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LINSEED FIBRE – EFFECT ON COMPOSITE FLOUR PROPERTIES AND CEREAL PRODUCTS QUALITY

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ABSTRACT
Wheat flour was fortified by 2.5 or 5.0 wt. per cent of linseed fibre, gained from seeds of golden flax varieties Amon and Raciol and brown one Recital (granulation 500 – 700 m), prepared from 2015 harvest. Technological quality of six flour composites was described analytically by Falling Number and Zeleny sedimentation test. Both screening methods shown a little impact on amylases activity and protein quality, respectively. Rheological tests included the farinograph, the extensigraph and the Rapid Visco Analyser (RVA) proofs. Additions of brown and yellow flax fibre significantly increased farinograph water absorption and shortened dough stability, somewhat stronger by addition of brown linseed fibre. Extensigraph curves course depended on dough resting time, higher differences between wheat control and flour composites were observed after 60 min dough resting. Linseed fibre supported dough extensibility, and energy as area under curve significantly decreased about 7 – 18%, mainly due to increasing alternative material portion in dough. In general, fibre is characterised as hydrophilic material, and pasting profiles of flour composites confirmed this experience. During dough leavening, tested samples were differentiated according to maturograph dough resistance; optimal leavening time of wheat-linseed fibre dough was shorter than control. Regardless described modifications in dough machinability, specific volumes of bread buns were similar though whole sample set. A weak worsening of buns vaulting reflected a partial dilution of dough gluten skeleton. Cut-off biscuits were characterised by gradually lowering spread ratio, correspondingly to elevated dough elasticity. Laboratory prepared elbow-pasta have the same cooking time as the control (8.0 min), and data variation could not be attributed to linseed fibre or addition level. All three cereal products were found to have acceptable sensory profiles. PCA method verified partial lowering of protein quality and pointed at tested sample differentiation according to linseed addition level.

Keywords: brown and golden linseed fibre; dough rheology; bread; biscuits; pasta; principal component analysis

INTRODUCTION
Flax (*Linum usitatissimum* L.) is old utility plant originated in Asia. In the Central Europe during the Middle Ages, canvas was manufactured from linen and hemp. The plant is characteristics by slim stalk and white or light-blue flowers. Fruit named boll contains tiny brown seeds. Nowadays, flax varieties producing yellow seeds, known as "golden flax", are bred, too. Within seeds cover, there could be found layers containing hetero-polysaccharides, characterised by high hydration capacity (up to 1,200%). Weight ratio of this fraction oscillates between 7 – 12%. Responsible structures were analysed as neutral arabinoxylans and acid complex of galacturonic acid and rhamnose (namely rhamnogalacturonan backbone) **(Kaewmanee et al., 2014)**. In water even at low concentrations (approx. 0.2%) **(Mazza and Biliaderis, 2006)**, they form viscous gel **(Prazdnik et al., 2016)** known as mucilage. Simple sugars, namely d-xylose, d-glucose and d-glucuronic acid could be also detected it the gel. **Troshchynska et al. (2016)** verified differences in flow properties between mucilage from brown and golden flax seeds. At concentration around 1%, flax mucilage exhibits good foam stability **(Mazza and Biliaderis, 2006)**. Mucilage viscosity is probably positively correlated with the neutral sugars and negatively with the amount of proteins – dependence on actual composition predefines its usage as either thickener, or stabiliser **(Kaewmanee et al., 2014)**.

Linseed fibre is a food supplement, gained at the end of milling and sieving of defatted linseed press cake. As mentioned in our previous article **(Hrušková and Švec, 2016)**, one of its world producer is the Walramcom company from the New Zeeland. They offer both golden and brown linseed fibre types, in which ca 45% of total dietary fibre is declared (38% insoluble and 7% soluble fraction). For significant health benefit, consumption of 13 g linseed fibre is recommended daily, e.g. as muesli or yogurt spread at breakfast, or a component of fruit cocktails. Linseed fibre could be consumed alone in form of water gel like chia seeds, or could be added into cookie, pancake or bread recipes. Besides good unsaturated fatty acids content, also polyphenols are represented in valuable extent **(Gutiérrez et al., 2010)**. **Oomah (2001)** manufactured biscuits with linseed lignans and genistein in recipe, and verified their usefulness in combating cancer. At least, diets containing flaxseed are able to amend unbalanced serum lipidemia to normal values **(Mervat et al., 2015)**.

