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Chia and Teff as Improvers of Wheat-Barley Dough and Cookies

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Abstract

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Basic wheat-barley flour premixes were blended at ratios 70 : 30 and 50 : 50 (w/w), and white or dark types of wholemeal chia and teff replaced 5 or 10% of these bases. All non-traditional plant materials increased farinograph water absorption up to 10% in total, and with likely dilution of the dough gluten network, their addition increased the degree of dough softening up to twice. Physicomechanical properties of non-fermented dough were changing stepwise, mainly in terms of rising dough elasticity. Higher elasticity of wheat-barley dough was reflected in better both specific volume and spread ratio of cut-out cookies. Further recipe modification by wholemeal chia and teff flours enhanced these positive changes; cookie volumes based on the wheat-barley premix 50 : 50 were about 22% higher than their counterparts from the premix 70 : 30. For both attributes of cookie quality, somewhat higher values were observed for dark variants of wholemeal chia and teff. Moreover, the spread ratio of cookies containing teff types reached higher values compared to chia ones. Characteristic barley flour flavour could be less acceptable for common consumers; both wholemeal chia and teff flours were able to mask that by-taste.

Keywords: composite flour; non-traditional plant material; baking test; cookie; PCA

In human life, sweet taste belongs among others to its pleasures. From a scientific point of view, sweet taste is classified among the four (or five) basic ones. Since the beginnings of civilisation, honey and matured fruits have been primary sources of carbohydrates characterised by sweet taste, indicating 'I'm not poisonous' and rendering energy to survive. From natural sources, industrial development contributed cane and beet sugar and artificial sweeteners later. In connection with cereal raw materials, the confectionery art covering gingerbreads, cakes, biscuits, and cookies was progressively established. According to the Czech Statistical Office data, the average annual consumption of preserved bakery products was 8.7 kg per capita in 2014 (ČSÚ 2015; www.czso.cz/documents/10180/20562003/2701391501.xlsx/80b4a62a-22d8-493b-9dc3-2c2648207246?version=1.1). For a comparison, the European per capita consumption of fine baked goods in the period 2005–2013 ranged from 7.52 kg to 8 kg (Statistica 2016).

Nowadays, at the time of increased interest of consumers in food composition as well as its health aspect, cookies represent a type of baked cereal product which could be easily adapted to such a trend. Cookies are a concentrated source of energy, mainly owing to high sugar and fat contents. Dosage of forgotten seeds of amaranth, sunflower, quinoa, chia, hemp, teff, and e.g. barley flour bring nutritionally beneficial compounds such as proteins, unsaturated fatty acids, or different forms of dietary fibre (Best

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2009; Ohr 2009) and could lower energy intake at the same time. On the other hand, the introduction of non-traditional raw materials and potential lowering of sugar content have some technological limits.

Barley (*Hordeum vulgare*, the family *Poaceae*) belongs among basic cereals, traditionally used for pearled barley, malt, and alcoholic drink production. Barley β-glucans were acknowledged as nutritionally valuable dietary fibre (EFSA 2011); in mixtures with wheat flour, barley flour increases farinograph water absorption and prolongs dough development time as well as it causes a rise of water suspension viscosity (Sullivan *et al.* 2010). Specific volume of bread containing 30% barley flour was about 25% lower compared to the wheat control, and its flavour was affected by typical barley taste (Hofmanová 2011).

Teff (*Eragrostis tef*, the family *Poaceae*) belongs to the main cereal produced in tropical Ethiopia. Very small seeds, coloured from white to red and dark brown, milled to wholemeal, are usually baked in a form of flat spontaneously fermented bread called ingera. A high portion of bran and germ present in wholemeal brings nutritionally valuable compounds, such as high amounts of iron, calcium, and magnesium, able to cover the main portion of recommended dietary allowances (Hager *et al.* 2012). Based on a large portion of prolamins, teff proteins are easily digestible. However, like in other cereals, a low content of lysine was reported (Adebowale *et al.* 2011).

Chia (*Salvia hispanica* L., the family *Lamiaceae*) is an annual herbaceous plant, typical of Mexico and Central America. Nowadays Argentina, Columbia, and Peru are the main producers. Seeds are rich in oil (30–33%) with important representation of unsaturated linolenic and linoleic acids (Ciftci *et al.* 2012) and naturally non-gluten proteins (16–26%, Ayerza & Coates 2011). The composition also includes a high content of dietary fibre (37–41%) and phenolic compounds with antioxidant activity (Reyes-Caudillo *et al.* 2008).

