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Wheat dough fermentation and bread trial results under the effect of quinoa and canahua wholemeal additions

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Abstract: To study the effect of quinoa and canahua wholemeals on wheat flour quality, addition dosages of 10 and 20% wt. were tested. Both non-traditional materials lowered protein baking quality (Zeleny sedimentation), and present dietary fibre increased the Falling number. The fermentograph and maturograph tests showed differences in the optimal fermentation and proofing times, as well as in dough volumes during both tests (which were somewhat higher for the wheat-quinoa flour composites). Besides this, dough volumes in the third stage of fermentation simulated on the oven-rise apparatus decided about baking trial results; in this regard, wheat-canahua flour composites reached statistically better results. All obtained data together with sensory scores pointed to the maximal tolerable quinoa or canahua dosage up to 15% wt.

Keywords: wheat composite flour; non-traditional plant; Zeleny sedimentation; Falling Number; fermentation process; bread volume

The genus *Chenopodium*, currently part of the family *Amaranthaceae*, involves also food plants rendering both leaves (vegetable) and seeds. The best known members which were used for human nutrition by Aztecs and Incas thousands of years ago are quinoa and canahua (or also kañiwa, *Ch. quinoa* and *Ch. pallidicaule*, respectively). Both plants are tolerant to climate, growing mainly in South America. On the continent, they are able to fruit from the coast up to the Altiplano heights (Vega-Gálvez et al. 2010; Lim 2013; Pérez et al. 2016). Quinoa seeds are produced not only for local consumption, but also as trading goods – FAO statistics documents Bolivia, Peru and Ecuador as the main world exporters. The appearance of the plants and tested seeds is compared in Figure 1; however, quinoa is also able to produce seeds of red and black colour with nutty taste.

In terms of the nutrition benefit, seeds from both alternative plants overcome wheat in an exceptional balance between oil, protein and fat (Vega-Gálvez et al. 2010). Protein content is slightly higher (approx. 14.5%; Repo-Carrasco-Valencia et al. 2009), but in fat and minerals portions, both *Chenopodium* species are richer (Rosell et al. 2009; Table 1). Also the portion of crude fibre is satisfactory, varying from 1.9% to 10.9% in dependence on genetic diversity (Vega-Gálvez et al. 2010). In comparison of both species, the total dietary fibre portion is statistically higher in canahua seeds (8.87% vs 12.56%; Repo-Carrasco-Valencia et al. 2010). It has been experimentally documented that the deep heat treatment of bran by extrusion diminished the total high content of dietary fibre to a small extent (from ca 25% to 18.9% and 20.1% for 2 canahua varieties; Repo-Carrasco-Valencia et al. 2009). Further, the insoluble indigestible fraction (ca 61%) accounts for a major portion of fibre.

From a technological point of view, quinoa and canahua are naturally gluten-free, and that fact is reflected in machinability of composite dough as well as in bread-making potential of flour blends. In the Mixolab

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Figure 1. Comparison of plants and seeds of (A) quinoa and (B) canahua

test, Rosell et al. (2009) observed a decrease in dough consistency and a reduction in dough stability during the mixing of dough containing both alternative plant materials. Differences in starch granule shape and size affected pasting temperatures as well as stability of hot gel. According to the conclusions published by Wang et al. (2015), a lesser extent of quinoa starch retrogradation is based on higher resistance to swelling and heat treatment. The same authors tested six wheat flour-based composites and they proved that quinoa flour diminished the specific volume of cookie, bread and steamed bread at an addition level overcoming 60, 15, and 14%, respectively. Iglesias-Puig et al. (2015) tested additions of quinoa flour at a level of 25 and 50%, and the recipe changes led to a reduction in loaf volumes as well as in crumb softness to one half.

The present study is aimed at the rheological behaviour of leavened wheat dough as affected by 10% or 20% addition of quinoa or canahua wholemeals. The technological potential of prepared bi-composite blends was tested directly in a laboratory baking trial, manufacturing hand-moulded buns. All tested recipe variants were further evaluated in terms of consumer quality. Obtained data were processed by a multivariate statistical method (HCA) to find an interaction between the type and addition level of alternative raw materials tested.

