly smaller, probably due to the high fibre content in coconut flour, they were highly acceptable in terms of crumb structure and flavour. Based on literature data concerning the nutrition profile of both, we would recommend improving bread formulation with flax and coconut flours, which would be beneficial regarding the nutritional value and sensory attractiveness of baked products. On the other hand, although chestnut flour did not affect the dough properties, and hemp flour even improved it, we do not recommend them in bread making due to the adverse effect on bread appearance. They both gave the final products very strong, strange and musty aroma, and chestnut flour also gave a strange and streaky colour to the crumb. We think that further studies, either on reduced level of chestnut and hemp flours replacement (5% and less) or improving the formulation and dough preparation, could help to suppress the adverse flavour and taste.

REFERENCES

1. Chan, S.: Dietetic bakery products. In: Hui, Y. H. (Ed.): Bakery products: science and technology. Oxford : Blackwell Publishing, 2006, pp. 455–470. ISBN 978-0-8138-0187-2.
2. Indani, D. – Soumya, C. – Rajiv, J. - Venkateswara Rao, G.: Multigrain bread – its dough rheology, microstructure, quality and nutritional characteristics. Journal of Texture Studies, *41*, 2010, pp. 302–319. DOI: 10.1111/j.1745-4603.2010.00230.x.
3. Sacchetti, G. – Pinnavaia, G. G. – Guidolin, E. - Dalla Rosa, M.: Effects of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice-flour based snack-like products. Food Research International, *37*, 2004, pp. 527–534. DOI: 10.1016/j.foodres.2003.11.009.
4. Do Carmo Barbosa Mendes De Vasconcelos, M. – Bennett, R. N. – Rosa, E. A. S. - Ferreira-Cardoso, J. V.: Industrial processing effects on chestnut fruits (*Castanea sativa* Mill.). 2. Crude protein, free amino acids and phenolic phytochemicals. International Journal of Food Science and Technology, *44*, 2009, pp. 2613–2619. DOI: 10.1111/j.1365-2621.2009.02092.x.
5. Hagenmaier, R. D. – Quinitio, P. H. – Clark, S. P.: Coconut flour: technology and cost of manufacture. Journal of the American Oil Chemists' Society, *52*, 1975, pp. 439–443. DOI: 10.1007/BF02637484.
6. Gunathilake, K. D. P. P. – Abeyrathne, Y. M. R. K.: Incorporation of coconut flour into wheat flour noodles and evaluation of its rheological, nutritional and sensory characteristics. Journal of Food Processing and Preservation, *32*, 2008, pp. 133–142. DOI: 10.1111/j.1745-4549.2007.00170.x.
7. Trinidad, P. T. – Divinagracia, H. V. – Aida, C. M. – Faaridah, C. A. – Angelica, C. A. – Loyola, A. S. – Masa, D. B.: Coconut flour from residue: A good source of dietary fibre. Indian Coconut Journal, *32*, 2001, pp. 9–13.
8. Rajiv, J. – Indrani, D. – Prabhasankar, P. – Rao, G. V.: Rheology, fatty acid profile and storage characteristics of cookies as influenced by flax seed (*Linum usitatissimum*). Journal of Food Science and Technology, *49*, 2012, pp. 587–593. DOI: 10.1007/s13197-011-0307-2.
9. Aliani, M. – Ryland, D. – Pierce, G. N.: Effect of flax addition on the flavor profile of muffins and snack bars. Food Research International, *44*, 2011, pp. 2489–2496. DOI: 10.1016/j.foodres.2011.01.044.
10. Conforti, F. D. – Davis, S. F.: The effect of soya flour and flaxseed as a partial replacement for bread flour in yeast bread. International Journal of Food Science and Technology, *41*, 2006, pp. 95–101. DOI: 10.1111/j.1365-2621.2006.01410.x.
11. Leizer, C. – Ribnicky, D. – Poulev, A. – Dushenkov, S. – Raskin, I.: The composition of hemp seed oil and its potential as an important source of nutrition. Journal of Nutraceuticals, Functional and Medical Foods, *2*, 2010, pp. 35–53.
12. Norajit, K. – Gu, B.-J. – Ryu, G.-H.: Effects of the addition of hemp powder on the physiochemical properties and energy bar qualities of extruded rice. Food Chemistry, *129*, 2011, pp. 1919–1925. DOI: 10.1016/j.foodchem.2011.06.002.
13. Novak, J. – Zitterl-Eglseer, K. – Deans, S. G. – Franz, C. M.: Essential oils of different cultivars of *Cannabis sativa* L. and their antimicrobial activity. Flavour and Fragrance Journal, *16,* 2001, pp. 259–262. DOI: 10.1002/ffj.993.
14. Rosell, C. M.: The nutritional enhancement of wheat flour. In: Cauvain, S. P. (ed.): Bread making. Improving quality. Cambridge : Woodhead Publishing, 2003, pp. 253–269. ISBN 1 85573 553 9.
15. Dhingra, S. – Jood, S.: Effect of flour blending on functional, baking and organoleptic characteristics of bread. International Journal of Food Science and Technology, *39*, 2004, pp. 213–222. DOI: 10.1046/j.0950-5423.2003.00766.x.
16. PN-EN ISO 20483:2014-02. Ziarno zbóż i nasiona roślin strączkowych – Oznaczanie zawartości azotu i przeliczanie na zawartość białka surowego – Metoda Kjeldahla. Warszawa : Polski Komitet Normalizacyjny, 2014.
17. PN-ISO 5530-1:1999. Mąka pszenna – Fizyczne właściwości ciasta – Oznaczanie wodochłonności i właściwości reologicznych za pomocą farinografu. Warszawa : Polski Komitet Normalizacyjny, 1999.
18. PN-ISO 7973:2001. Ziarno zbóż i przetwory zbożowe – Oznaczenie lepkości mąki – Metoda z zastosowaniem amylografu. Warszawa : Polski Komitet Normalizacyjny, 2001.
19. Demirkesen, I. – Mert, B. – Sumnu, G. – Sahin, S.: Utilization of chestnut flour in gluten-free bread formulations. Journal of Food Engineering, *101*, 2010, pp. 239–336. DOI: 10.1016/j.jfoodeng.2010.07.017.
20. Wang, Y.-Y. – Norajit, K. – Kim, M.-H. – Kim, Y.-H. – Ryu, G.-H.: Influence of extrusion condition and hemp addition on wheat dough and bread properties. Food Science and Biotechnology, *22*, 2013, pp. 89–97. DOI: 10.1007/s10068-013-0053-5.
21. Dall'Asta, C. – Cirlini, M. – Morini, E. – Rinaldi, M. – Ganino, T. – Chiavaro, E.: Effect of chestnut flour

supplementation on physico-chemical properties and volatiles in bread making. LWT – Food Science and Technology, *53*, 2013, pp. 233–239. DOI: 10.1016/j.lwt.2013.02.025.

22. Gujral, H. S. – Singh, N.: Effect of additives on dough development, gaseous release and bread making properties. Food Research International, *32*, 1999, pp. 691–697. DOI: 10.1016/S0963-9969(99)00148-9.
23. Singh, N. – Kaur Bajaj, I. – Singh, R. P. – Gujral, H. S.: Effect of different additives on mixograph and bread making properties of Indian wheat flour. Journal of Food Engineering, *56*, 2002, pp. 89–95. DOI: 10.1016/S0260-8774(02)00151-6.

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