In wheat composite dough, additions of flax seed flour increased water absorption and mixing tolerance index, but shortened dough stability and extensibility **(Koca and Anil, 2007; Xu et al., 2014)**. Nor roasting of flaxseed flour did not suppress its negative effects **(Chetana et al., 2010)**. Mentioned changes were only softly reflected in bread quality characteristics as the specific volume. Within their study, **Mervat et al. (2015)** evaluated properties of wheat-flax bread variants containing full fat or partially defatted flax flour and concluded comparable quality of both enriched modifications. Contrary to that, 5% flaxseed hull flour decreased bread specific volume and increased crumb firmness **(Sęczyk et al., 2017)**.

Flaxseed flour portion, added at level 18%, significantly decreased cookies stickiness but supported their firmness. Lower alternative material dosages (6 and 12%) resulted in cookies still acceptable for common consumers **(Khouryieh and Aramouni, 2012)**. Muffins are further type of cereal product suitable for such enrichment – 20% raw flaxseed flour decreased volume of the final product softly, but its roasted version significantly (from 150 to 145 and 125 mL, respectively). In combination with rising weight of muffin pieces, their specific volume flaxseed flour was lowered approximately about 5% and about 17% for counterparts with non-treated and roasted flaxseed flour, respectively **(Chetana et al., 2010)**.

Addition of majority of non-traditional plant materials leads to disruption of gluten net in wheat-composite dough. In case of pasta containing flaxseed flour, loss of mechanical compactness did not avoid a higher rate of dried pasta shattering **(Manthey et al., 2000)**. In comparison to traditional pasta, the same authors have reported lower cooked firmness and cooking loss for fresh pasta containing 15% of flaxseed flour, stored 1 week at 4 °C **(Manthey et al., 2008)**. By usage of non-linear regression, **Kishk et al. (2011)** found addition of 3% flaxseed mucilage and drying temperature ranging between 68.2 and 70 °C as optimal for production of noodle with high cooking quality; mucilage improved the texture and overall acceptability of prepared product.

The presented study is aimed at complex evaluation of linseed fibre additions effect on technological quality of wheat flour, and comparison of influence of fibre from golden and brown oilseeds. Study covered basic analytical properties, rheological behaviour of non-fermented and fermented dough as well as final-usage potential of wheat-linseed fibre in form of bread, cookies and pasta.

MATERIAL AND METHODOLOGY

Preparation of flour composites

Semi-bright wheat flour (WF) was delivered by industrial mill Delta Prague, and it was characterized by protein content 11.2%, Falling number 372 s and Zeleny value 44 mL. Linseed fibre was produced at laboratory conditions, treating seeds from golden varieties Amon and Raciol and brown one Recital – all prepared from flax of 2015 harvest. To disintegrate the seeds, mill Stephan UM/SK 5 (Stephan Machinery, Hameln, Germany) was employed. Using vibration laboratory hand sieve machine (Stavební strojírenství n.p. Brno, Czechoslovakia) with sieve openings: 1.0, 0.8, 0.71, 0.50, 0.315 and >0.315 mm, demanded fraction 500 – 700 m was collected to ensure comparability with our previous study **(Hrušková and Švec, 2016)**. In tested composites, linseed fibre replaced either 2.5 or 5.0 wt. % wheat flour. Samples abbreviations combined simplified wheat flour sign, addition level of linseed fibre and first letter of flax variety name (W2.5A, W5.0A, W2.5Ra, W5.0Ra, W2.5Re, and W5.0Re).

Technological quality of flour composites

Technological features of WF and flour composites are described by Zeleny test (ČSN ISO 5529) and Falling number (ČSN ISO 3093). Non-fermented dough properties were determined with the help of farinograph and extensigraph Brabender (Germany), following the international norms (ISO 5530-1, 5530-2, respectively). Behaviour of suspension flour-water was recorded on the RVA 4500 equipment (Perten Instruments, Sweden; AACC method 76-21). According to internal procedures of the UCT Prague, rheological parameters of fermented dough were measured, using fermentograph SJA (Sweden), maturograph and oven spring recorder (OTG) Brabender (Germany). From prepared wheat-flax composites, manually moulded bread, cut-off biscuits and pasta were manufactured, following further internal methods including quality evaluation and sensory analysis.

Statistical evaluation of linseed fibre effect

Influence of non-traditional material type and addition level on selected dough rheological and final product features was evaluated by Tukey HSD test (p = 95%). Aim of Principal Components Analysis (PCA) usage was an identification of main quality features of bread, biscuits and pasta quality. In mentioned three cases, the PCA datasets analogously comprised two analytical features, three farinograph and two extensigraph ones, a pair of the pasting characteristics and foursome of the product quality attributes immanent to the product type.