MATERIAL AND METHODS

Flour and flour composites. Wheat flour samples (WF1 and WF2) as a base of flour composites were produced from grain harvested in 2015 and 2017 by the Czech commercial mill Jaroslav Chochole, Delta (Prague, Czech Republic). Both are characterised by optimal quality for a partial substitution.

Quinoa and canahua seeds were bought in a specialised food shop Country Life CZ; they were processed into a form of fine wholemeal using a Concept KM 5 000 blade grinder (Elko Valenta, Czech Republic) as a batch production (sample weight 25 g, operation time 3.0 min; abbreviations QW, CW). Flour bi-composites were mixed from WF1 and quinoa, while canahua counterparts were based on the WF2 control. In both cases, wheat flour substitution levels were chosen as 10 and 20% wt. (flour composite codes WF1+10QW, WF1+20QW, WF2+10CW, WF2+20CW).

In terms of the nutrition benefit, both quinoa and canahua overcome wheat in protein, fat and mineral contents (Table 1, adapted from Rosell et al. 2009).

Analytical testing of technological quality. Basic analytical tests covered technological quality of proteins (Zeleny sedimentation) and estimation of α-amylase activity and rate of damaged starch (Falling number) according to international standards ISO 5529 and ISO

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Table 1. Proximate composition (%) of wheat, quinoa and canahua flour (Rosell et al. 2009)

Flour type	Moisture content	Protein*	Ash	Fat
Wheat	14.21 ± 0.09	9.81 ± 0.10	0.53 ± 0.08	0.92 ± 0.09
Quinoa	8.31 ± 0.06	13.83 ± 0.23	2.09 ± 0.09	5.04 ± 0.14
Canahua	11.46 ± 0.10	14.75 ± 0.19	3.27 ± 0.06	6.40 ± 0.15

*Protein conversion N × 6.25 for wheat, N × 5.7 for quinoa and canahua

3093, respectively. Both tests were carried out with WF1 and WF2 controls, quinoa and canahua wholemeals and all four bi-composites in two replications. For the WF1 control, protein content was 12.5%, Zeleny value 40 mL and Falling number 421 s. The values for the WF2 sample were 13.0%, 55 mL and 317 s, respectively.

Rheological testing of technological quality. Changes in the rheological behaviour of leavened composite wheat dough were recorded using a fermentograph (FER) (SJA Company, Sweden), maturograph (MAT) and oven rise recorder (Ofentriebgerät, abbreviation OTG; both apparatuses Brabender GmbH. & Co KG, Germany), with respect to three technological phases of the fermentation process in bakery (fermentation, proofing and the first stage of baking). The abovementioned rheological proofs were performed according to internal methods of the Cereal Laboratory of the University of Chemistry and Technology (UCT) Prague (hereinafter Cereal Laboratory) in one replication each, with the repeatability of methods determined earlier. In this stage of evaluation, together eleven parameters describing the rheological behaviour of leavened dough were collected.

Baking trial. A laboratory baking trial ended by sensory profile quantification was performed according to an internal procedure of the Cereal Laboratory (Švec & Hrušková 2010). Three trained panellist participated in sensory scoring, thus results have an informative nature only. Due to the non-gluten character of quinoa and canahua wholemeals, both non-traditional materials were excluded from rheological testing as well as baking trial (inability to form compact dough of demanded consistency).

Statistical analysis. Data variance, caused by the addition of two non-traditional wholemeals and two addition levels, was described by HSD test at a confidence level of 95% with the help of the Statistica 13.0 software (Statsoft, USA). The impact of both factors as the type and the addition level of non-traditional materials was compared by Hierarchical Cluster Analysis (HCA) using the Euclidean distance and the furthest neighbour clustering algorithm. In the following technological steps of leavened bread manufacturing, the HCA procedure should confirm relationships between the evaluated quality parameters and quantify statistical similarity between the tested flour composites and composite breads.