As for final products, cereal researchers solved the application of chia and teff to recipes for bread, pastry (cookies, cakes), and pasta to a lesser extent. The use of chia as a novel food is usually tested at rates of 5–20%, although there exists a limitation by the decision of the European Commission (EC 2013) due to potential allergenicity and anti-effect to some hypertonic drugs. Verdú *et al.* (2015) replaced 5, 10, and 15% of wheat flour by chia flour, and stated the slower bread staling due to higher water retention. Steffolani *et al.* (2015) compared the effect of 10% of dry and pre-hydrated chia flour on bread properties; the latter chia form caused a lower diminishing of bread specific volume. Combined with fat, Coelho *et al.* (2015) recommended 7.8% of whole chia seeds and 10% of chia wholemeal flour for industrial use because a decrease in bread specific volume was still acceptable. On the other hand, the authors declared a benefit of such enhanced breads in a lower content of saturated fatty acids. For gluten-free diet, Costantini *et al.* (2014) created bread based on chia-Tartary buckwheat blends (90 : 10 or 10 : 90); final products were characterised by 20% of protein and 74% of insoluble dietary fibre together with over 67% of α-linolenic acid.

Wheat biscuits containing 5–20% of chia flour had a higher nutritional value, mainly a higher amount of protein, dietary fibre, antioxidants, and especially polyunsaturated fatty acids. Reversely, higher fat content leads to accelerated lipid oxidation, indicating a shorter storage time (Mesías *et al.* 2016). Chia wholemeal flour can also lower the specific volume of pound cakes (Luna Pizzaro *et al.* 2013); for this type of cereal product, the negative effect could be limited by addition of hydrogenated vegetable fat.

Callejo *et al.* (2016) compared the effect of 15% or 30% portion of red and white teff flour, added into two wheat bread flour types of distinct baking quality. Regardless of the tested recipe, such enhancement resulted in deterioration of principal parameters of the bread structure, albeit dough rheological characteristics were dependent on the teff variant and level of its addition. The authors summarised that the teff variant must be chosen carefully to produce good quality teff-based breads. Alaunyte *et al.* (2012) verified their conclusion that a higher level of teff flour (up to 30%) worsened dough development and increased crumb firmness and bitter flavour; the addition of selected enzymes may improve the loaf volume, crumb firmness and structure as well as overall acceptability of straight dough or sourdough bread. Gluten-free breads, prepared by Campo *et al.* (2016), were based on rice flour supplemented with teff flour at ratios of 5, 10, or 20%, with or without three sourdough types. In terms of overall appearance, consumers preferred the variant containing 20% of teff flour, but in terms of flavour, bread combining 10% teff and rice sourdough reached the best evaluation.

Among six variants of gluten-free cookies, the teff cookies did not overcome the product from coarse-grained rice flour, evaluated as the best in diameter and spread factor, darker colour, and lower hardness

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(Mancebo *et al.* 2015). Kenney *et al.* (2011) examined the effect of 25 and 50% replacement with teff flour on properties of gluten-free sugar and peanut butter cookies. Teff decreased the spread ratio and hardness of cookies. Related to a control, the sensory analysis did not demonstrate any difference in appearance, flavour, and taste of cookies containing both proportions of teff.

Hager *et al.* (2013) prepared a set of gluten-free pasta; the sensory profile of oat variant was close to the wheat standard, but teff reduced its quality. Determining in vitro digestibility, gluten-free teff spaghetti had a lower glycaemic index than the control.

In the last several years, chia seeds have become very popular and their usage has spread from kitchens to industrial production; not only bread but also crackers or cookies containing dark chia seeds can be bought in groceries specialised in healthy nutrition. Also oatmeal already belongs to industrial raw materials for cookies manufacturing. Compared to chia and oats, teff and barley have a similar nutrition potential, nevertheless they could still be categorised as non-traditional materials. Such alternative materials are usually gluten-free, and evaluation of the rheological behaviour of composite dough based on wheat or wheat-barley flour with addition of chia and teff may facilitate their industrial usage. Farinograph, amylograph, and Mixolab tests were used for this purpose; changes in viscoelastic properties of non-fermented composite dough were assessed by the extensigraph test. In cut-out cookies, the bakery potential of tested tri-composite flour was quantified during a laboratory baking test. The impact of the type and dosage of non-traditional plant material was tested statistically, using analysis of variance and principal component analysis (ANOVA and PCA, respectively).