Owing to non-gluten character of flax proteins, worsening of protein quality in composite dough is presumed. Pasting behaviour of wheat flour-linseed fibre composites will be influenced by high water absorption ability of the non-traditional material. Quality of leavened bread, cut-off buscuits and elbow-pasta may be varied for single cereal products in a different way; e.g. for biscuts, diluted gluten net in dough can support cookie spread during baking. With respect to low addition levels, all three types of cereal products could reach a sensory score in acceptable category.

RESULTS AND DISCUSSION

Evaluation of technological quality of flour composites

With respect to measured ratio of Zeleny test values (37 – 44 mL), linseed fibre lowered protein technological

Table 1 Falling number and RVA Peak Viscosity for wheat flour (WF) and flour composites.

	Linseed fibre type						
	none	*golden*				*brown*	
Flour, flour composite	**WF**	**W2.5A**	**W5.0A**	**W2.5Ra**	**W5.0Ra**	**W2.5Re**	**W5.0Re**
Falling Number* (s)	372a	362a	387a	386a	384a	378a	364a
Peak Viscosity* (mPa·s)	1452a	1565ab	1682bc	1902d	1767cd	1822cd	1794cd

Note: WF: wheat flour. Flax varieties: A – Amon, Ra - Raciol (both golden), Re – Recital (brown). RVA – Rapid Visco Analyser. Example of sample coding: W2.5A – wheat flour composite containing 2.5 wt. % of linseed fibre from variety Amon. * a – d: row means described by the same letter are not significantly different (p = 95%).

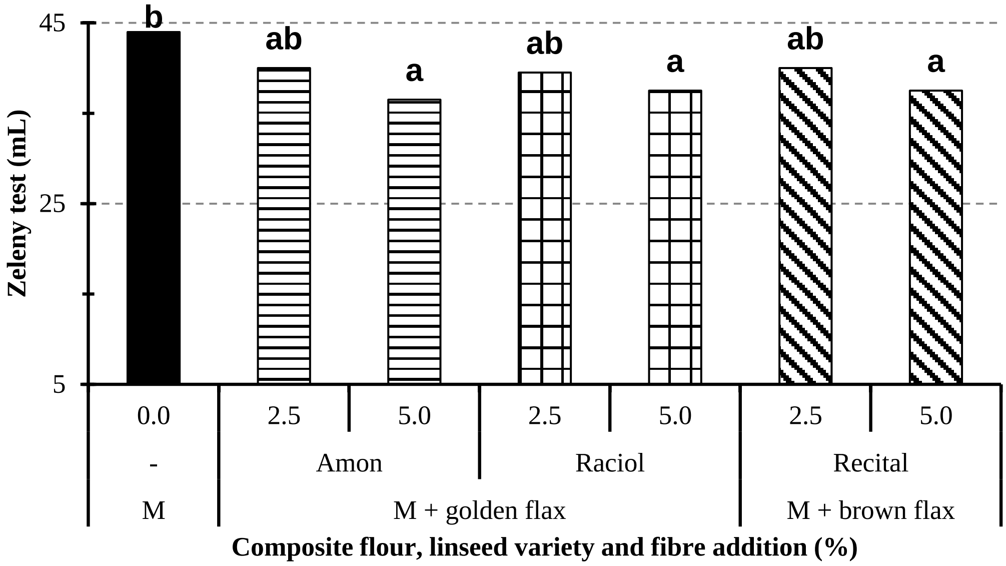

Figure 1 Zeleny test results of wheat flour (WF) and wheat-linseed fibre composites. For samples coding, see Table 1.

quality softly. The higher addition, the lower Zeleny value could be noticed on Figure 1. The same plot declares, there could not be differentiated type of added linseed fibre. The same conclusion could be stated above results of Falling number test (Table 1), which estimates amyloses activity and degree of damaged starch. For the test, measured range 362 – 387 s is covered by its repeatability (25 s).