RESULTS AND DISCUSSION

Evaluation of technological quality of raw materials and flour composites. Although protein technological quality was significantly higher for WF2 (55 mL vs. 40 mL), the volume of quinoa or canahua sediments reached an equal level of 43 mL. The sediment height was most likely based on non-starch polysaccharides with great absorption capacity at room temperature. The addition of both non-traditional materials resulted in comparable results, reflecting actual dosages of quinoa or canahua (Figure 2). The finding implies a somewhat higher negative influence of quinoa than canahua. In addition, fonio as a naturally gluten-free tiny seed material had a similar impact, 10% of fonio wholemeal decreased the Zeleny value from 32 to 27 mL (Švec & Hrušková 2018).

Rheological behaviour of leavened composite dough. From a viewpoint of the bakery technologist, the stable volume of dough pieces at a demanded level during all operation phases on the industrial bread line is expected to produce the bread type (recipe) in question. On a laboratory scale, such comparison is possible using the three apparatuses: fermentograph, maturograph and oven-rise recorder (OTG; Brabender GmbH. & Co KG, Germany). Based on long-term testing, the above-mentioned rheological proofs could be represented by the features drawn in Figure 3 (fermentograph final dough volume, maturograph dough resistance, OTG bread volume; Švec & Hrušková 2014). Comparing two wheat controls WF1 and WF2, leavened dough from the former was slightly weaker in dough resistance. In the other two characteristics, quality was comparable although the Zeleny test pointed to a higher technological potential of WF2.

In relation with the twofold ratio in dough, quinoa wholemeal blended with WF1 caused a partial decrease of the dough volume, mainly of the OTG one

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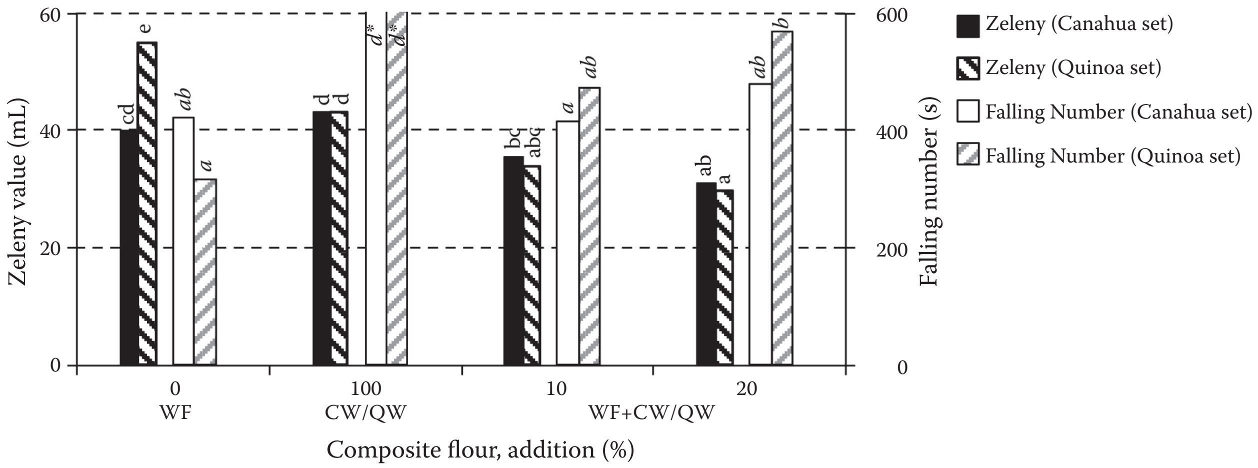

Figure 2. Comparison of quinoa or canahua wholemeal effect on protein quality and amylolytic activity of wheat flour

WF – wheat flour control; CW – canahua wholemeal; QW – quinoa wholemeal; [a–d]values of the Zeleny sedimentation, resp. *[a–d]*values of the Falling number signed by the same superscript do not differ significantly ($P > 0.05$); *values of Falling number higher than 900 s

