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Rheological Characteristics of Composite Flour with Linseed Fibre – Relationship to Bread Quality

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Abstract

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Linseed fibre represents a rich natural source of dietary fibre. Here, we report that the addition of linseed fibre at levels of 2.5 and 5.0% changes the viscosity of wheat flour as well as the rheological properties of non-fermented and fermented dough. The differences recorded between fibre from golden and brown flax seeds (GF and BF, respectively) were not significant; BF caused a stronger increase in non-fermented dough elasticity. The addition of both variants reduced fermentation times and partially decreased dough volumes during the three phases of the fermentation process. The results of the baking test corresponded with the altered rheological parameters of dough. Based on principal component and cluster analyses, representative features for each rheological test were identified: amylograph maximum (amylograph test), the pasting temperature (RVA test), dough softening degree (farinograph test), extensigraph ratio (extensigraph test) were selected as the representative features. For the evaluation of fermented dough behaviour, wheat flour-linseed fibre composites could be differentiated according to fermentation time (fermentograph test) and dough volume (OTG test). Statistics also confirmed the appropriateness of the crumb firmness parameter for a detailed specification of bread quality.

Keywords: bread charasteristics; correlation analysis; dough rheology; flax fibre; PCA

Flax (*Linum usitatissimum* L.) is an ancient plant that originated in Asia, and which is now used in both industry and food production. The term flax is used for the variant bred for the production of thread and linen, whereas linseed denotes the variant whose seed is used for oil and as a source of dietary fibre. The original colour of flax seeds is brown, but there are also Czech varieties (e.g., Amon, Raciol) with lighter seed colour known as "golden" or "yellow flax".

Apart from these differences in colour, no differences in nutritional content have been confirmed. Flax seeds are characterised by high levels of oil (40%), dietary fibre (28%), and proteins (21%). Further, minerals represent 4% and lignans, hemicelluloses and phenolics 6% dry matter (DM) (Fitzpatric 2008, Bernacchia *et al.* 2014; Ding *et al.* 2014; Dziki *et al.* 2014; Nitrayová *et al.* 2014). Similarly to chia seeds, when water is in excess flax seeds form mucilage, a substance which is composed of heteropolysaccharides and which influences blend viscosity (Praznik *et al.* 2016). Flaxseed oil is rich in omega-3 unsaturated, short chain fatty acids; α-linolenic acid content is also substantial (Cunnane *et al.* 1993). The stability of these bioactive compounds in flaxseed and fortified foods was discussed by Marpalle *et al.* (2015).

Wholemeal flaxseed is the basic flax form used to modify dough recipes – rheological properties as well as bread quality and sensory profile are changed according to dosage level (Inglett *et al.* 2013; Marpalle *et al.* 2014; Xu *et al.* 2014; Pejcz *et*

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al. 2015). Wholemeal flaxseed can also be prepared from roasted seeds (Xu *et al.* 2014; Marpalle *et al.* 2015). Flaxseed flour or fibre can be used to improve the quality of wheaten biscuits (Hrušková *et al.* 2013), muffins or pasta.

Flaxseed dietary fibre is produced as a commercial food supplement by the Walramcom Company (New Zealand). Its proximate chemical composition is the following: saccharides 2.4%, proteins 32.0%, total fat 16.6% (of which 13% are unsaturated fatty acids) and dietary fibre (TDF 45.2%, IDF 37.9%, and SDF 7.3%).

This paper aims to explore the differences in the rheological properties of non-fermented and fermented dough augmented with golden and brown linseed fibre at amount 2 and 5%. A further goal was statistical analysis of representative rheological parameters that predetermine bread specific bread volume, shape and crumb firmness.

MATERIAL AND METHODS

Flour samples and composites. Fine wheat flour (WF) was provided by the Delta mill (Prague, Czech Republic). Protein content, Zeleny sedimentation volume, and falling number were 11.2%, 37 ml and 392 s, respectively. Golden and brown linseed fibre (GF, BF) were produced by Walramcom (New Zealand), and the selected granulation was 500–700 μm.