Viscous and viscoelastic behaviour of flour composites

During RVA proof, detailed description of pasting behaviour of tested flour composites shown a partial differences among tested samples. In the point of Peak Viscosity, linseed fibre from Amon variety interacted with addition level and obviously increased measured maximum (from 1492 mPa·s for WF to 1682 mPa·s for W5.0A). For other composite samples, higher viscosities in peak than for control were determined for lower enhancement tested (e.g. 1822 and 1794 mPa·s for W2.5Ra and W5.0Ra, respectively; Table 1). At the end of the RVA proof, only WF and W2.5A samples could be considered as outlayers owing to the lowest viscosity (1869 and 2046 mPa·s, respectively, vs. 2296-2562 mPa·s for resting fivesome; Figure 2). Addition of the same portions of linseed fibre produced from seeds bred in New Zealand also caused significant increase of viscosity during RVA test **(Hrušková and Švec, 2016)**. **Inglett et al. (2013)** arrived at contrary conclusion for ground flaxseeds mixed with barley flour used as control; thus, the higher portion of flaxseed flour in barley flour composite, the lower viscosity was measured.

Table 2 Farinograph characteristics of non-fermented dough from wheat flour (WF) and flour composites.

Flour, composite flour	**Water absorption* (%)**	**Dough stability (min)**	**Dough softening degree* (FU)**
WF	66.5a	10.00b	55a
W2.5A	70.0b	9.75b	100b
W5.0A	72.5c	7.00a	95b
W2.5Ra	70.0b	9.25b	85b
W5.0Ra	72.5c	6.50a	135c
W2.5Re	70.3b	7.45a	80b
W5.0Re	72.8c	6.75a	95b

Note: WF: wheat flour. Flax varieties: A – Amon, Ra – Raciol (both golden), Re – Recital (brown). RVA – Rapid Visco Analyser. Example of sample coding: W2.5A – wheat flour composite containing 2.5 wt. % of linseed fibre from variety Amon. * a – d: row means described by the same letter are not significantly different (p = 95%).

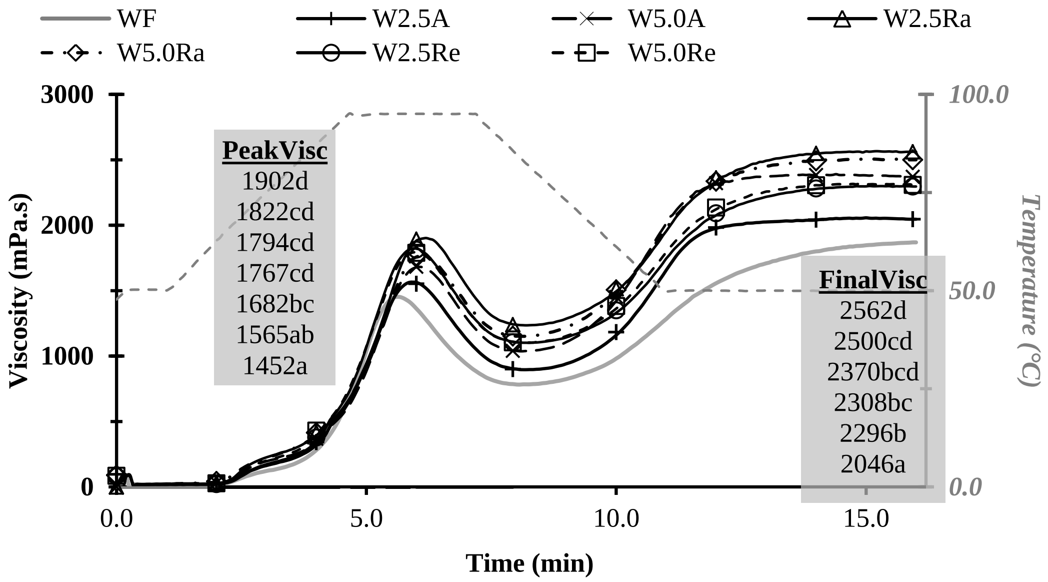

Figure 2 Pasting profiles of wheat flour (WF) and wheat-linseed fibre composites. For samples coding, see Table 1.

Water absorption of WF has risen according to enhancement level, as is documented in Table 2, no difference between three types of linseed fibre was observed. Dough development time was rather not influenced by dough recipe modifications, but dough stability did. The shorter stability about 7.00 min was revealed out for both composites containing brown linseed fibre (W2.5Re and W5.0Re), and similar values were recorded for dough with 5% dosage of both golden linseed fibre types (Table 2). Course of farinograph curves confirmed empirical knowledge about a reversal relationship between dough stability and its softening degree. Satisfying compactness of WF dough (55 FU) was lowered to half (100 FU, sample W2.5A) or almost to one-third (135 FU, sample W5.0Ra). In previous study **(Hrušková and Švec, 2016)**, linseed fibre produced by Walramcom company had a reversal influence on dough softening degree. **Koca and Anil (2007)** incorporated flaxseed flour into wheat one at level 5%, and stated any changes in water absorption, but twice prolongation of dough development due to full-fat character of the alternative material. Stability of that composite dough was dough development due to full-fat character of the comparable to wheat control, but its softening degree increased twice.