MATERIAL AND METHODS

Flour types and composite flours. Both cereal flour types, wheat flour (WF) and barley flour (BF), were from grain harvested in 2014. In WF and BF, protein contents were 11.98 and 9.40%, respectively. White and dark chia seeds were bought in a specialised food shop, and fine wholemeal flours Ch1 and Ch2 were prepared using a Concept KM 5001 blade grinder (seed dosage 50 g, operation time 1 min). A UK company supplied fine wholemeal teff flour T1 and T2, i.e. industrially milled white and brown teff seeds. Protein content in the tested alternative plant material was determined according to the standard ČSN 560512-12:1995, and the value reached 20.2 and 10% for both wholemeal chia and teff types, respectively. Similarly to the previous paper (Hrušková & Švec 2015), composite flours included two groups based on cereal premixes C300 and C500 (WF/BF 70 : 30 and 50 : 50, respectively); in both cases, wholemeal chia or teff flour substituted 5 or 10% of each premix in total (Table 1). The same table summarises sample coding; prefix 'C3xy' and 'C5xy' identifies composite flours based on premixes C300 or C500, respectively; for the tested wholemeal Ch1, Ch2, T1, and T2 flours, x is progressively equal to 1, 2, 3, and 4, respectively. Finally, y identifies the level of wholemeal flour addition: y = 1 means 5%, while y = 2 means 10%.

Flour and composite flour rheological properties. Following the standards ČSN ISO 5530-1:1995, ČSN ISO 5530-2:1995, and ICC 126/1:1972, rheological and pasting behaviour of non-fermented dough and flour water suspension, respectively, was evaluated using the Brabender apparatuses Farinograph, Extensigraph, and Amylograph (Brabender GmbH, Germany). Following the ICC 173:2011 procedure, similar characteristics of composite flours were recorded on a Mixolab modern apparatus (Trippete & Renaud Chopin, France). Based on previous experience, among the farinograph features only the water absorption and mixing tolerance index (degree of dough softening) were used because these traits are

Table 1. Composition of tested flour blends

Flour, composite flour	WF (g)	BF (g)*	Non-traditional flour (g)*
WF	300	–	–
C300	210	90	–
C3xy	200	85	15
C3xy	189	81	30
C500	150	150	–
C5xy	200	85	15
C5xy	189	81	30

WF – wheat flour; C300/C500 – wheat-barley composite flour of 70:30 and 50:50 (w/w), respectively; BF – barley flour; non-traditional wholemeals: chia white seed Ch1 (x = 1), chia brown seed CH2 (x = 2); teff white seed T1 (x = 3), teff dark seeds T2 (x = 4); wholemeal addition levels: 5% (y = 1), 10% (y = 2); examples: C311 – composite flour based on C300, containing 5% Ch1; C542 – composite flour based on C500, containing 10% T2; *all amounts are percent of WF weight (i.e. enhancement levels 5 and 10%, respectively)

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sufficient to describe dough behaviour in relation to cookie quality. Going through laboratory practice, rheological measurement was carried out in one replication; repeatability of the tests was evaluated before, using an independent WF sample. Values of standard deviations are attached below data tables.

Cookies preparation. Baking trial was conducted in laboratory conditions, and the procedure was described in detail in a previous article (Hrušková & Švec 2015). Briefly, composite flour was premixed with sugar, $NaHCO_3$, salt, and ascorbic acid using a farinograph for 10 min (dough formula based on Kulp 1994). Then, sunflower oil was added, and distilled water was titrated until reaching the consistency of 600 Brabender units (BU). Dough rested in a thermostat set to 32°C and relative humidity 95% for 30 min, and round cut-out cookies of 5 cm in diameter were formed manually. Baking without steaming was conducted in a laboratory oven preheated to 180°C, finished in 14 minutes. Quality evaluation of cookies was executed after 10 min cooling at ambient temperature. Specific volume was evaluated on the basis of six samples, coupled in pairs; volume was determined by a rapeseed displacement method similarly to volume determination of laboratory prepared bread (Alaunyte *et al.* 2012). The spread ratio was calculated from cookie diameter and height, evaluated in triplicate with a calliper.

Quantification of the sensory quality of cookies was also described earlier (Hrušková & Švec 2015). Evaluated attributes are (surface) colour, aroma, taste, consistency, stickiness during mastication, and overall acceptability. Each of the parameters could be scored by points 1–3, where the value 2 means an optimum; in fact, there are five categories for each sensory attribute because scoring 1.5 or 2.5 is also allowed. Complex sensory score is then expressed as a sum of all six parameters, with the value 12 meaning optimum.

Data statistical treatment. Using the Statistica 7.1 software (Statsoft, USA), differences in non-fermented dough behaviour and cookie properties were described by the HSD Tukey test (ANOVA, P = 95%). Comparison of the type of non-traditional plant material and addition level was analysed by principal component analysis (PCA).