Linseed fibre was added at 2.5 or 5.0 wt % WF to give the following composite flours: GF-2.5, GF-5.0, BF-2.5, and BF-5.0.

Rheological properties of flour, non-fermented and fermented dough. Viscous behaviour was described by using an amylograph (Brabender GmbH, Germany; ICC method 126/1) and a rapid visco analyser (Perten Instruments, Sweden; AACC method 76-21.01). The viscoelastic behaviour of non-fermented dough was recorded in farinograph and extensigraph tests (ISO 5530-1 and ISO 5530-2, respectively).

Following in-house methods, the behaviour of fermented dough was evaluated over the course of three technological stages, i.e., fermentation, leavening and the first phase of baking, employing fermentograph (SJA, Sweden) (Švec & Hrušková 2004), maturograph and oven rise apparatuses (OTG; Brabender, Germany) (Hrušková & Skvrnová 2003). Owing to the previously determined repeatability of the rheological tests, measurements were carried out only once. The accuracy of the measured values is given in the tables.

Laboratory baking trial. Baking tests were carried out with standard WF and the four wheat-linseed fibre composites, following a previously described method (Švec & Hrušková 2015a). Fermented dough was prepared by using a farinograph to achieve a consistency of 600 Brabender units (BU). Baking lasted for 14 min in a laboratory steam oven (Research Institute of Baking Industry Ltd., Poland), preheated to 240°C. After 2 h of cooling at ambient temperature, three buns were selected for the determination of specific bread volume and bread shape ratio. Crumb firmness was calculated as the mean of five replicates and was evaluated using the PNR-10 penetrometer (Petrotest Instruments, Germany).

Statistical analysis. Effects of linseed type and addition level were compared using Tukey's test (P = 95%) in Statistica v7.0 software (StatSoft Inc., USA). The impact of linseed fibre on the recorded data as well as an estimation of the relationship between the different variables was analysed using the principal component analysis. To quantify the tightness of the relationships, both correlation (P = 95 and 99%) and hierarchical cluster analyses were used.

RESULTS AND DISCUSSION

Viscosity of flour and the viscoelastic behaviour of non-fermented dough. Mueller *et al.* (2010) reported that the water binding capacity of insoluble linseed fibre from golden and brown seeds was comparable. This observation was confirmed for GF and BF in the amylograph test, because linseed fibre increased the high initial value of 960 BU of the WF control over the technical limit of the amylograph (1000 BU – data not shown). In view of this, possible differences between GF and BF or addition levels could not be evaluated. The positive effect of wholemeal flaxseed on the amylograph maximum was also described by Pejcz *et al.* (2015) – wheat flour replacement at levels of 5, 10, and 15% caused significant increases in viscosity from 440 BU to 680 BU, 835 and 990 BU, respectively.

The composite RVA profiles revealed an interaction of the studied factors. In Figure 1, a statistically stronger effect is demonstrated for the golden fibre variant, especially for the GF-5.0 and BF-5.0 samples. The largest differences were identified at the end of the RVA test (at minute 16 min, curve point final viscosity). The RVA profile of pure golden wholemeal flaxseed was very flat without any peaks