Dough machinability was changed verifiably, as indicated elasticity-to-extensibility ratio after 60 min of dough resting – value 1.94 of control was elevated to 2.31, 3.17 and 2.74 for dough composites W5.0A, W5.0Ra and W5.0Re, respectively. By Tukey's test, mentioned differences were marked as significant (data not shown). Increase of extensigraph ratio means multiplying of dough elasticity by linseed addition, as documented Inglett et al. (2013) for flaxseed flour combined with barley one. Reversely, extensigraph energy decreased only softly, from 128.8 cm2 to 117.5, 119.6 and 105.6 for composites in the same order as supra. There could be noticed, that addition of linseed fibre produced from brown seeds of Recital variety caused the highest change, although partially provable only. Wheat dough containing 5% of flaxseed flour exhibited similar extensigraph energy as control (111.0 vs. 107.0 cm2, respectively; Koca and Anil, 2007). A clear drop in such bi-composite dough quality meant 20% dosage of the non-traditional material (85.0 cm2).

Evaluation of fermented dough behaviour

During simulation of three technological stages of the fermentation process, negative effect of linseed fibre on dough behaviour varied. Scatter in the fermentograph trait final dough volume was evaluated as the narrowest (homogenous groups 'a'-'b'). Contrary, dough proofing on maturograph was unequivocally dependent on dough composition, differentiating tested samples from ca 57%

Table 3 Quality features of leavened bread prepared from wheat flour and flour composites.

Flour, flour composite	Specific bread volume** ($mL.100g^{-1}$)	Bread shape*, ** (-)	Crumb penetration** (mm)
WF	352a	0.65de	22.8ab
W2.5A	331a	0.69e	23.6b
W5.0A	349a	0.62cd	22.6ab
W2.5Ra	397b	0.62bcd	23.1ab
W5.0Ra	354a	0.53a	19.9a
W2.5Re	336a	0.58abc	21.5ab
W5.0Re	341a	0.56ab	22.0ab

Note: WF: wheat flour. Flax varieties: A – Amon, Ra - Raciol (both golden), Re – Recital (brown). Example of sample coding: W2.5A – wheat flour composite containing 2.5 wt. % of linseed fibre from variety Amon. * a – d: row means described by the same letter are not significantly different (p = 95%).

