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Technological and nutritional aspect of different hemp types addition: Comparison of flour and wholemeal effect

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Summary

Addition of non-traditional raw-materials and flours into wheat flour follows contemporary trend of manufacturing nutritionally healthier fermented bakery products. Aim of the study follows this tendency, evaluating nutritional improvement of composite flour and baking potential of prepared wheat-hemp flour composites. Hemp products addition significantly increased both protein and dietary fibre contents. Between five types of hemp flour, differences were observed according to incorporated amount (wheat flour substitution from 5% to 20%). In composites containing 20% of hemp flour and dehulled hemp wholemeal, protein content increased to 14.9% and to 15.7%, respectively (compared to 12.5% proteins in control wheat flour). Dietary fibre content change was governed unequivocally by addition level for both hemp flour and hemp wholemeal. Hemp wholemeal affected the solvent retention capacity (SRC) profile of the wheat flour used in a broader extent than hemp flour done, interacting moreover with addition level applied. Significant diminishing was measured for the sucrose and the lactic acid SRC, which describe physicochemical stage of starch and proteins in prepared composites. Addition of 5% and 20% of dehulled hemp wholemeal decreased the formed SRC from 112.0% to 102.3% and to 64.1%, and the latter SRC from 182.6% to 108.0 and to 78.3%, respectively. Smaller bread volume and worse shape were evaluated as the amount of hemp flour gradually increased; wholemeal form had more or less a positive effect. Correspondingly to that, crumb firmness measured by penetration test was found approximately half for hemp flour composite bread than for the hemp wholemeal ones.

Keywords: wheat/hemp composite, protein content and quality, solvent retention capacity, dietary fibre, bread volume

Introduction

Bakery cereal products represent a basic daily-eaten food, and their role lay in a filling function. Traditionally, mainly wheat and rye flours undergo fermentation process, and common rolls and bread are manufactured. The composite flours on basis of wheat and others cereals and non-grain seeds have become popular in the baking technology, reflecting customers' increasing interest in healthier food. In a few last decades, soy or spelt have successfully extended offered products portfolio. Further non-traditional ingredients (e.g. amaranth, quinoa, lupine, chickpea, chia, hemp, teff) are in researchers' focus nowadays, their multiple roles in enhancing the rheological properties of dough, in increasing of bread quality and nutritional value are steadily explored (Hrušková, 2008; Best, 2009; Ohr, 2009; Mironeasa et al., 2011; Ortega-Ramirez et al., 2011).
Hemp (*Cannabis sativa*) is planted as two subspecies, namely ssp. *culta* a ssp. *indica*. The latter is called hash hemp and belongs to forbidden raw material with respect to intoxicating substances production (Perlín, 2002). Hemp flour composition differs according to used feedstock (dependent on variety and planting locality), means of preparation and defatting. Protein, fat and starch rates are known to be 30-33%, 7-13% and approx. 40%, respectively. It contains a significant level of beta-carotene and vitamins B_1 and E. Considering mineral component aspect, a benefit could be found in higher portion of iron and zinc (Peč and Dušek, 2008). Approx. two-thirds of hemp proteins is composed by edestin, belonging to low molecular weight globulins. Hemp flour is naturally gluten-free, suitable for celiatics.
Presented work was aimed at alternative flour type and addition level effects comparison, as in terms of analytical and nutritional aspect, so from viewpoint of bread quality characteristics.

Materials and methods

Cereal mixtures were based on commercial wheat flour (WF), which was blended with three samples of commercial hemp flour (K1, K2, K3), and with two samples of hemp wholemeal (dehulled K4 and

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hulled K5). Samples K1 and K2 have a domestic origin (E. Citterbartová's company, Czech Republic). The sample K3 was prepared from hemp seeds bred under organic-regime and produced in Germany by Hanf & Natur Company. Hemp wholemeals were prepared in a laboratory scale using blade grinder Concept KM 5001, disintegrating dehulled (K4) and hulled hemp seeds (K5) delivered by the Hemp production CZ (Chraštice, Czech Republic). Model samples were blended in ratios 95:5, 90:10, 85:15 and 80:20 (w/w), and samples were named by hemp flour type and substitution level, e.g. K1.10 or K5.20. Four dosage levels tested were selected to find a compromise between two antithetical factors: nutritional improvement and acceptable technological and quality properties of leavened bread as the final product.