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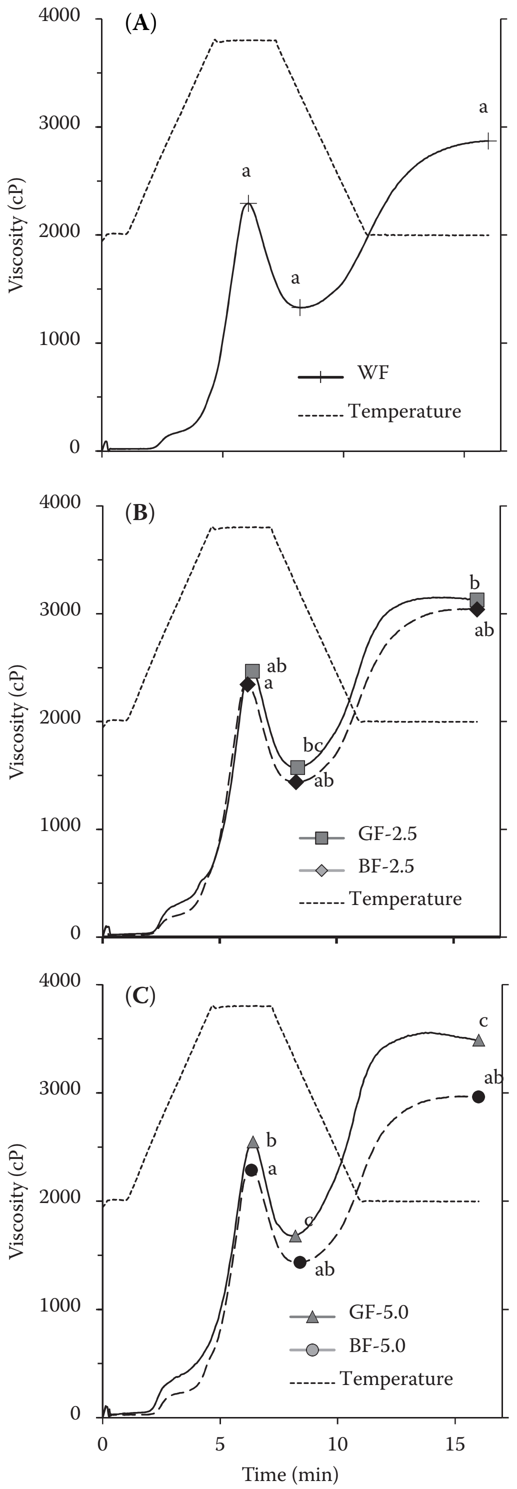

Figure 1. Effect of linseed fibre on the RVA profile of wheat flour (WF): (**A**) WF control, (**B**) flour composites with 2.5% of golden or brown linseed fibre (GF and BF, respectively), and (**C**) flour composites with 5.0% GF or BF data points (from right to left peak visc, hold visc, final visc, respectively) denoted by different letters are statistically different (P = 95%)

(Inglett *et al*. 2013); in mixtures with cereal flour, the wholemeal could decrease viscosity and such composite flour may be suitable for nutritional bars or biscuit production.

The hydrophilic character of linseed fibre was also noted during the kneading of non-fermented dough – the farinograph water absorption rose gradually with the amount of added fibre, independently of tested fibre type (Table 1). Partial dilution of the total gluten content of wheat dough was described to contribute to a prolonged development time (Xu *et al*. 2014). Oil present in flaxseed flour may decelerate the absorption of water molecules into protein and polysaccharide structures. Due to an approx. 7% error in measurement accuracy, a similar trend as for the water absorption could not be estimated. The non-traditional material strengthened dough resistance to overmixing – after 15 min kneading, only a small drop of 10–20 BU was seen in the consistency curve (Table 1). In summary, the degree of dough softening could also not be used to differentiate the tested flour composites. Owing to the higher fat content in flaxseed flour than in our linseed fibre, replacing 6, 10 or 15% of wheat flour with the former was described to increase dough softening degree significantly from 33–83 BU (Xu *et al*. 2014).