RESULTS AND DISCUSSION

Flour and composite flour rheological behaviour. During farinograph testing, a verifiable increase in water absorption was caused by all three types of non-traditional materials; regardless of the dosage used and white/dark wholemeal types, the role of chia or teff was significantly more important than that of barley flour (Table 2). Barley, chia, and teff flour contain a high portion of dietary fibre, which is a known hydrocolloid. Rieder *et al.* (2012) confirmed the ability of BF to raise the water amount quantitatively for reaching demanded dough consistency. Water absorption increased by about 10–12% maximally, compared to values recorded for C300 and C500 controls, owing to only 10% of chia or teff added. A consequence of the higher water portion in dough together with dilution of the supporting gluten network was dough weakening after its overmixing. Barley flour did not contribute in this aspect at all, but in combination with chia, the degree of dough

Table 2. Rheological characteristics of wheat flour and tested composite flours

Flour, composite flour	Farinograph		Amylograph		
	WAF (%)	MTI (BU)	T_{beg} (°C)	T_{max} (°C)	AMA (BU)
WF	61.6[a]	55[a]	61.0[d]	91.0[ef]	680[a]
C300	65.5[b]	60[ab]	61.0[d]	91.7[ef]	790[b]
C311	70.6[d]	80[bcd]	60.2[cd]	94.7[f]	820[c]
C312	75.1[fg]	120[ij]	56.5[b]	90.3[ef]	900[g]
C321	70.8[d]	80[bcd]	58.0[bc]	91.8[ef]	960[i]
C322	75.2[fg]	100[fghi]	56.5[b]	90.3[ef]	1000[l]
C331	72.1[e]	85[def]	65.5[ef]	84.5[bcd]	990[k]
C332	75.9[gh]	100[fghi]	64.0[e]	82.0[b]	1000[l]
C341	71.2[de]	115[ij]	64.0[e]	82.5[b]	860[d]
C342	74.9[fg]	130[j]	67.0[f]	75.5[a]	950[h]
C500	67.1[c]	65[abc]	60.3[cd]	91.0[ef]	820[c]
C511	72.1[e]	65[abc]	58.0[bc]	91.0[ef]	980[j]
C512	77.0[h]	60[ab]	52.0[a]	84.3[bc]	1020[m]
C521	72.2[e]	50[a]	58.0[bc]	89.5[de]	960[i]
C522	77.0[h]	55[a]	56.5[b]	88.8[cde]	960[i]
C531	70.8[d]	90[fgh]	65.5[ef]	83.5[b]	900[g]
C532	74.9[fg]	90[fgh]	65.5[ef]	82.5[b]	1000[l]
C541	71.1[de]	105[ghi]	65.5[ef]	83.5[b]	870[e]
C542	74.6[f]	110[hij]	66.3[ef]	83.8[bc]	890[f]
Repeatability	0.2	4	0.5	0.9	4.2%

WF – wheat flour; C300/C500 – wheat-barley composite flour of 70 : 30 and 50 : 50 (w/w), respectively; WAF – water absorption; MTI – mixing tolerance index (dough softening degree); BU – Brabender unit; T_{beg}, T_{max} – temperature of gelatinisation beginning and maximum, respectively; AMA – amylograph (viscosity) maximum; [a–l]values in columns signed by different letters are statistically different (P = 95%)

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softening was determined to be approx. twice higher than that for both cereal premixes. In this regard, behaviour of wheat-barley-chia systems differed according to a barley flour portion. Data in Table 2 allows presuming that not 30% but only 50% BF was a sufficient amount to hold water released from the protein structure during prolonged mixing, which leads to significant dough strengthening during the test. An opposite tendency of an increase in the degree of dough softening was confirmed by Alaunyte *et al*. (2012) for wheat flour and WF-teff blend 90 : 10 (61.7 and 108.3 BU, respectively).

Figure 1 shows that all non-traditional raw materials restricted non-fermented dough extensibility, and owing to this, an extensigraph ratio increased. For C300 and C500 samples, elasticity increased about ca 40%, but extensibility diminished to 60 and 40%, respectively. For WF-BF blend 60 : 40 (w/w), Rieder *et al*. (2012) mentioned an extensibility decrease to ca 65% of the wheat control. In wheat and teff flour, the protein structure has a similar character; due to that, T1 and T2 wholemeal flours partially alleviated the BF effect on dough extensibility. In all tested cases, extensigraph energy decreased about one-quarter and two-thirds, respectively, as 30% and 50% of BF modified the dough composition; areas of curves were generally smaller. The influence of both wholemeal flours could be depicted as minor, causing diminishing in the extent depending on the enhancement level (Figure 2). Extensigraph energy corresponds directly to the volume of baked product, which does not have a prior function in such pastry manufacturing compared to bread.

