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EVALUATION OF TEXTURAL PROPERTIES FOR WHEY ENRICHED DIRECT EXTRUDED AND PUFFED CORN BASED PRODUCTS

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Abstract

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Processing of various foodstuffs with extrusion cooking represents a very effective process applicable in biotechnology and food industry while products of extrusion cooking are of major importance today as well. The issue of this work was to incorporate different amount of whey protein concentrate (WPC) in corn flour as raw material during extrusion cooking for achievement extrudates with higher protein content in order to enrich and improve nutritional quality of product and determination of textural-mechanical properties of such a manufactured product. Research was conducted in co-rotating twin screw extruder with setup designed to manufacture direct expanded extrudates based on pure corn flour and enriched with whey protein concentrate. Experimental data were analyzed with multiparameter correlation analysis using software package statistica 6. Achieved textural properties of direct expanded extrudates with addition and without addition of whey protein concentrate as: extrudate diameter (de), expansion ratio (Er), bulk density (BD), extrudate weight equivalent (EWE), hardness and breaking strenght index (BSI) in bending mode, and penetration mode as well were compared with versatile process parameters (feed moisture content and whey protein concentrate intake). Also water apsorption index (WAI), and water solubility index (WSI) were also corelated with empirical models.

Key words: extrusion, texture, whey protein concentrate

Introduction

Various innovated processes in food industry as power ultrasound (PUS), pulsed electric fields (PEF), high hydrostatic pressure (HHP), extrusion cooking (EC), magnetic fields (MF) and pulsed light (PL) have replaced or improved older and less efficient procedures (Knorr, 1999; Knorr; 2004; Garcia-Perez et al., 2007; Fuente-Blanco et al., 2006; Cucheval et al., 2008; Ting et al., 2002; Toepfl and Knorr D, 2006; Yang et al., 2004; Wouters et al., 2001). In modern food industry and food technology today extrusion processing becomes very important procedure and during past two decades is in expansion (Li et al., 2005). This technology is advantageous, more effective, cleaner and less expensive with a product of the

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same quality or even better than manufactured with traditional technologies. Just a first step during purchasing of equipment is needed. Everything else while using extruders for food manufacturing offers versatile benefits. Various foodstuffs is possible to be produced with single-screw and twin-screw extruders (Akdogan, 1999; Njoki and Faller, 2001; Obatolu et al., 2006; Pelembe et al., 2006). That especially concerns technology of "ready to eat" food, "baby" food, "snack" food and breakfast cereals which are growing market almost everywhere in the world (Brncic et al., 2006; Chinnaswamy, 2003). Lately even pet food is manufactured with extruders. Direct expanded products (extrudates) are just some foodstuffs manufactured with extrusion which are no necessary to be modified after expansion. Mostly this kind of food products are obtained with "twin screw" extruders with setup of co-rotating turning of the properly balanced screws in continuous procedure known as "extrusion cooking" or "High temperature-short time" extrusion (HTST) processing. In brief this means that in very short times of processing (1-2 min) and extreme conditions of temperature, pressure and shear forces, raw materials are being processed. Input properties of raw materials are completely changed after expansion which means that final product has different physical, chemical and textural properties.

Food extrusion of breakfast cereals is defined as a cooking-extrusion process based on expanded, high voluminous, crispy and taste acceptable products-extrudates (Chinnaswamy and Hanna, 1995; Hagenimana et al., 2005; Brncic et al., 2006; Sacchetti et al., 2004). These products are manufactured under conditions of high temperature of process and short residence time retention of raw material in each section of extruder (cooker). The extruder itself (Figure 1) is divided in sections (Onwulata & sur., 2001). Each section has got its own purpose during extrusion-cooking (Elsey et al., 1997). With corn flour as based material a various concentrations of different proteins may be used such as soya proteins and whey proteins. Hence, products with i.e. whey proteins are available in health food supermarkets and specialized stores in form of enhanced and flavoured shakes, protein bars, and various dietary supplements and as concentrated proteins for fitness needs (Allen et al., 2007). Furthermore, many authors presented their point of view in whey utilization for food products in extruded products with significant conclusions how there is no alternative to incorporation of whey or some other proteins in extruded or puffed products despite some limitations due to textural properties of achieved products (Onwulata et al., 1998; Comfort and Howell, 2002; Martinez-Serena and Villota, 1992; Brncic et al., 2008a; Onwulata and Konstance, 2006).