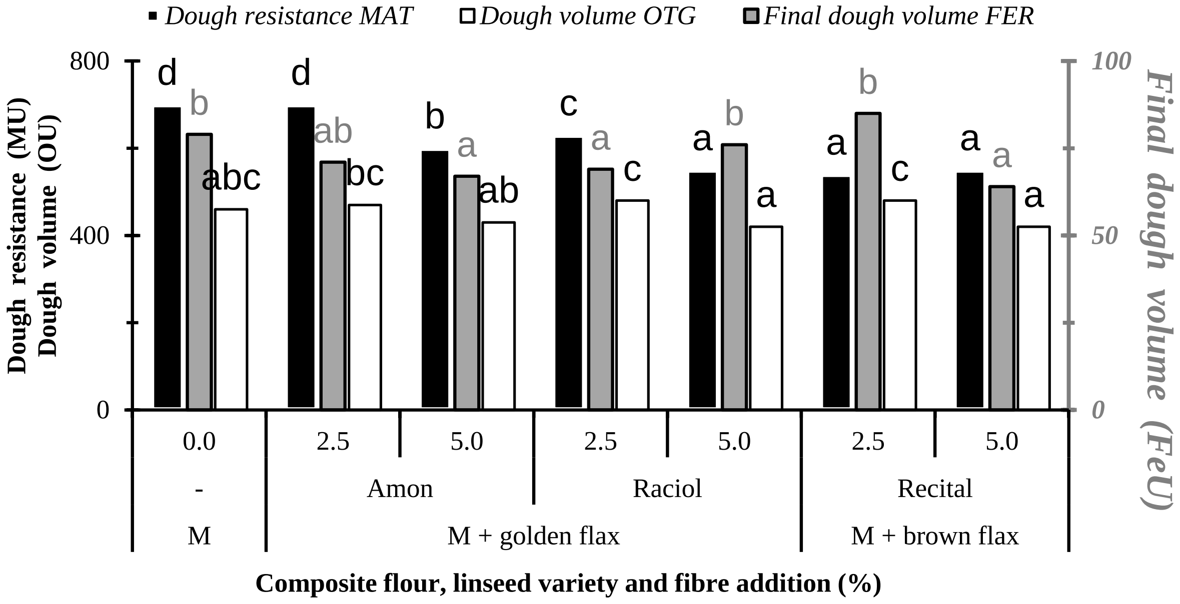

Figure 3 Rheological behaviour of leavened dough prepared from wheat flour (WF) and wheat-linseed fibre composites. Note: FER – fermentograph, MAT – maturogarph, OTG – oven-rise recorder. For samples coding, see Table 1.

(feature dough resistance – 4 groups 'a' – 'd' from 7 possible). Within the third fermentation stage of simulated baking on the OTG apparatus, determined values fell into close interval 420-480 OTG units, allowing statistical distinguishing of 3 groups only (Figure 3).

Evaluation of wheat and wheat composite bread quality

In agreement with small changes in extensigraph energy, also specific volumes of bread enhanced by linseed fibre were assessed in narrow extent (331 – 397 mL.100 g^{-1} vs. 352 mL.100 g^{-1} for control, Table 3). With respect to measurement accuracy (±15 mL.100 g^{-1}), partial and significant rise of bun sizes could be considered for the sample W2.5Ra only (397 mL.100 g^{-1}).

Verifiably higher changes were found in bread pieces shape, for which some negative effect of increasing amount of linseed fibre could be remarked. Crumb of all bread modifications was very pleasant to masticate, as indicated penetration depth over 20 mm (Table 3). Golden and brown linseed fibre from New Zeeland caused undoubtedly worsening of bread quality, a drop came to 33% **(Hrušková and Švec, 2016)**. Bread shape as well as crumb penetration got worse, too (e.g. range 5.8-10.4 vs. 14.3 mm for the latter feature). Flaxseed meal replacing 15% wheat flour also significantly lowered bread volume as well as increased crumb firmness about 8% and 40%, respectively **(Conforti and Davis, 2006)**. Flaxseed hulls up to 3% in leavened bread recipe had no verifiable negative effect on bread volume; 5% of that flax form lowered bread volume about approx. 8% and increased crumb firmness about approx. 22% **(Sęczyk et al., 2017)**.

With respect to PCA results, the first two principal components (PC) explained 74% data variability, 57% by PC1 and 17% by PC2 (Figure 4). Within PC1 x PC2 plot, baking potential of flour composites decreased contrariwise along PC1 axis. As mentioned supra, wheat-linseed blends have partially lowered protein and consecutively dough quality, resulting in soft increase of dough softening degree (mixing tolerance index, MTI). Further, higher water absorption capacity of linseed was reflected in higher Peak Viscosity (PV). In summary, technological and bread quality of flour composites containing 5% of three types of linseed fibre were more or less comparable.

Table 4 Quality features of biscuits prepared from wheat flour and flour composites.

Flour, flour composite	Specific biscuit volume** (mL.100g^{-1})	Spread ratio*, ** (-)	Sensory profile** (-)
WF	139.9ab	4.00a	12.0a
W2.5A	150.1ab	3.68a	12.0a
W5.0A	142.2ab	3.55a	12.0a
W2.5Ra	143.4ab	3.53a	11.0a
W5.0Ra	153.7b	3.76a	11.0a
W2.5Re	127.1a	3.73a	11.0a
W5.0Re	129.5ab	4.34a	11.0a

Note: WF: wheat flour. Flax varieties: A - Amon, Ra – Raciol (both golden), Re – Recital (brown). Example of sample coding: W2.5A – wheat flour composite containing 2.5 wt. % of linseed fibre from variety Amon. * Diameter-to-height ratio. ** a – b: row means marked by the same letter are not statistically different (p = 95%).