The physical properties of non-fermented wheat dough change mainly in terms of dough elasticity with increasing linseed fibre addition (Koca & Anil 2007); as seen from the extensigraph ratio, a markedly larger effect is elicited by BF (Figure 2). In comparison to the WF control, 5% GF increased

Table 1. Effect of flax fibre on farinograph properties of non-fermented composite dough

Flour composite	Water absorption (%)	Dough development time (min)	Dough softening degree (BU)
WF	67.8^{a}	3.15^{ab}	50^{b}
GF-2.5	70.0^{b}	2.50^{a}	20^{a}
GF-5.0	72.0^{c}	4.00^{bc}	10^{a}
BF-2.5	70.3^{b}	3.50^{abc}	15^{a}
BF-5.0	72.3^{c}	4.50^{c}	10^{a}
Repeatability (%)	0.93	6.90	8.57

WF – wheat flour; GF – golden linseed fibre; BF – brown linseed fibre; GF-2.5, GF-5.0 – wheat flour composite containing 2.5 or 5.0 wt% of golden linseed fibre, respectively; flour composites with BF are indicated in a similar way; $^{a-c}$values in columns with different letters are statistically different (P = 95%)

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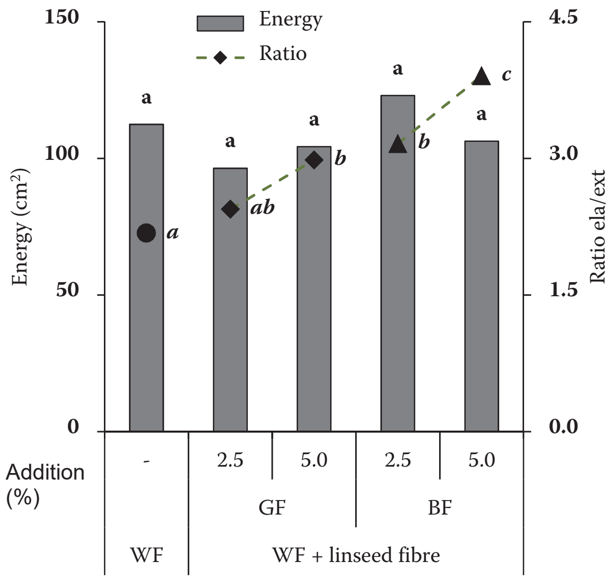

Figure 2. Effect of type of linseed fibre and addition level on extensigraph parameters of non-fermented wheat dough

WF – wheat flour; GF – golden linseed fibre; BF – brown linseed fibre; ratio – elasticity-to-extensibility ratio (dough resting time 60 min)

the ratio by about 37%, and 5% BF by about 79%. Although the extensigraph curve shapes changed in a stepwise manner, the areas under them (i.e., energy) remained comparable (Figure 2). A significant decrease was triggered by the addition of more than 10 or 15% flaxseed flour (Koca & Anil 2007) – this fall may be attributed to the higher fat content in flaxseed flour than in linseed fibre.

Rheological parameters of fermented dough. Oppositely to linseed fibre dosage, fermentograph, and maturograph times and maximal dough volumes (i.e., fermentation time, leavening time, dough volume FER, and dough resistance, respectively) decreased (Table 2). The additions of the same volumes of hydrated white/dark chia wholemeal led to prolongation of the leavening time and to an elevation in dough resistance (Švec & Hrušková 2015b). This finding is connected to the higher absorption ability of chia polysaccharides compared to flax ones, especially polysaccharides that form mucilage (absorption ability 27 times its own weight compared to 12 times for flax) (Praznik *et al.* 2016). As in the case of GF and BF linseed, no significant differences were found between the effects of the two types of chia.

In the OTG test, the behaviour of the GF-composite samples differed from their BF counterparts – compared to control, initial dough and final bread volumes were insignificantly lower and higher, respectively, for the GF flour composites. Composites containing BF demonstrated a reverse tendency, i.e., lower specific bread volumes were obtained using W-BF blends.

Baking test results. The quality of control bread was evaluated as sufficient – the specific volume of the WF control reached 334 ml/100 g (Table 3). Bread recipe modification by GF contributed to gradual diminishing in all three attributes of bread quality – the two GF dosages resulted in drops of approx. 19 and 45%, respectively. The quality of bread derived from the BF-5.0 composite was slightly higher compared to the one from the GF-2.5 blend. This finding may be related to the extensigraph features – owing to comparable energy values, the increased extensigraph ratio affected the specific bread volume. Crumb firmness was the trait which was most sensitive to the used flour base; its values fell in a stepwise manner to approx. one-half.