In this work to provide a product with higher protein amount, which leads to improved nutritional quality some mixtures of corn flour (CF) and whey protein concentrate (WPC) were prepared. WPC was used to enrich direct expanded extrudates. Enrichment means that taste, colour, crispiness, other textural-mechanical properties and complete amount of preserved proteins during processing should be balanced in best ratio (Onwulata et al., 2001).

Usefulness ratio of WPC is very strong in various food products (Herceg et al., 2004a; Herceg et al., 2004b). The main problem is to establish conditions of extrusion for this temperature sensitive concentrated product. Therefore HTST (high temperature-short time) production must be adjusted. WPC must be well mixed with corn flour. Also temperatures in each section of extruder should be adapted to precise operation, since the WPC is sticky with particle size of average 50 μm and it has a denaturation temperature around 60°C due to which retention time in extruder sections with higher temperatures must be shortened. This is necessary precaution because of all above mentioned reasons. Twin-screw extruder APV Baker, MPF 50:15 (co-rotating setup) was used for direct expanded extrudates manufacturing in this work.

The goal of this work was to combine CF and WPC in form of mixtures to achieve acceptable and enriched direct expanded extrudate with optimal textural properties in course of mastication by simulating chewing in mouth which was conducted due to texture analysis research.

Materials and Methods

Materials

Samples of CF were purchased in the local market. WPC was purchased directly from producer MILEI, GmbH, Leutkircl and it has a commercial name Milacteal 60. It contains 60% of whey protein. Chemical composition of WPC and CF on dry matter basis is shown in Table 1.

Mixtures

Three mixtures of CF and WPC were made in following ratios: 5% of WPC and 95% of CF, 10% of WPC and 90% of CF and 15% of WPC and 85% of CF. Since the WPC is temperature very sensitive it was important do determine Feed moisture content (FMC). After preliminary investigations with various inputs of water under unchanged processing conditions of extruder (setup) FMC was determined to withhold an experiment and it was: 10.08 L/h, 12.18 L/h and 14.28 L/h.

As a standard with which other samples (mixtures) are compared lately for their physical and textural properties, three control samples of pure CF were extruded with experimentally achieved and above mentioned known FMC. Extrudate samples were marked as 1-3 CF (pure CF) and 1-9 CFW (mixtures of CF and WPC). Description of manufactured extrudates with markings are presented in Table 2.

Extrusion

Extruder used in this research was APV Baker, MPF 50:15 (Figure 2) with following processing conditions setup of: 300 rpm; Temperature profile in sections: 30, 60, 90, 110 and 130°C; constant mixture feed of 70 kg/h; FMC of 10.8, 12.18 and 14.28 L/h and with quadruple die setup with 2 mm in diameter of each die.

Physical and textural properties

Textural properties of direct expanded extrudates were determined using TA-HD plus texture analyser produced by "Stable micro systems", Godalming, Great Britain under setup presented in Table 3. A penetration mode was used and bending mode as well as shown in Figures 3a and 3b.

Following textural properties of the extrudates were determined within these investigations:

- Extrudate diameter (d_e) – The sample was cut and diameter of cross section was measured using digital calliper. At least ten measurements were performed for each sample. Arithmetic mean of samples was taken into consideration.

- Expansion ratio (Er) – Represents value of the d_e divided with the extruder die. At least ten measurements were performed for each sample. Arithmetic mean of samples was taken into consideration.

- Extrudate weight equivalent (EWE) – Ten samples of each manufactured group of extrudates was weight at analytical balance. Value is expressed as mass (g) of this measurement and represents degree of incorporation of WPC within raw material during extrusion. It is FMC and percentage of WPC intake dependable value of the direct expanded product.