(from 645 to 440 Brabender units, BU; i.e. –33%). In case of the wheat flour blends with CW, the recipe enrichment supported the maturograph dough resistance only (increase up to 52% against WF2; Figure 3); both final dough and bread volumes oscillated around the values of 74 fermentograph units and 640 BU, respectively. Similar variation was observed previously during the testing of leavened composite dough containing two dosages of barley flour and four types of hemp flour (Švec & Hrušková 2014). For example, the flour from dehulled hemp seeds supressed a negative technological impact of barley flour in all three technological phases of dough fermentation, perhaps owing to the reduced non-starch polysaccharide content.

Baking trial evaluation. During dough preparation, slightly higher water absorption was determined for the WF2 control. The increased addition of about 2.5 percentage points of water should mean an economic ben-

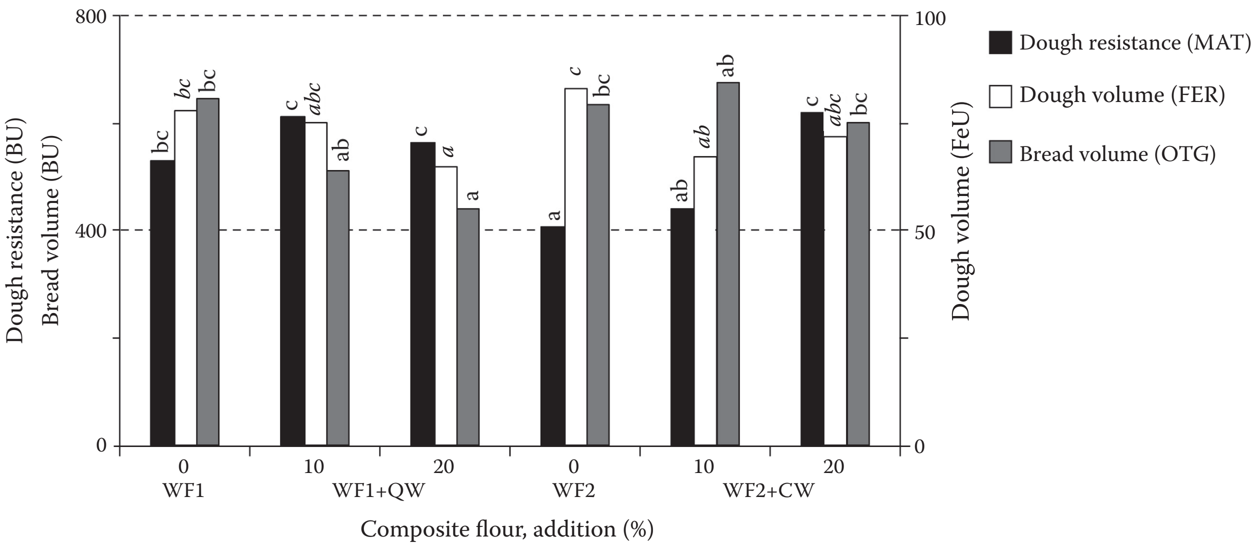

Figure 3. Comparison of quinoa or canhua wholemeal effect on rheological behaviour of wheat dough during technological stages of fermentation, leavening and the first phase of baking

WF – wheat flour control; QW – quinoa wholemeal; CW – canahua wholemeal; FeU, BU – fermentograph, and Brabender unit; FER, MAT, OTG – fermentograph, maturograph and oven-rise apparatus, respectively; [a–d]values of the dough resistance a bread volume signed by the same superscript do not differ significantly (P > 0.05); *[a–c]*values of the dough volume signed by the same superscript do not differ significantly (P > 0.05)

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Table 2. Influence of quinoa and canahua wholemeals on baking test results