Table 2. Effect of flax fibre on behaviour of fermented composite dough

Flour composite	Fermentograph		Maturograph		Oven rise apparatus (OTG)	
	fermentation time (min)	dough volume FER (FeU)	leavening time (min)	dough resistance (BU)	dough volume OTG (BU)	bread volume (BU)
WF	46^a	73^b	30^a	570^a	390^a	550^a
GF-2.5	44^a	68^b	32^a	540^a	350^a	575^a
GF-5.0	40^a	61^a	28^a	525^a	320^a	550^a
BF-2.5	41^a	68^b	32^a	600^a	370^a	510^a
BF-5.0	41^a	55^a	32^a	540^a	380^a	510^a
Repeatability (%)	4.9	1.8	7.7	3.5	8.7	4.6

WF – wheat flour; GF – golden linseed fibre; BF – brown linseed fibre; GF-2.5, GF-5.0 – wheat flour composite containing 2.5 or 5.0 wt% of golden linseed fibre, respectively; flour composites with BF are indicated in a similar way; FeU – fermentograph unit; BU – Brabender unit; $^{a-c}$values in columns with different letters are statistically significantly different (P = 95%)

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Table 3. Effect of flax fibre on qualitative features of composite flour bread

Flour, flour composite	Specific bread volume (ml/100 g)	Bread shape (–)	Crumb penetration (mm)
WF	334[c]	0.61[a]	14.3[c]
GF-2.5	283[bc]	0.53[a]	10.4b[c]
GF-5.0	182[a]	0.42[a]	6.2[a]
BF-2.5	197[a]	0.44[a]	6.6[ab]
BF-5.0	246[ab]	0.56[a]	9.1[ab]
Repeatability (%)	5.4	6.2	7.3

WF – wheat flour; GF, BF – golden and brown linseed fibre, respectively; GF-2.5, GF-5.0 – wheat flour composite containing 2.5 or 5.0 wt% of golden linseed fibre, respectively. Flour composites with BF are indicated in a similar way; [a–c]values in columns with different letters are statistically significantly different (P = 95%)

Decreases in specific bread volume were documented by Marpalle *et al.* (2014) and Xu *et al.* (2014), for mixtures of both non-treated and roasted flaxseed flour with wheat. The addition of these flax

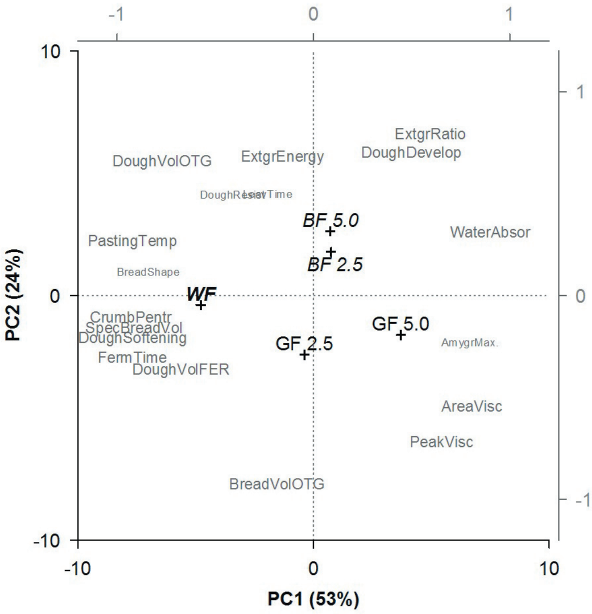

Figure 3. Principal component biplot – comparison of two linseed fibre types and two addition levels on the technological quality of wheat dough and wheat bread
WF – wheat flour; GF 2.5, GF 5.0, BF 2.5, BF 5.0 – wheat flour composites containing 2.5 or 5.0% of golden or brown linseed fibre