- Bulk density (BD) – This property represents an index of the degree of expansion expressed in g/cm^3. It was determined as presented in work conducted by Pan et al. (1998).

- Hardness of the extrudates is the peak in the Force/Distance curve when the sample breaks (peak breaking force or collapse). BSI was calculated by dividing peak breaking force and d_e. This was recalculated for both penetration and bending determination of hardness.

$$\text{BSI} = \text{peak breaking force/ extrudate diameter} \quad \text{N/mm} \tag{1}$$

- Water absorption index (WAI) and water solubility index (WSI) were also calculated using standard methods (Anderson et al., 1969).

Results and Discussion

Dependence of difference concentrations of WPC addition and three different FMC are presented in Figure 4. It can be observed that d_e is largest in the

Table 1
Chemical composition of WPC and CF, g/kg

Product	CF	WPC
Carbohydrate	828	516
Protein	55.9	349
Ash	5	64.3
Fat	13.9	37
Moisture	98	36

Table 2
Description of extrudates

Sample	CF, %	WPC, %	FMC, L/h
1 CF	100	0	10.8
2 CF	100	0	12.18
3 CF	100	0	14.28
1 CFW	95	5	10.8
2 CFW	95	5	12.18
3 CFW	95	5	14.28
4 CFW	90	10	10.8
5 CFW	90	10	12.18
6 CFW	90	10	14.28
7 CFW	85	15	10.8
8 CFW	85	15	12.18
9 CFW	85	15	14.28

samples without WPC addition which is understandable because of no influence to expansion properties of CF and a proper distribution of remaining moisture in the moment of expansion. Also, there is decrease of the d_e within the groups of the samples (WPC 0%, WPC 5%, WPC 10%, WPC 15%). For the first three control samples (WPC 0%), d_e is largest and for all other samples (with various concentrations of WPC) d_e has tendencies of serious decrease. The reason lies in WPC incorporation within corn flour and mutual expansion which leads to decrease in radial size of extrudate. Therefore samples without WPC addition are with higher values for mentioned properties. Since the ER represents recalculated d_e values the results are similar (Figure 5). ER is necessary to be recalculated because this value is indicator of properly expanded product.

Table 3
Experimental setup of texture analyser device for both penetration and bending mode

Loading	Penetration mode	Bending mode
Pre-test speed (before contact with extrudate)	1 mm/s	3.5 mm/s
Test speed (from beginning until the end of measuring)	1 mm/s	3.0 mm/s
Post-test speed (after performed measuring)	10 mm/s	10 mm/s
Distance	4 mm	10 mm
Mode of work	Trigger	Trigger
Number of measuring	600 data per/second	600 data per/second
Probe moving	Return	Return
Load cell	30 kg	30 kg
Fixtures/Probes	Cylinder probe (P/2)	Three point bending rig (HDP/3PB)

In Figure 5 it can be observed also how values of ER are in tendencie to decrease with higher inputs of FMC and WPC, but results are optimal since the extruder setup was stationed for this kind of materials. Also EWE values showed correct behaviour within this research (Figure 6). It is obvious how EWE is in lowest values for non enriched extrudates. It is reasonable because there was no addition of WPC for those samples.

The bulk density (BD) represents an index of the

Table 4
Textural-mechanical properties of extrudates

Sample	BSI-Penetration, F/d_e	BSI-Bending F/d_e
1 CF	0.092	0.294
2 CF	0.184	0.326
3 CF	0.228	0.399
1 CFW	0.098	0.387
2 CFW	0.482	1.043
3 CFW	2.094	2.461
4 CFW	0.665	2.163
5 CFW	0.805	2.399
6 CFW	0.997	2.788
7 CFW	0.704	2.266
8 CFW	1.088	3.011
9 CFW	1.226	3.804

Table 5
Influence of process parameters on WAI

	Regresion coefficient	p value
Intercept	12.2357	0.00000
WPC	0.85399	0.01888
Q_{H20}	1.86681	0.00056
$s^2 = 0.4309$	$R^2 = 0.9199$	$R^2_{adj} = 0.8903$