Variance in amylograph features was comparable to the farinograph data; the impact of non-traditional material type and addition level factors intensified from the beginning of gelatinisation to viscosity maximum. Tested materials supported the rise of viscosity maximum, and the level of chia and teff addition could be considered as a dominant factor, although BF also contributed to this trend (from 680 BU to 490 and 820 BU for WF, C300, and C500 samples, respectively; Table 2). On the other hand, hydrophilicity of wholemeal teff flour was lower during the RVA test of wheat-teff blend 90 : 10; the peak viscosity was statistically comparable to the WF control (595 vs. 588 mPa·s; Alaunyte *et al*. 2012). Differences within C300 and C500 groups were actually comparable; the range of measured values is equal to 200 BU.

The Mixolab test allows evaluating both the protein behaviour during mixing and polysaccharide pasting properties (analogy of the farinograph and amylograph tests). Owing to the preparation of dough at constant water absorption (59.4%), modification based on non-traditional material enhancement led to a significant increase in torque (parameter C1), mainly for combination of WF-BF-teff (Table 3). Torque points C2, in which the heating input weakens

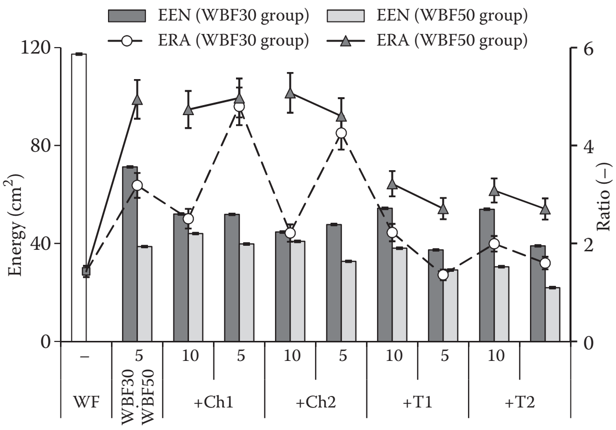

Figure 1. Effect of barley flour and chia or teff wholemeal addition on extensigraph test results; vertical lines identifies 0.95 confidence interval; EEN, ERA – extensigraph energy and elasticity-to-extensibility ratio; WF – wheat flour; WBF30, WBF50 – wheat-barley flour premixes 70 : 30 and 50 : 50 (w/w), respectively; Ch1, Ch2, T1, T2 – white and dark chia/teff seeds wholemeal

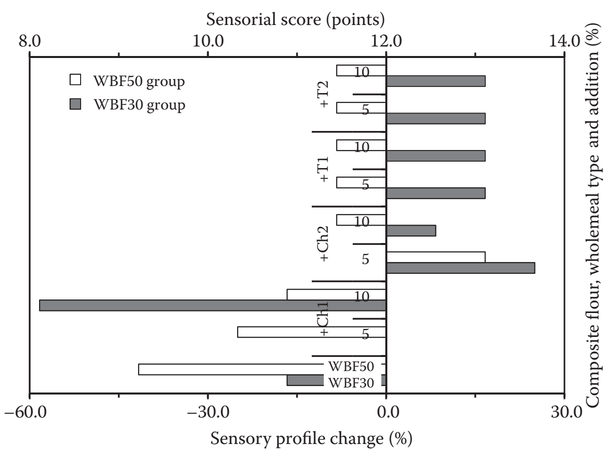

Figure 2. Effect of barley flour and chia or teff wholemeal addition on cookies sensory score; value 12 points is considered as optimum (i.e. reached by wheat cookies); WBF30, WBF50 – wheat-barley flour premixes 70 : 30 and 50 : 50 (w/w), respectively; Ch1, Ch2, T1, T2 – white and dark chia/teff seeds wholemeal

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protein functionality, confirmed a partial change in protein structures. Within the C500 group, C2 median was somewhat higher than within the C300 one (0.51 vs. 0.46 N·m, respectively); in these composite flours, a higher amount of barley β-glucans likely absorbed released water and thickened the dough. The pasting phase of the Mixolab test showed a course similar to the amylograph test, i.e. a dependence on the flour blend composition, especially at torque points C4 and C5 (stability of hot gel and retrogradation rate, respectively). The barley flour portion in composite flours did not play a decisive role; both wholemeal teff additions markedly shortened the stability of hot gel, and retrogradation did not occur to such a large extent as in WF, C300, or C500 samples. In practice, the baked product should be staling at a slower rate.