Table 4. Percentage of explained data variability – principal component (PC) analysis results

Form of flour composite	Rheological test	Feature	PC1	PC2	PC3	PC4
Flour suspension	amylograph	amylograph maximum	63[a]	7	17	14
	rapid visco analyser	pasting temp	87*	5	5	3
		peakvisc	41	58[a]	0	0
		areavisc	64[a]	34	0	2
Non-fermented dough	farinograph	water absorption	79*	7	13	1
		dough development time	24	43	16	17
		dough softening degree	86*	4	0	9
	extensigraph	extensigraph ratio	34	56[a]	8	1
		extensigraph energy	3	41	45	12
Fermented dough	fermentograph	fermentation time	87*	12	0	1
		dough volume fer	47	17	36	0
	maturograph	leavening time	6	22	1	71[a]
		dough resistance	18	21	61[a]	0
	oven rise aparatus	dough volume otg	61[a]	38	0	1
		bread volume	4	93**	2	1
Bread	baking trial	specific bread volume	85*	4	9	2
		bread shape	72[a]	1	26	1
		crumb penetration	88*	3	9	0
		average	53	26	14	8

*,**pairwise correlations provable at likelihoods of 95 and 99%, respectively; [a]correlation coefficients were higher than 0.70 (P = 0.188120)

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forms at 5% contributed to slightly diminished bread specific volumes (approx. –2%). In the case of milled flax hull enrichment, Sęczyk *et al.* (2017) described only a weak decrease in loaf volume (ranging from 415–390 ml, ≈ –6%). The modified composition also led to a verifiable increase in crumb hardness in accordance with our findings.

Statistical analysis of the effect of linseed fibre. Principal component analysis (PCA). The first three principal components (PC) explained 92% of data variability (53% by PC1, 26% by PC2, and 14% by PC3; Table 4). The fourth PC was important for the maturograph feature of leavening time (communality 71%). Due to the lower number of tested items, the high value of the critical correlation coefficient (r_{crit} (0.05) = 0.878) required us to take into account also coefficients ≥ 0.70 (calculated probability P = 0.18820, i.e., variability explained from min. 56%).

The PC1 included mainly RVA and farinograph parameters together with bread quality attributes. The PC2 covered the dough extensigraph and OTG characteristics primarily, showing a logical connection between the viscoelastic properties of non-fermented dough and the behaviour of fermented dough during simulated baking. PC3 explained especially the fermentograph and the maturograph traits (Table 4).

In the PC1 × P2 area, the biplot covered 79% of data variability (Figure 3); brown linseed fibre mainly influenced non-fermented dough characteristics (positive PC2 half-axis); golden linseed fibre affected bread volume (negative PC1 half-axis). Generated clusters of features are based on the different forms tested for the flour composites (i.e., flour suspension, dough, bread). Farinograph dough softening, fermentograph fermentation time, and dough volume plus crumb firmness parameters, located within the 3rd quadrant, influenced the specific bread volume directly (Švec & Hrušková 2009). The majority of flour pasting and dough viscoelastic parameters had, in contrast, a negative relationship with final product quality.

Relation of dough rheological parameters to bread quality attributes. Linear correlation analysis and clustering in a multidimensional space are based on the same principle – the comparison of values in pairs. The results of both approaches are presented

Table 5. Relationship of dough rheological features to bread quality attributes (correlation analysis, hierarchical clustering)