In terms of basic analytical composition of wheat flour and tested composites, protein content and quality (Zeleny sedimentation value) as well as amylase estimation (Falling Number) were evaluated. For this aim, the Czech standards (ČSN 56 0512, ČSN ISO 1871 'Kjeldahl method', ČSN ISO 5529 and ČSN ISO 3093) were followed. The solvent retention capacity (SRC) profiles were gained according to AACC No. 56-11, including a standard 5g flour sample and centrifugation by usage the Eppendorf 5702 apparatus (Eppendorf AG, Germany). The measured characteristics were water, sucrose, sodium carbonate and lactic acid SRC. Nutritional benefit of hemp addition was assessed by insoluble, soluble and total dietary fibre contents determination (IDF, SDF and TDF, respectively) by using commercial Megazyme kit (AOAC method 985 29). Baking test was performed according to internal method of UCT Prague (Hrušková et al., 2006), examining wheat and composite flour water absorption and a final product characteristics (specific bread volume, bread shape as height-to diameter ratio, sensory profile and crumb firmness as a penetration rate). Sensory quality was described by 9-point score, including attributes bread vaulting (shape), crust parcelling, crust colour and shine, crust crispness, crumb elasticity, crumb porosity, overall taste and aroma, sensation during mastication and stickiness to palate. Hedonic scale degrees for the each of listed attributes are 1 – 2 – 3 as optimal – acceptable – unacceptable, with "between" points 1.5 (like "somewhat different to optimum") and 2.5 (like "even, still acceptable") allowed. Total score has thus limits between 9 and 27 points for the best and unacceptable bread consumer's quality, respectively. Crumb porosity and chewiness were accessed also objectively by using the penetrometer PNR 10 (Petrotest Instruments, Germany), measuring a penetration depth of steel semisphere during 5 second deformation. For the specific bread volume and crumb penetration, repeatability as variation coefficients 7.1% and 9.8%, respectively, were evaluated earlier (Hofmanová, 2011).

For statistical analysis, Statistica 7.1 software (StatSoft Inc, USA) was employed. Effect of hemp products type (K1-K5) or hemp products form (flour: K1-K3, wholemeal: K4, K5) vs. addition level was explored by two-way analysis of variance (ANOVA). Combining all gained data, a linear correlation matrix was calculated. The mentioned methods were evaluated on likelihood level 95%.

Results and discussion

A. Hemp effect on analytical composition

Pure wheat flour WF is characterised by standard baking quality (protein content 12.5%, Zeleny value 41 ml; Table 1), suitable for partial replacement by non-gluten material. Data in the same table shows, that amylase activity estimated as the Falling Number reached value common in the Central Europe region (310 s), indicating satisfying bread dough volume increase during fermentation.

In terms of protein content and quality, hemp flour incorporation had a reversal effect, i.e. a positive change has occurred for protein content and a negative one for Zeleny value (effect of hemp globular edestin). Between five tested hemp flour types, the highest protein content increase around 30% was determined in K3.20 and K4.20 blends (Table 1a). ANOVA results in Table 1b document stronger impact of addition level than hemp type/form – only 5% and 20% supplements were found statistically different. Both studied factors, hemp product type and addition level, participated equally on gradual weakening of protein technological quality (the Zeleny value). An exception represents the K4 composites, for which verifiably lowest sedimentation volumes were evaluated (19 and 13 ml for K4.5 and K4.20 samples, respectively; Table 1a). Because of high measurement uncertainty of the Falling Number (±25 s), only the values 278 s and 333 s could be considered as statistically different (Table 1a). As could be noticed, the hemp addition level factor slightly prevailed in the Falling Number course, supporting the amylases activity.