Flour base	Recipe water addition (%)	Specific bread volume (mL 100 g^{-1})	Bread shape (h/d)	Crumb penetration (mm)	Sensory score (points)
WF1	54.5^{bc}	313^{c}	0.53^{ab}	8.5^{abc}	9.0b
WF1+10QW*	57.5^{cd}	258^{ab}	0.52^{ab}	9.2^{abc}	17.0^{d}
WF1+20QW	56.5^{cd}	235^{ab}	0.47^{a}	5.8^{a}	18.0^{d}
WF2	58.0^{d}	282^{abc}	0.72^{c}	12.2^{bc}	8.0^{a}
WF2+10CW	55.5^{ab}	371^{c}	0.57^{bc}	13.1^{c}	9.5^{b}
WF2+20CW	58.0^{a}	208^{a}	0.68^{bc}	7.1^{ab}	10.0^{bc}
Repeatability	0.35%	6.3%	5.55%	9.8%	0.06%

WF – wheat flour; WF1 – protein content 12.5%, Zeleny value 40 mL, and Falling number 421 s; WF2 – protein content 13.0%, Zeleny value 55 mL, and Falling number 317 s; QW – quinoa wholemeal; CW – canahua wholemeal; *WF1+10QW – flour composite containing 10 wt. % of quinoa wholemeal; $^{a-d}$values in columns signed by the same superscript do not differ significantly ($P > 0.05$); h – height of a bun; d – diameter of a bun

efit in part. Consumer's quality of WF1 and WF2 bread controls was comparable: the rapeseed displacement method of bun volume determination did not allow the higher accuracy than ± 15 mL 100 g^{-1}. Determined specific volumes of 313 vs. 282 mL 100 g^{-1}, respectively, were thus statistically similar. The shape of both controls as a diameter-to-height ratio differed significantly, but the respective values 0.53 and 0.72 (Table 2) did not fall into the empiric optimal range of 0.60–0.65 in either case. A higher water amount in wheat bread for WF2 likely influenced its bread crumb: a penetration depth of 12.2 mm is normal, suggesting an easily chewable mouthful. The compression level between 8.0 and 10.0 mm shows somewhat harder, but still acceptable quality of the crumb. Visual comparison of manufactured bread variants is given in Figure 4.

Figure 4. Comparison of overall buns and crumb texture appearance between wheat and composite breads containing quinoa and canahua wholemeal (WF, QW, and CW, respectively)

WF – wheat flour (control); QW – quinoa wholemeal; CW – canahua wholemeal; 10, 20 – addition level of wholemeals QW or CW (% wt. on WF base)

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In relation to the seed colour, there is a noticeable darkening of both the crust and the crumb, especially in case of enrichment with CW.

The addition of QW or CW slightly influenced the recipe amount of water, but the actual values did not correspond to a fortification level. On the other hand, the effect of both tested alternative materials differed in bun measured specific volumes and shapes. An increasing portion of QW induced a reduction in bun volumes: a significant decrease was determined for the lower addition level only (drop from 313 mL 100 g^{-1} to 258 mL 100 g^{-1}), but the twofold amount did not cause any increase in the negative effect (diminishing from 258 mL 100 g^{-1} to 235 mL 100 g^{-1}). Morita et al. (2001) demonstrated a boundary of the quinoa negative effect around a 15% decrease in wheat bread volume. In case of composite flour based on WF2, canahua first supported the specific bread volume (+32%), but in the other case, the volume decreased by about 26% (Table 2). Similar trends were published also by Rosell et al. (2009): the addition of 12.5% of QW or CW did not significantly affect the bread specific volume, even the addition of canahua (listed there as kañiwa) induced an increase of this parameter (3.1 mL g^{-1} for wheat control and 3.6 mL g^{-1} for wheat-canahua bread). The authors attributed such an effect to higher content of fermentable sugars, allowing the production of a huge amount of fermentation gases. Differences between both alternative plant materials were enhanced by twofold dosage (approx. 2.1 mL g^{-1} for wheat quinoa bread and approx. 2.9 mL g^{-1} for the canahua composite counterpart). The latter value was statistically comparable to their control. As presumed, harder crumb determined by the TA-XT2i texture analyser was related to lower bread volume.