Table 6
Influence of process parameters on WSI

	Regresion coefficient	P value
Intercept	14.93391	0.00000
WPC	-5.08356	0.00031
Q_{H20}	-1.81611	0.03284
$s^2 = 2.6113$	$R^2 = 0.9245$	$R^2_{adj} = 0.9007$

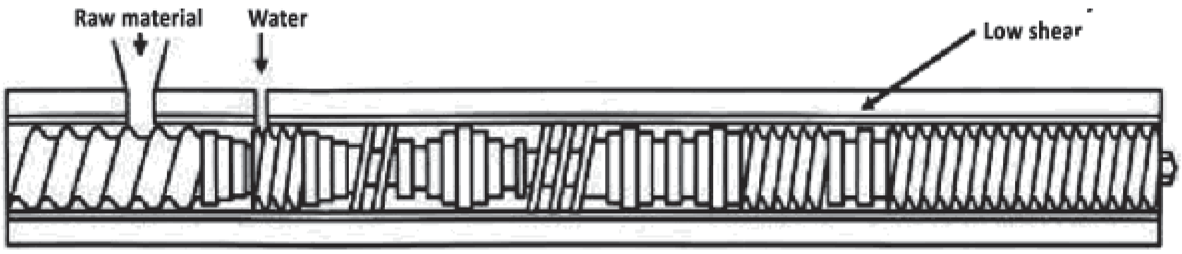


Fig. 1. Schematic representation of low shear screw configuration (Onwulata et al., 2001)

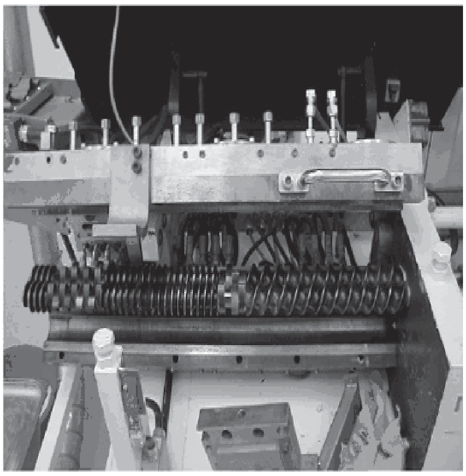
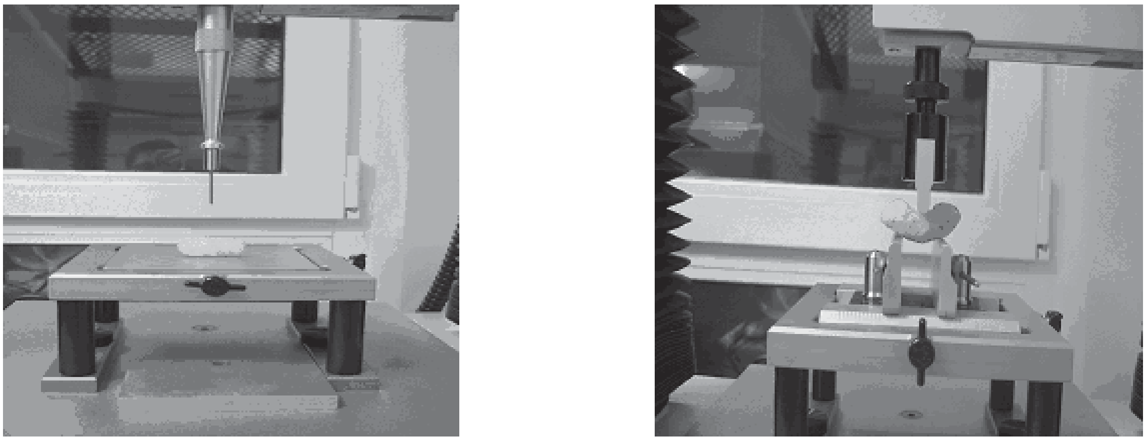


Fig. 2. Extruder APV Baker, MPF 50:15

extent expansion-puffing (Hagenimana et al., 2005) and values for extrudates without WPC addition were between 328-377 kg/m^3 as shown in Figure 7. For complete research in this work BD was changed according to known data. Sample 1CF was in lower values because of its higher d_e values. The highest d_e for this value makes BD of this value lowest. Explanation is in fact that when gelatinization increases, the volume of extruded products increases and opposite effect is decrease of BD (Case et al., 1992; Mercier and Feillet, 1975; Hagenimana et al., 2005) which is in agreement with results of this work. Also BD increase as (in each group) FMC increase.