Table 1. Influence of hemp type/form and addition on analytical features of flour blends

a) Hemp type × Addition (trends between 5% and 20% hemp composites)				
Hemp type	Hemp addition (%)	Protein content (%)	Zeleny value (ml)	Falling Number (s)
WF	0	12.5a	41i	310ab
K1	5	13.3bcd	38h	308ab
	20	14.9hi	26d	297ab
K2	5	13.1abc	36gh	309ab
	20	14.8hi	20c	292ab
K3	5	13.5cde	34fg	315ab
	20	15.9k	16b	278a
K4	5	13.3bcd	19c	333b
	20	15.7jk	13a	287ab
K5	5	12.6ab	34fg	333b
	20	14.5ghi	14ab	286ab
b) Hemp form × Addition				
Hemp form	Hemp addition (%)	Protein content (%)	Zeleny value (ml)	Falling Number (s)
WF	0	12.5a	41c	310a
Hemp flour (K1, K2, K3)	5	13.3a	36bc	311a
	10	13.8ab	30abc	307a
	15	14.4bc	26abc	303a
	20	15.2c	21ab	289a
Hemp wholemeal (K4, K5)	5	13.0a	27abc	333a
	10	13.7ab	21ab	310a
	15	14.4bc	18a	307a
	20	15.1c	14a	287a

WF - wheat flour; K1, K2, K3 - commercial hemp flour; K4, K5 - dehulled/hulled hemp wholemeal, respectively.
a-i: values in columns signed by the same letter are not statistically different (P = 95%).

B. Hemp flour effect on the SRC profile

Overall holding capacity of all network-forming flour constituents, level of damaged starch, pentosans and gliadins characteristic as well as glutenin characteristics are described by the results of the SRC test (Gaines, 2000; Kweon et al., 2011). In this regard, quality of the used wheat standard overcame quality of both 19 European commercial flour samples (water, sucrose, sodium carbonate and lactic acid SRC averages 61.5%, 93.7%, 79.7 and 124.0%, respectively; Duyvejonck et al., 2011) and also of 80 Czech commercial flour samples (averages 64.9%, 105.2%, 85.6% and 136.9%, respectively; Hrušková et al., 2012) from years 2009 and 2010.
Table 2a presents results of the SRC test for used hemp types, which caused the highest variation in sucrose SRC and lactic acid SRC (at least twice compared to both other SRC). Generally, hemp flour supplements did not seriously diminished the sodium carbonate SRC only, and results related to hemp flour K1-K2-K3 samples were significantly higher than ones assessed for wholemeal K4-K5 composites. The finding is surprising owing to non-starch polysaccharides (as pentosans) localisation in seed covering layers, which are usually removed at flour manufacturing.
Combined influence of hemp form and addition level was revealed for sucrose SRC, sodium carbonate SRC and lactic acid SRC in case of hemp wholemeal and for lactic acid SRC in case of hemp flour addition. Besides, the SRC profiles were remarkably different between wheat flour, hemp flour composites as well as hemp wholemeal counterparts in their sodium carbonate SRC and lactic acid SRC parts (Table 2b). Into wheat flour blend, hemp flour and wholemeal introduced dietary fibre (pentosans) and non-gluten proteins in a different rate, and that composition change was verified by the SRC test. For both hemp forms, important changes occurred in the lactic acid SRC.

Table 2. Influence of hemp type/form and addition on the Solvent Retention Capacity profile (SRC) of wheat flour