Table 3. Rheological characteristics of wheat flour and tested composite flours – Mixolab

Flour, composite flour	C1*	C2	C3	C4	C5	Energy PA
	(N.m)					
WF	1.07	0.60	2.12^{a}	1.92^{i}	2.99^{o}	138
C300	1.17	0.51^{ab}	2.24^{a}	1.69^{gh}	2.56^{k}	126
C311	1.16	0.46^{ab}	2.12^{a}	1.62^{efgh}	2.52^{i}	123
C312	1.17	0.46^{ab}	2.12^{a}	1.64^{fgh}	2.58^{l}	123
C321	1.18	0.48^{ab}	2.12^{a}	1.67^{fgh}	2.55^{j}	125
C322	1.16	0.48^{ab}	2.14^{a}	1.71^{h}	2.61^{n}	125
C331	1.27	0.48^{ab}	2.18^{a}	1.43^{ab}	2.25^{f}	118
C332	1.23	0.44^{a}	2.08^{a}	1.40^{a}	2.05^{a}	111
C341	1.17	0.46^{ab}	2.20^{a}	1.47^{abcd}	2.15^{c}	115
C342	1.18	0.45^{ab}	2.19^{a}	1.45^{abc}	2.14^{b}	114
C500	1.23	0.54^{ab}	2.34^{a}	1.72^{h}	2.60^{m}	131
C511	1.16	0.53^{ab}	2.23^{a}	1.61^{defgh}	2.58^{l}	126
C512	1.13	0.51^{ab}	2.18^{a}	1.59^{cdefgh}	2.52^{i}	123
C521	1.14	0.52^{ab}	2.23^{a}	1.60^{defgh}	2.45^{h}	123
C522	1.15	0.54^{ab}	2.18^{a}	1.65^{fgh}	2.57^{k}	125
C531	1.26	0.50^{ab}	2.24^{a}	1.55^{bcdefg}	2.32^{g}	120
C532	1.23	0.47^{ab}	2.14^{a}	1.47^{abcd}	2.18^{d}	114
C541	1.21	0.51^{ab}	2.30^{a}	1.54^{abcdef}	2.23^{e}	120
C542	1.22	0.49^{ab}	2.23^{a}	1.49^{abcde}	2.18^{d}	117
Repeatability	–	0.03	0.05	0.03	0.00	–

WF – wheat flour; C300/C500 – wheat-barley composite flour of 70 : 30 and 50 : 50 (w/w), respectively; C1 – C5: points of the Mixolab curve; energy PA – energy equivalent to area under curve; *constant water addition (59.4%); $^{a-o}$values in columns signed by different letters are statistically different (P = 95%); *all amounts are percent of WF weight (i.e. enhancement levels 5 and 10%, respectively)

Evaluation of cut-out cookie quality. The recipe water amount corresponded well with the farinograph water absorption, i.e. BF at first and then wholemeal chia and teff flour increased the portion of added water (about 14% compared to WF). Within the subset of C500 samples, amounts of added water were comparable to C300 counterparts, although all these values were lower than for C500 samples (59.7–64.1% vs. 68%; Table 3). In this regard, wholemeal teff flours proved a higher capability than chia in both subsets.

Similarly to the influence of hemp products on cookie properties (Hrušková & Švec 2015), the specific volume of baked pastry was more significantly dependent on the tested recipe than the spread ratio; a partial dependence on extensigraph features could also be identified. Within the WF-BF-chia subset, specific volume of cookies was supported by the extensigraph ratio (r = 0.697, P = 95%), while the volume of teff counterparts had a negative insignificant relation to extensigraph energy (r = –0.505, P = 0.11333). Owing to quite high uncertainty of measurement (repeatability 0.3), ANOVA conjoined almost all samples of enhanced cookies into one group (Table 4). Within the C500 group, the average of specific volumes was about ca 10% higher than for C300 counterparts; in detail, there could be estimated an interaction of BF with wholemeal chia and teff flours, stronger in the latter case (see the column 'Group Mean' in Table 4). According to the spread ratio, teff samples based on the C500 premix (specimen foursome C531–C542) differed from the chia ones (foursome C511–C522); an average increase was 28 and 8%, respectively (as shown by the 'Group Mean' column in Table 4). Finely ground chia replacing 20% of wholemeal oat flour significantly increased both cookie diameter and height (about 12.3 and 4.3%, respectively), but not the spread ratio (comparable to the wheat cookie control; Inglett *et al.* 2014). Among 11 elaborations of gluten-free sugar snap cookies, Mancebo *et al.* (2015) highlighted buckwheat and teff ones due to a higher spread ratio, which corresponded with a higher protein content in their composition.

Organoleptic profiles of cookies were changed slightly, the determined range was between 8.5 and 13.5 points (optimum 12 points; Figure 2). The main shifts occurred in colour (paler wheat-barley cookies, dark dots on the surface when Ch2 was applied), taste, and consistency (data not shown); for sample

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Table 4. Characteristics of baked cookies prepared from composite flours