After getting of extrudates procedure of determination of textural-mechanical properties due to rea-



a **b**

Fig. 3. Penetration mode (a); bending mode (b)

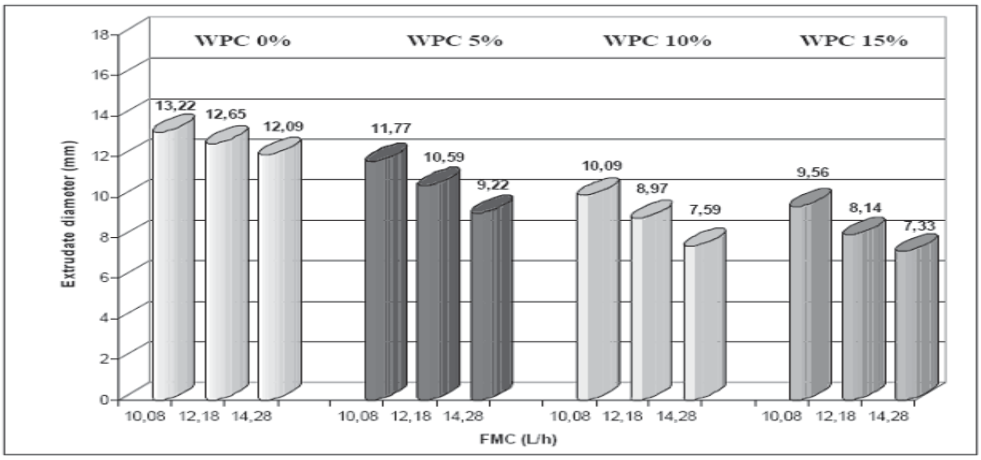


Fig. 4. Diameter of extrudates with and without WPC addition in dependence of FMC

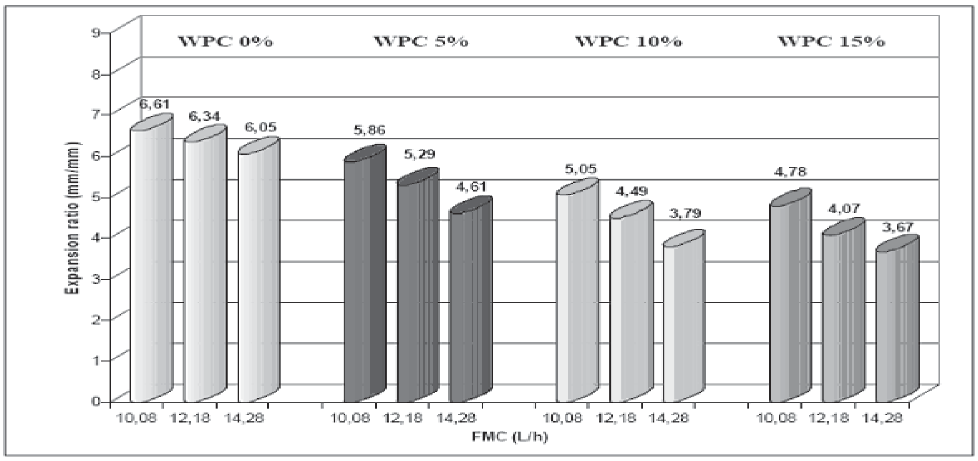


Fig. 5. Expansion ratio of extrudates with and without WPC addition in dependence of FMC