a) Hemp type × Addition (trends between 5% and 20% hemp composites)					
Hemp type	Hemp addition (%)	Water SRC (%)	Sucrose SRC (%)	Sodium carbonate SRC (%)	Lactic acid SRC (%)
WF	0	90.9f	112.0k	117.8d	182.6n
K1	5	86.5e	109.4jk	108.8cd	153.7m
	20	86.5e	102.3hij	106.7cd	112.1gh
K2	5	86.3e	100.9ghij	107.5cd	141.2l
	20	86.4e	106.7ijk	108.2cd	109.9fgh
K3	5	86.9e	93.0efg	106.2cd	137.1kl
	20	87.9e	99.8ghi	106.9cd	102.7e
K4	5	70.3d	102.3hij	88.2b	108.0efg
	20	61.6a	64.1a	70.5a	78.3ab
K5	5	69.5cd	102.5hij	88.4b	120.6i
	20	68.3cd	74.3b	76.1ab	77.2ab
b) Hemp form × Addition					
Hemp form	Hemp addition (%)	Water SRC (%)	Sucrose SRC (%)	Sodium carbonate SRC (%)	Lactic acid SRC (%)
WF	0	90.9b	112.0d	117.8e	182.6e
Hemp flour (K1, K2, K3)	5	86.6b	101.1cd	107.5d	144.0d
	10	90.4b	98.2cd	107.6d	125.5cd
	15	86.7b	99.5cd	105.3d	115.1c
	20	86.9b	102.9cd	107.3d	108.2bc
Hemp wholemeal (K4, K5)	5	69.9a	102.4cd	88.3c	114.3c
	10	67.7a	88.8bc	80.9b	87.2ab
	15	66.7a	79.3ab	77.8ab	80.7a
	20	65.0a	69.2a	73.3a	77.8a

WF - wheat flour; K1, K2, K3 - commercial hemp flour; K4, K5 - dehulled/hulled hemp wholemeal, respectively.
a-n: values in columns signed by the same letter are not statistically different (P = 95%).

C. Hemp flour effect on dietary fibre (DF) content

As was published earlier, hemp flour (and similarly hemp wholemeal) is characterised by crude fibre content approx. 25-30% (EFSA 2011). Seeds dehulling and disintegration of such material brings flour with partially lowered fibre content; due to that, differences between the tested flour forms could be presumed. However, analysis of five pure hemp flour samples shown only soft oscillation – determined levels of SDF, IDF and TDF varied in close extents (3.98%-4.39%, 5.49%-8.58% and 11.7%-12.6%, respectively) independently on hemp flour type of form (data not shown). Correspondingly to that, statistically diverse fibre contents were distinguished for 5% and 20% blends just for the TDF (Fig. 1).

According to hemp form (flour/wholemeal), wheat hemp blends could be identified somewhat accurately; but also in this case, addition level factor dominated (Fig. 2). Increment of dietary fibre oscillated between 13-14% for hemp flour blends and between 8-16% for wholemeal ones. Owing to the lowest level, only small significant differences in the SDF contents were found in comparison of wheat-hemp flour and wheat-hemp wholemeal composites. On the other hand, both factors positively interacted in case of the TDF level in wheat blends containing hemp in both forms of flour and wholemeal (Fig. 2). That finding of TDF content is related to generally higher fibre level in hemp products than in wheat flour and to non-starch polysaccharides presented in hemp seed cover layers.

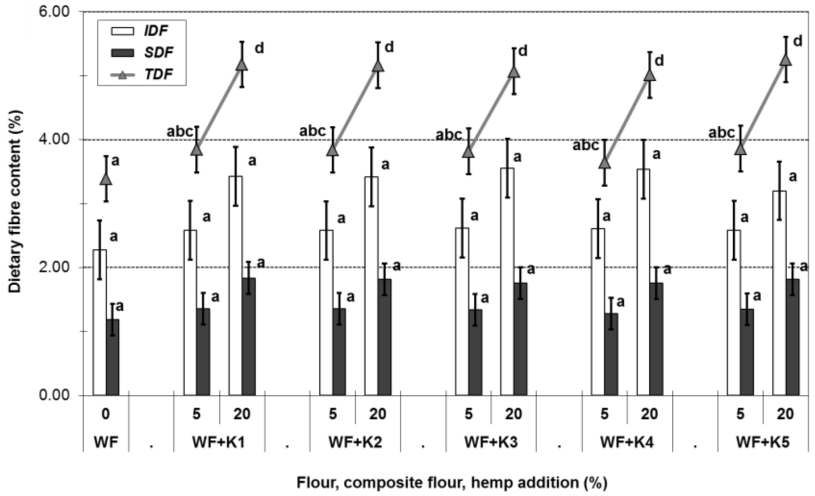

Fig. 1. Effect of five tested hemp types on dietary fibre content. IDF, SDF, TDF – insoluble, soluble and total dietary fibre. a-d: columns and points signed by the same letter are not statistically different (P = 95%)