Flour, composite flour	RWA	SVB		SPREAD	
		mean	group mean	mean	group mean
WF	54.0^{a}	160.1^{ab}	160.1^{a}	3.2^{a}	3.2^{a}
C300	56.3^{b}	155.8^{ab}	155.8^{a}	4.1^{ab}	4.1^{a}
C311	57.3^{b}	152.5^{a}	167.6^{a}	4.3^{ab}	4.4^{ab}
C312	59.7^{c}	180.3^{abcde}		4.9^{ab}	
C321	62.5^{fg}	162.4^{abc}		4.2^{ab}	
C322	60.1^{cd}	175.5^{abcde}		4.3^{ab}	
C331	63.4^{gh}	169.3^{abcd}	180.7^{ab}	5.0^{ab}	4.4^{ab}
C332	63.7^{h}	159.7^{ab}		4.1^{ab}	
C341	67.1^{i}	207.9^{e}		4.1^{ab}	
C342	64.0^{h}	186.2^{abcde}		4.4^{ab}	
C500	68.0^{i}	160.0^{ab}	160.0^{a}	4.6^{ab}	4.6^{ab}
C511	59.7^{c}	174.5^{abcde}	183.6^{ab}	4.8^{ab}	4.7^{b}
C512	61.0^{de}	190.0^{bcde}		5.0^{ab}	
C521	61.2^{de}	198.2^{cde}		4.8^{ab}	
C522	60.7^{cde}	171.8^{abcde}		4.3^{ab}	
C531	63.3^{gh}	197.3^{cde}	197.2^{b}	5.0^{ab}	5.3^{c}
C532	64.1^{h}	198.0^{cde}		5.4^{b}	
C541	61.8^{ef}	202.9^{de}		5.1^{b}	
C542	64.0^{h}	190.7^{bcde}		5.7^{b}	
Repeatability	0.2	6.5		0.3	

WF – wheat flour; C300/C500 – wheat-barley composite flour of 70:30 and 50:50 (w/w), respectively; RWA – recipe water addition; SVB – specific volume of baked biscuits; SPREAD – spread ratio (diameter-to-height); $^{a–i}$values in columns signed by the different letter are statistically different (P = 95%)

C312 (C300 + 10% Ch1), all these negative variants were counted up. Acceptability of C300 and C500 controls was affected by typical barley flavour, for which phenolic acids and proanthocyanidins are responsible (Holtekjølen *et al.* 2004). These chemical compounds cause bitter and astringent taste. Wholemeal chia and teff flours were able to supress that odour and aftertaste, but the higher recipe water amount tempted to partial mouthful stickiness.

Statistical comparison of effects of non-traditional material type and addition level. The first three principal components (PC) explained 73% of data variability; on average, PC1 accounted for 39%, PC2 18%, and PC3 16% (Table 5). The first PC is related mainly to dough rheological properties and cookie characteristics, PC2 to protein mechanical properties and cookie organoleptic profile, while PC3 to polysaccharide pasting properties and cookie profile, too. Comparing the explanation rate for cookie specific volume and spread (PC1–PC3 sum 39 and 76%, respectively), a higher importance of the latter characteristic could be considered in cookie quality description. Summarised, the PCA method confirmed the effect of the three tested plant raw materials and their dosages on the rheological behaviour of non-fermented dough and cookie characteristics.

Among dough and cookie quality features, five main groups could be found in PC1 × PC2 area; e.g. biopolymer absorption and pasting properties (parameters MTI, TBE, RWA) or organoleptic attributes (Figure 3). Within the groups, known relationships were confirmed as well; depending on water absorption, dough consistency (C1) with diastatic power (C34) determines the specific of volume cookies (2nd quadrant). In case of cookies, higher extensigraph energy (EEN) means lower specific volume; reversely, higher extensigraph ratio (ERA) allows better spread of such products.

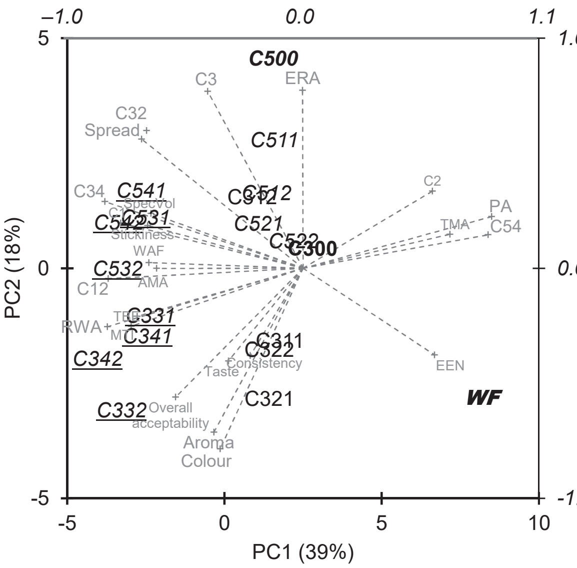

Figure 3. Biplot of first two principal components (PC); non-traditional wholemeals: chia white seed Ch1 (x = 1), chia brown seed Ch2 (x = 2); teff white seed T1 (x = 3), teff dark seeds T2 (x = 4); wholemeal addition levels: 5% (y = 1), 10% (y = 2); examples: C311 – composite flour based on C300, containing 5% Ch1; C542 – composite flour based on C500, containing 10% T2; flour tri-composites bases on C500 are written using italic, wheat-barley-teff composites are differentiated by underlining; for variable abbreviations (see Tables 2–4)