Rheological test	Characteristic	Spec. bread volume r (SS)	Bread shape r (SS)	Crumb penetration r (SS)
Amylograph	amylograph maximum	–0.75[a] (7%)	–0.86[a] (4%)[a]	–0.82[a] (5%)[a]
Rapid Visco Analyser	pasting temp	0.85[a] (73%)	0.90* (77%)	0.90* (78%)
	peakvisc	–0.47 (14%)	–0.65 (9%)	–0.49 (14%)
	areavisc	–0.63 (10%)	–0.72[a] (7%)	–0.64 (9%)
Farinograph	water absorption	–0.76[a] (6%)[a]	–0.54 (12%)	–0.78[a] (6%)[a]
	dough development time	–0.52 (13%)	–0.21 (22%)	–0.46 (15%)
	dough softening degree	0.84[a] (72%)[a]	0.70[a] (61%)[a]	0.89* (77%)
Extensigraph	extensigraph ratio	–0.59 (11%)	–0.27 (20%)	–0.60 (11%)
	extensigraph energy	–0.22 (22%)	–0.19 (23%)	–0.15 (24%)
Fermentograph	fermentation time	0.95* (85%)	0.79[a] (68%)	0.95* (84%)
	dough volume fer	0.53 (51%)	0.23 (38%)	0.54 (52%)
Maturograph	leavening time	0.21 (37%)	0.29 (40%)	0.10 (33%)
	dough resistance	0.06 (32%)	0.00 (29%)	0.08 (32%)
Oven rise aparatus	dough volume otg	0.62 (56%)	0.74[a] (64%)	0.63 (57%)
	bread volume	0.43 (46%)	0.16 (35%)	0.39 (45%)
Baking trial	spec. bread volume	1.00 (100%)	0.93* (82%)	0.99** (92%)
	bread shape	0.93* (82%)	1.00 (100%)	0.92* (81%)
	crumb penetration	0.99** (92%)	0.92* (81%)	1.00 (100%)

r – Pearson correlation coefficient; SS – statistical similarity (relative Euclidean distance); *,**pairwise correlations provable at likelihoods of 95 and 99%, respectively; [a]correlation coefficients were higher than 0.70 (P = 0.188120)

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in Table 5; in correlation analysis, a prevailing reverse dependence of bread quality on non-fermented dough properties is confirmed.

The numbers of medium-tight relationships with specific bread volume, bread shape, and crumb firmness were 7, 8, and 7, respectively; bread shape is probably the trait with the worst predictive power (Table 5). From the list of 15 evaluated characteristics, only pasting temperature, dough softening degree, and fermentation time had a direct impact on all the considered bread attributes.

Statistical similarities were calculated to be in the range of 4–85%, which corresponded well with the correlation analysis results. For the mentioned features, this triple (pasting temperature, dough softening degree and fermentation time), statistical similarity oscillated between 61–85% (Table 5).

With respect to the results of multivariable analyses, amylograph maximum and RVA Pasting temperature could be used to give composite flour pasting. Dough softening degree and perhaps extensigraph ratio cover dough physico-mechanical properties. Within the linseed composites set, the fermentation process is represented by fermentograph fermentation time and OTG dough volume. To describe the 2nd phase of the fermentation process, the maturograph dough resistance should be incorporated into the bread quality prediction model with some limitations.

CONCLUSIONS

The testing of two linseed fibre types confirmed the known impact of fibre on the properties and behaviour of flour and non-fermented dough – suspension viscosity as well as water absorption significantly increased and dough elasticity was improved. During the fermentation process, diluted dough gluten skeleton decreased the volumes of the wheat-linseed fibre composite dough in the fermentograph and OTG tests. Changes in dough properties were negatively reflected in specific bread volume and crumb firmness, and somewhat stronger effects were observed for the linseed fibre in the form of golden seeds.

Principal component analysis indicated differences in the dependence of bread quality attributes on rheological parameters of flour and dough. Relationship tightness, determined, as is common, by correlation analysis, could, to a certain extent, be altered by the statistical similarity calculated on the basis of Euclidean distances between samples. In agreement with the results of our statistical analyses, each of the tested seven rheological parameters could be represented by one feature. For description of non-fermented dough properties, the amylograph maximum (amylograph test), the pasting temperature (RVA test), dough softening degree (farinograph test), extensigraph ratio (extensigraph test) could be selected as the representative features. For evaluation of fermented dough behaviour, such a role could be assigned to fermentation time (fermentograph test) and dough volume (OTG test).

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