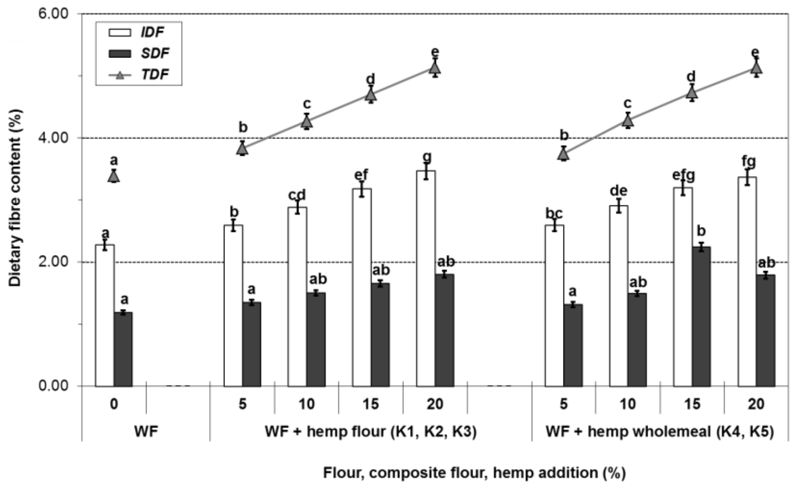

Fig. 2. Effect of two tested hemp forms (flour, wholemeal) on dietary fibre content. IDF, SDF, TDF – insoluble, soluble and total dietary fibre. a-g: columns and points signed by the same letter are not statistically different (P = 95%)

D. Hemp flour effect on baking test results

The specific bread volume worth in consumer's quality description was clearly demonstrated also within wheat/hemp composites set. Value 257 mL/100 g, evaluated for standard M, belongs to common bread volumes. Its vaulting (bread shape) is close to empirical optimum, laying between 0.60 and 0.68. Also the crumb penetration of 10.2 mm represents acceptable crumb firmness, i.e. bread chewiness at consummation.

Bakery products from composites with 5% hemp flour were characterised by still satisfying, while pieces including 20% by unacceptable specific bread volume (diminishing approx. about 25%), and by worse vaulting as well as very firm crumb (crumb penetration lower than 5.0 mm) (Table 3a). Mentioned worsening of fortified bread quality was demonstrated markedly for K3 samples – bakery products from K3.5 and K3.20 were statistically different. Trends registered as a result of wholemeal hemp fortification were in opposite to ones caused by hemp flour, perhaps due to higher fat content. Both K4 and K5 flour improved quality of laboratory prepared bread. Specific volumes of K4-bread have risen about 47% and 38% for cases of 5% and 20%

addition. Size rise of hulled hemp wholemeal buns was somewhat lower (9% and 28%, respectively. Although the height of K5 bread pieces was better, crumb compressibility has been shown lower in accordance to samples volumes (Table 3a).

Sensory score of control wheat bread was changed differently in dependence on hemp product form (Table 3a, 3b). Hemp flour contributed to gradually darker both crust and crumb in shades of brown, while dehulled hemp wholemeal K4 had not visible impact on bread cut appearance. Image of samples containing hemp K3 and K5 was varied by darker dots coming from disintegrated hemp seeds cover layer; such product laying on a counter could be more attractive for consumers. Chewiness of composite bread corresponded to penetration levels measured – crumb containing 15% or 20% of K1, K2 or K3 was partially drier and very tough to masticate. Reversely, hemp wholemeal allowed easy chewing and swallowing of bread crumb; during chewing, disintegrated cover layer in K5 wholemeal were identified as harder particles (“sand between teeth”). Overall acceptance of wheat-hemp flour bread was gradually worsened by hay-like aroma and bitter aftertaste. Consumer quality of composite bread with hemp wholemeal bread was comparable to control – sensory score was positively influenced by sweetish black elder by-taste.