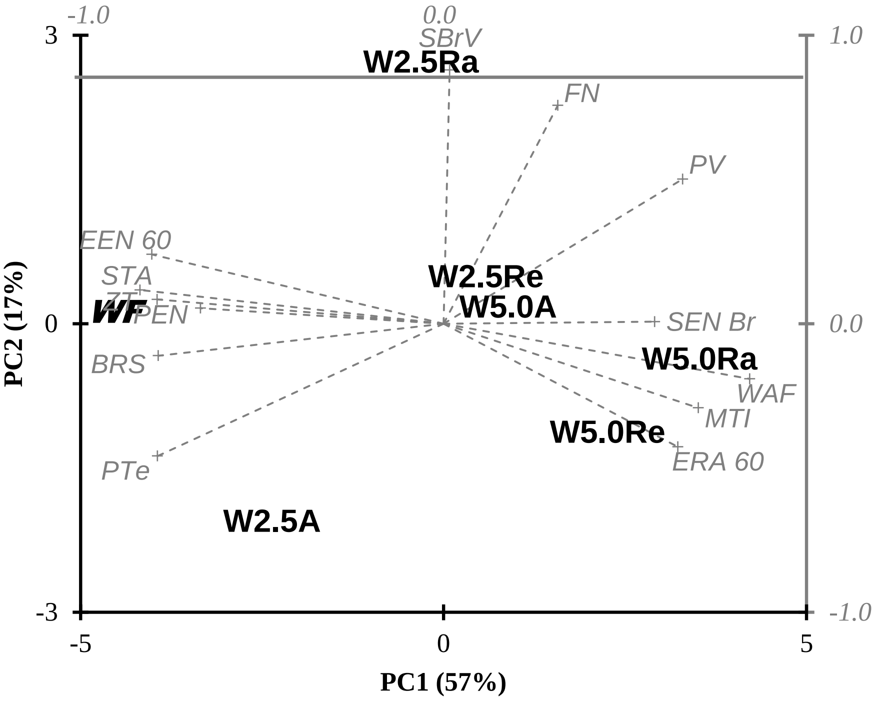

Figure 4 Principal component (PC) analysis of flax fibre effect on dough and bread technological quality. FN – Falling number, ZT – Zeleny test; WAB – water absorption, STA – dough stability, MTI – mixing tolerance index (dough softening degree); ERA 60, EEN 60 – extensigraph elasticity-to-extensibility ratio and energy, respectively (dough resting 60 min); PTe – pasting temperature, PV – peak viscosity; SBV – specific bread volume, BRS – bread shape (height-to- diameter ratio), PEN – crumb penetration, SEN Br – bread sensory profile. For samples coding, see Table 1.

Table 5 Quality features of pasta prepared from wheat flour and flour composites.

Flour, flour composite	Absorption* (%)	Swelling index* (-)	Sediment†, * (mL)
WF	159.2b	1.45a	120b
W2.5A	128.0a	1.51a	120b
W5.0A	130.4a	1.46a	100a
W2.5Ra	118.8a	1.43a	140c
W5.0Ra	124.4a	1.46a	120b
W2.5Re	129.6a	1.46a	110a
W5.0Re	126.8a	1.44a	120b

Note: WF: wheat flour. Flax varieties: A – Amon, Ra - Raciol (both golden), Re – Recital (brown). Example of sample coding: W2.5A – wheat flour composite containing 2.5 wt. % of linseed fibre from variety Amon. † Equivalent to cooking loss. * a – d: row means described by the same letter are not significantly different (p = 95%).

Evaluation of wheat and wheat composite biscuits quality

Biscuit appearance was influenced in similar extent as wheat bread one – any of analysed factors (linseed type and addition level) was not recognized as dominant. In sweet composite dough, linseed fibre supported dough elasticity – during cooking, biscuit pieces retracted in diameter lowering their spread ratio (Table 4). Sensory analysis results show acceptability of all sweetmeat modifications. Linseed fibre moderated intensity of sweet taste, and mouthful seemed to be drier with lowered stickiness to teeth. **Khouryieh and Aramouni (2012)** confirmed our findings by statement, that incorporation of flaxseed flour up to 12% did not vary physical and sensory aspect of biscuits.

Principal components analysis confirmed presumed primary effect of extensigraph features (i.e. dough machinability) on biscuits quality. Summarised, PC1 x PC2 plot indicated a medium role of linseed addition level – the higher non-traditional material ratio in recipe, the higher difference in biscuit quality related to WF control was observed (results not shown).

Evaluation of wheat and wheat composite pasta quality

Cooking proof of laboratory prepared elbow-pasta pointed at lowered water amount absorbed during boiling, perhaps due to higher fat content in composite flour. In further two pasta quality features, swelling index and sediment, any statistical differences were not evaluated. Cooking loss expressed as sediment volume in boiling water 1 hour after pasta straining varied accidentally without any observable tendency (Table 5). Brown linseed fibre produced by Walramcom company affected both absorption and sediment features **(Hrušková and Švec, 2016)**. Higher quality of noodles could be attributed to products containing up to 3% of flax mucilage **(Kishk et al., 2011)**.