Wheat-quinoa products could not be compared in the round shape of bread with their wheat-canahua counterparts. The former group including also WF1 bread had a height-to-diameter ratio clearly lower than the empirical optimum 0.60–0.65, i.e. buns were broader than higher. In the latter bread group, the insufficient shape of bread prepared from WF2 control was a bit closer to the above-mentioned optimal range. Better dimensions of WF2-CW bread were perhaps based on more homogeneous porosity, as it could be derived from verifiable higher crumb penetration values as well as sensory scores. It could be noticed that 20% of both alternative raw materials worsened the overall consumer's quality of wheat bread: crumb chewiness (penetration depth) was approx. half compared to the 10% fortification level (Table 2). For practical use, maximum tolerable dosage of both non-traditional materials is between 10 and 15% wt.

Table 3. Effect of the type of non-traditional plant material and addition level on fermented dough behaviour and bread quality (ANOVA)

Proof	Characteristic	Variance factor		
		flour base (FB)	addition level (AL)	FB × AL
Fermentograph	fermentation time	+	+	+
	gas volume	−	−	−
	final dough volume	−	+	+
Maturograph	leavening time	−	−	−
	dough resistance	−	−	+
	dough elasticity	+	+	+
	dough stability	−	+	+
Oven rise recorder (OTG)	initial dough volume	+	−	+
	sample volume	+	+	−
	bread volume	+	+	+
	oven rise	+	+	+
Baking trial	recipe water addition	+	+	+
	specific bread volume	−	+	+
	bred shape *h*/*d*	+	−	+
	crumb penetration	+	+	+
	sensory profile	+	+	+
Count of "+" from 16		10	11	13
Distinguishing rate (%)		63	69	81

(+) presence, (−) absence of significant difference between the samples ($P > 0.05$)

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Relationships between quality features and statistical similarity of tested samples. Results of ANOVA (Analysis of variance) test of the flour base and addition level as the key factors together with their interactions are summarised in Table 3. Data show a significant impact of single factors in more than 2/3 of the technological features determined, and their concurrent effects in 4/5 of the cases (traits). Fermentation time, maturograph dough elasticity, OTG bread volume together with recipe water addition, specific bread volume and crumb penetration should be considered as representative features.

Clustering of technological features verified the presumed relationships and their exchangeability; within the primary cluster of four features (e.g. "Tfer" – "SEN"; fermentation time-sensory profile) statistical similarity lies in the range of 59–93%. For 24 pairs in total, statistical similarity was 50% at least (data not shown). As could be noticed, dough behaviour in the third phase of the fermentation process, simulated by using the OTG equipment, finalises the size of the final product. Bread shape is logically influenced by the used water amount which co-determines dough volumes and other dough properties during the fermentograph and maturograph tests. Crumb hardness or chewiness as penetration depth is reflected by maturograph dough elasticity in the best way (Figure 5a).

Focused on the tested dough and bread quality, the bakery value of WF1 and the WF2 samples was closer to each other than to their blends with QW or CW (Figure 5b). Comparing mutually the pairs of composite flours and breads, the type of non-traditional material somewhat dominated over the addition level for the WF1-QW samples, and vice versa for the WF2-CW ones (similarities 58 and 27%, respectively). In general, the cluster analysis confirmed a principal different influence of QW and CW on the fermentation time "Tfer", maturograph resistance of dough "Rmat" and bread sensory profile "SEN", and on the specific bread volume "SBV" at the same time.