By ANOVA test, a slight interaction of hemp form and addition level was confirmed. Increasing rate of wholemeal hemp in recipe affected specific bread volume, bread shape and also crumb penetration – significant differences were identified between bread including at least 10% of hemp flour.

Table 3. Influence of hemp flour/type and addition level on baking test results

a) Hemp type × Addition (trends between 5% and 20% hemp composites)

Hemp type	Hemp addition (%)	Specific bread volume (ml/100 g)	Bread shape (-)	Crumb penetration (mm)	Sensory profile (points)
WF	0	257def	0.59ef	10.2abcde	11.5ab
K1	5	243cdef	0.59def	6.7abcd	12.5b
	20	195abc	0.56cdef	1.8a	16.5e
K2	5	290fg	0.52bcdef	7.9abcd	12.0b
	20	172a	0.41a	2.3a	19.0f
K3	5	215abcd	0.54bcdef	5.1abc	14.0d
	20	191ab	0.45ab	1.9a	17.0ef
K4	5	378ij	0.53bcdef	21.5g	11.5ab
	20	354hij	0.50abcde	14.6defg	13.0c
K5	5	282efg	0.61f	9.6abcd	10.5a
	20	329ghi	0.59ef	12.9cdef	13.5cd

b) Hemp form × Addition

Hemp form	Hemp addition (%)	Specific bread volume (ml/100 g)	Bread shape (-)	Crumb penetration (mm)	Sensory profile (points)
WF	0	257abc	0.59ab	10.2abc	11.5a
Hemp flour (K1, K2, K3)	5	249ab	0.55ab	6.6ab	12.8ab
	10	230a	0.49a	4.5a	14.8cd
	15	208a	0.50a	3.2a	16.5de
	20	186a	0.47a	2.0a	17.5e
Hemp wholemeal (K4, K5)	5	330bc	0.57ab	15.5c	11.0a
	10	365c	0.55ab	15.2c	12.3a
	15	361c	0.61b	15.3c	12.3a
	20	342c	0.55ab	13.8bc	13.3b

WF - wheat flour; K1, K2, K3 - commercial hemp flour; K4, K5 - dehulled/hulled hemp wholemeal, respectively.
Bread shape calculated as height-to-diameter ratio.
a-j: values in columns signed by the same letter are not statistically different (P = 95%).

E. Relationships between analytical, nutritional and technological characteristics

Pearson correlation matrix was built on base of 21 samples, with highlighted relationships provable on the levels 0.05, 0.01 and 0.001. Basic analytical quality descriptors (protein content, Zeleny value, Falling Number) were correlated primarily with the SRC profile and DF components (Table 4). The highest numerousness was found for the Zeleny value parameter – positive links to the former features group confirm observed hemp flour effect on protein quality diminishing and vice versa on DF content. Mutual correlations within the triple of protein content – Zeleny value – lactic acid SRC testify a general knowledge that higher protein content cannot mean higher protein quality in cases of addition of non-wheat plant materials. This statement confirm Sudha et al. (2007) indirectly during testing of 40% oat/barley bran-wheat flour mixture by using the farinograph. Addition of both non-traditional materials significantly shortened non-fermented dough stability from 9.5 min for wheat control to 4.0 and 3.5 min, respectively). Also mixing tolerance index, referring about dough tolerance to overmixing, underwent such substantial change. Further, the possible alternation of the Zeleny value and the lactic acid SRC (r = 0.83, P = 99.99%) confirm Xiao et al. (2006).