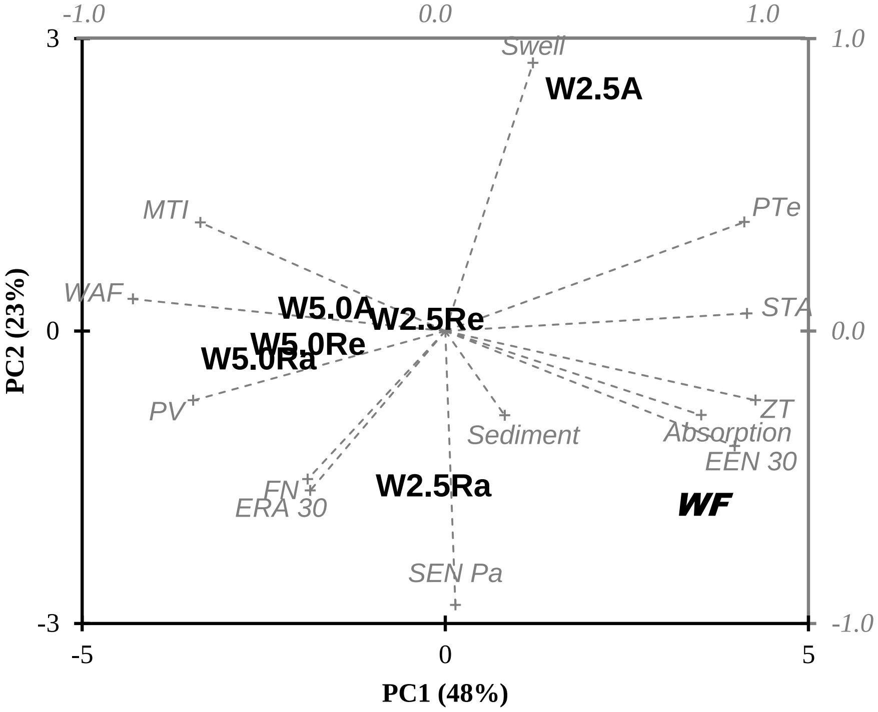

Figure 5 Principal component (PC) analysis of flax fibre effect on dough and pasta technological quality. FN – Falling number, ZT – Zeleny test; WAB – water absorption, DDE – dough development time, MTI – mixing tolerance index (dough softening degree); ERA 30, EEN 30 – extensigraph elasticity-to-extensibility ratio and energy, respectively (dough resting 30 min); PTe – pasting temperature, PV – peak viscosity; Absorption – amount of water absorbed by pasta, Swell – Swelling ratio, Sediment – height of sediment after pasta cooking, SEN Pa – pasta sensory profile. For samples coding, see Table 1.

Multivariate analysis of dough composition on wheat-linseed fibre pasta quality explained 71% of data scatter; PC1 and PC2 expressed 48% and 23% of data variance (Figure 5). Comparably to bread and biscuits, wheat pasta position in Figure 5 reflects higher protein and non-fermented dough quality. Samples W5.0A, W5.0Ra, W5.0Re are grouped together, based on higher water absorption during dough preparation on farinograph and reversely lower after proper pasta samples cooking. In our previous study **(Hrušková and Švec, 2016)**, pasta quality was also dependent on golden and brown linseed granulation; dominant role was attributed to linseed type tested.

CONCLUSION

Nowadays, non-traditional or forgotten plant materials are recognized to be a functional component of novel food. Their benefit lies in presence of unsaturated fatty acids, dietary fibre or minerals, together able to correct some health or metabolic disharmony. Full-fat flaxseed flour or purified linseed fibre fulfil these presumptions, and our study documents its possible usage in cereal products, namely bread, biscuits and pasta. Leavened wheat-linseed fibre dough was characterised by higher water absorption, presenting important aspect for baker technologists. Such modified dough perhaps requests a shorter leavening stage in bakery to ensure optimal bread volume and crumb properties. Quality of composite cut-off biscuits was comparable to standard without dependence on golden or brown linseed type or their addition level. Fibre partially masked biscuits sweetness, and visible light orange-beige dots in their surface may be attractive for consumers. Non-traditional materials also did not affect process of pasta pressing. Surface of pasta variants was smooth with recognizable spots of fibre particles. In cooked form, quality of elbow-pasta was statistically comparable to control, and optimal cooking time was 8.0 min for all seven samples.

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