CONCLUSION

Correspondingly, as the recent trend has been to apply non-traditional plant materials in the food industry, especially in bakery technology, the influence of wholemeals from botanically similar crops quinoa and canahua (kañiwa) on the baking value of wheat flour was evaluated. The addition of both non-gluten plant materials led to a similar decrease in protein sediment

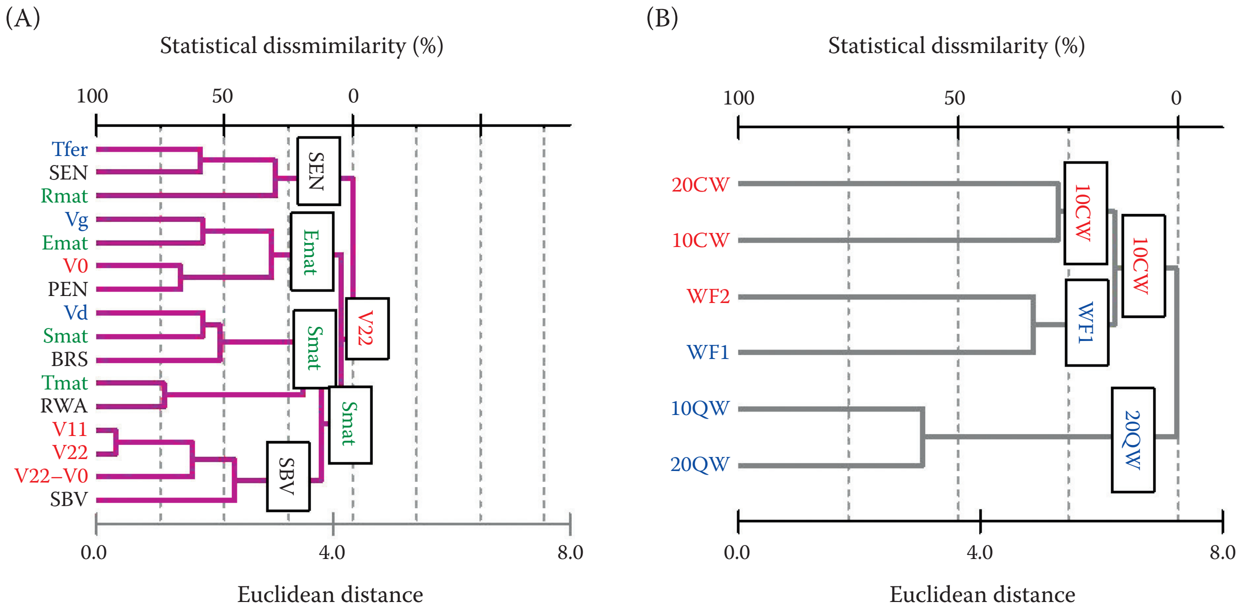

Figure 5. Statistical similarities among technological parameters of a) leavened wheat dough – wheat bread and a) tested samples as affected by quinoa and canahua wholemeal additions.

Fermentation features: Tfer – fermentation time, Vg – volume of fermentation gases, Vd – final dough volume; maturograph features: Tmat – leavening time, Rmat – dough resistance, Emat – dough elasticity, Smat – leavening stability; oven rise recorder (OTG) features: V0, V11, V22 – initial, sample and bread volume, respectively; V22–V0 – volume rise; baking trial features: RWA – recipe water addition, SBV – specific bread volume, BRS – bread shape (vaulting as height to diameter ratio), PEN – crumb penetration, SEN – bread sensory score

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in agreement with the addition level tested. In quinoa and canahua, dietary fibre polysaccharides are present at a higher level than in wheat; it leads to an increase in the Falling number, indicating perhaps a less intensive fermentation process. In agreement with the baking test results, the behaviour of fermented (leavened) dough during the three technological stages of the fermentation process was somewhat more favourable in the wheat-canahua flour composites than in the wheat-quinoa counterparts. Quinoa significantly lowered consumer's bread quality, i.e. bread specific volume or crumb penetration were diminished to a larger extent, and reversely in the sensory score. According to cluster analysis results, the dependence of bread quality features on fermented dough characteristics was confirmed. In conclusion, the effect of quinoa and canahua wholemeals differed mostly during the first phase of fermentation, while it was exerted on the specific volume of bread and its sensory profile.

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