Changes in the SRC profile of wheat flour WF under hemp flour incorporation could be depicted by sucrose SRC at the best, which was influenced and which also affected 10 of 13 measured characteristics. Generally, this retention capacity characterises content and properties of pentosans (i.e. arabinoxylans). Their progressively increased amount reduced the specific bread volume (the tightest correlation, r = -0.80; P = 99.9%), and also the crumb penetration of tested bread has moderately affected (r = -0.70; P = 99.9%).

Besides relationships above, three DF constituents had no significant link to used bread quality characteristics. Considering a reversal influence of hemp flour and wholemeal on baking test results, such conclusion is understandable. Compared to previous comparison of hemp and teff effect on 10% and 20% blends composition and baking quality (Hrušková et al., 2012), the DF content has positively contributed to bread sensory quality, and negatively to crumb penetration (r = -0.65 and 0.82, respectively).

Finally, specific bread volume, bread shape and crumb penetration data verified satisfying correspondence of the features, mainly in the second pair (r = 0.96, P = 99.9%; Table 4). A lower verifiability of bread shape relations to specific bread volume and crumb penetration could be explained by this attribute susceptibility on moulding technique during bread hand-forming.

Table 4. Significant correlations among analytical, nutritional and bread quality characteristics of wheat-hemp flour composites

Parameter	Zeleny value	Falling Number	Water SRC	Sucrose SRC	Sodium carbonate SRC	Lactic acid SRC	IDF	SDF	TDF	Specific bread volume	Bread shape	Crumb penetration
	B	C	D	E	F	G	H	I	J	K	L	M
A	-0.73***	-0.79***	ns	-0.44*	ns	-0.58**	0.93***	0.64**	0.82***	ns	ns	ns
B		0.44*	0.56**	0.66**	0.66**	0.91***	-0.75***	-0.56**	-0.68***	-0.44*	ns	ns
C			ns	ns	ns	ns	-0.76***	ns	-0.78***	ns	ns	0.45*
D				0.74***	0.96***	0.71***	ns	ns	ns	-0.82***	-0.43*	-0.76***
E					0.84***	0.78***	-0.46*	-0.53*	-0.45*	-0.61**	ns	-0.44*
F						0.82***	ns	ns	ns	-0.80***	ns	-0.70***
G							-0.69***	-0.60**	-0.67***	-0.50*	ns	ns
H								0.66**	0.96***	ns	ns	ns
I									0.65**	ns	ns	ns
J										ns	ns	ns
K											0.47*	0.96***
L												0.49*

Parameter 'A' - protein content. SRC - Solvent retention capacity. IDF, SDF, TDF - insoluble, soluble and total dietary fibre,
Bread shape calculated as height-to-diameter ratio.
*, **, *** - pair relationships significant at P = 95%, 99% and 99.9%, respectively; ns - non-significant.

Conclusions

Addition of hemp flour and hemp wholemeal into wheat flour brought a significant increase of protein and dietary fibre contents, meaning a nutritional benefit. Tested non-traditional material provably changed Solvent Retention Capacity profile of wheat flour – hemp wholemeal caused a deeper decrease in the sucrose, sodium carbonate as well as lactic acid SRC, indicating changes in contents of damaged starch, pentosans and gluten-net forming proteins, respectively. Statistical differences were verified among addition levels used, but not between forms of hemp products tested.

Recipe addition of hemp flour lessened volume of laboratory prepared bread, followed by crumb firmness increase up to an unacceptable stage. Bread sensory profiles were generally worsened by hay-like aroma and bitter aftertaste. Due to higher fat content in both studied hemp wholemeals, bread samples were characterised by significantly higher volumes compared to wheat and wheat-hemp counterparts; a positive impact of higher extent was determined for dehulled hemp wholemeal. Crumb firmness clearly decreased and sensory score was extended by sweetish black elder by-taste. Summarised, 10% hemp flour and 15% hemp wholemeal could be recommended as a maximum recipe dosages.

Reciprocal correlation of recorded data was confirmed between content and quality of protein vs. dietary fibre content, mainly on 99% of probability level. Bread volume and crumb penetration were dependent also on protein properties as well as on the determined SRC profiles.

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