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Table 5. Portion (%) of explained variability by the first three principal component (PC)

Test	Feature	PC1	PC2	PC3	Total
Farinograph	water absorption	_32*_	0	55***	87
	mixing tolerance index	49***	6	1	57
Amylograph	temperature of gelatinisation beginning	_43**_	4	_44**_	91
	temperature of gelatinisation maximum	62***	2	0	65
	amylograph maximum	_26*_	0	62***	88
Extensigraph	extensigraph ratio	7	60***	28*	95
	extensigraph energy	54***	14	16	84
Mixolab (torque points and differences)	C1	_60***_	4	4	68
	C2	53***	11	4	67
	C3	2	59***	12	73
	C1–C2	_76***_	0	0	76
	C3–C2	34**	36**	6	76
	C3–C4	80***	8	1	89
	C5–C4	85***	2	3	90
	energy PA	87***	5	1	93
Baking trial	recipe water amount	_77***_	6	8	92
	specific volume of cookie	_30*_	6	3	39
	spread ratio	_39**_	32*	6	76
Organoleptic profile	colour	0	_62***_	1	62
	aroma	1	_51***_	1	52
	taste	0	16	32*	49
	consistency	1	14	39**	54
	stickiness	_33**_	3	16	53
	overall acceptability	13	_31*_	_38**_	83
Average		39	18	16	73

*, **, *** – correlation between dough or cookie quality feature and PC1, PC2, or PC3 – provable on P = 95%, 99%, and 99.9%, respectively; C1–C5 – points of the Mixolab curve; energy PA – energy equivalent to area under curve; underlined italic values signify a negative relationship

Distribution of the tested samples is based on the BF ratio (PC2) and type of non-traditional material in composite flour (PC1) (Figure 3). Along the vertical PC2 axis, sweet dough machinability is improving (decrease of extensigraph energy EEN and reversely an increase of ERA), resulting in a greater extent of cookie spread. An increase of the cookie-making potential of composite flours could be identified along the PC1 axis; in this regard, both wholemeal teff flours showed a significantly higher contribution.

CONCLUSIONS

Based on wheat-barley flour premixes 70 : 30 and 50 : 50, composite flours containing 5 or 10% of wholemeal chia or teff white/brown flours were analysed in terms of rheological behaviour by farinograph, amylograph, extensigraph, and Mixolab. According to 2 × 8 recipe modifications, cookies were prepared on a laboratory scale. Barley flour increased water absorption and so did both non-traditional materials (especially teff ones), in total about 10% absolutely. The higher water amount in dough together with non-gluten protein introduction increased the degree of dough softening up to twice. Barley flour strengthened dough resistance (elasticity) and reversely the extensibility; the extensigraph ratio increased approx. four times, allowing easier rolling out of dough and shaping of cookies. Further change of dough machinability was observed mainly during testing composite flours containing wholemeal chia. The extensigraph energy (as an area below the curve) fell from 128.4 cm^2 to 38.7 cm^2 owing to 50% supplement of barley flour

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for wheat flour, and to approx. 40.3 and 29.8 cm^2 on average by the addition of wholemeal chia and teff flours, respectively. The hydrophilicity of chia and teff was reflected in an increase of amylograph maxima up to the technical maximum of 1000 units (the values of 680, 790, and 820 units for wheat flour and both premixes, respectively), higher enhancement rate and higher amylograph viscosity. The Mixolab test revealed statistically verifiable differences during the heating and cooling phase of the test, indicating a dependence of the rheological profile rather on composition and properties of polysaccharides than proteins. Regardless of that, dough development of wheat-barley-teff composite flours was recorded earlier with sharper consistency maximum. Both wheat-barley cookie variants reached a similar evaluation as the control one. In correspondence to changed dough properties, tri-composite flour cookie volumes and shapes became greater as the enhancement level increased. In cookie volume, a significant difference was registered between wheat cookies, both wheat-barley controls and wheat cookies containing 50% of barley flour together with teff flour (160.1, 155.8, 160 ml/100 g vs. median 197.6 ml/100 g, respectively). Spread ratio of enhanced samples also rose, from 4.6 for cookies from wheat-barley premix 50 : 50 up to 5.7 for the respective counterpart containing 10% of brown wholemeal teff. Each of the tested non-traditional plant materials masked the barley characteristic flavour.

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