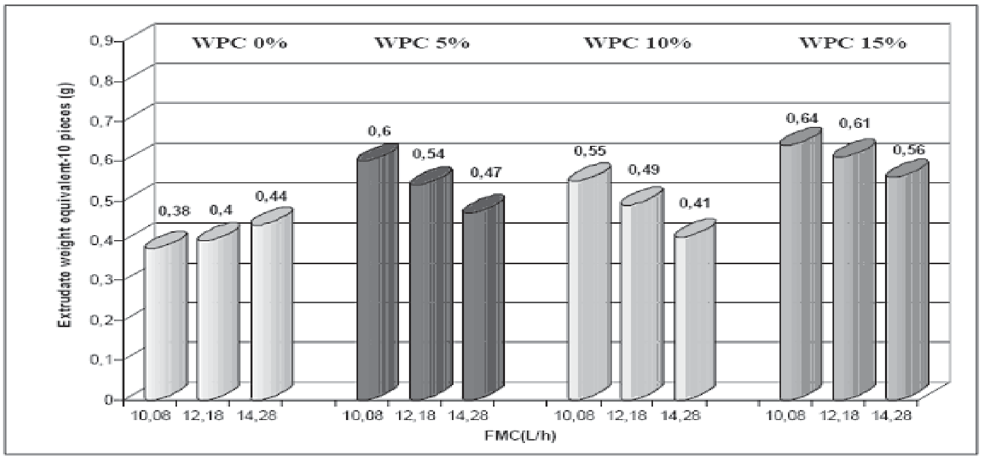


Fig. 6. Expansion weight equivalent extrudates with and without WPC addition in dependence of FMC

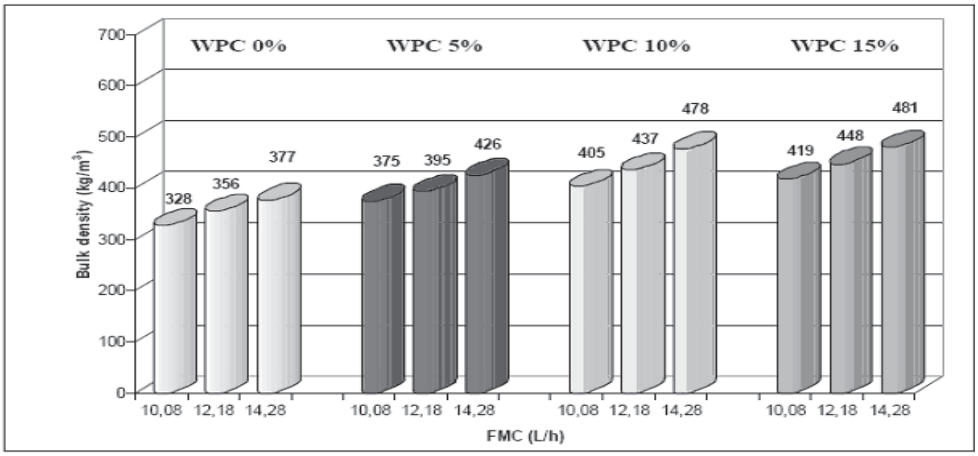


Fig. 7. Bulk density of extrudates with and without WPC addition in dependence of FMC

sonable mastication process in mouth was discussed and defined. During procedure of textural determination fracturabillity occurred during measurement. It is not value of the hardness. When the upper knife touches the sample it causes tiny deformation on sample called fracturabillity (FB) but not breakdown yet. In the moment when sample collapse that is hardness. In Figure 8 results for hardness of the samples in the penetration mode for samples 1CFW-3CFW are presented. In the same figure above mentioned FB is shown. It is the point when small breakdowns occurred but sample still withhold the force.

Based on point of collapse and d_e a BSI is recalculated. Modes of penetration and bending were chosen for this research. All textural measurements are conducted on „Stress/Strain"methodology. Our observation was, based on type and shape of the product, how two main textural-mechanical properties should be carried out as already mentioned in previous text (penetration and bending). Since one of the parameters for a proper recalculation is determination of hardness of first bite this value (expressed in Newtons) was recalculated and presented as BSI in both penetration and bending mode (Table 4).

In previous work (Brncic et al., 2008b) showed behaviour of mixtures with higher WPC amounts un-

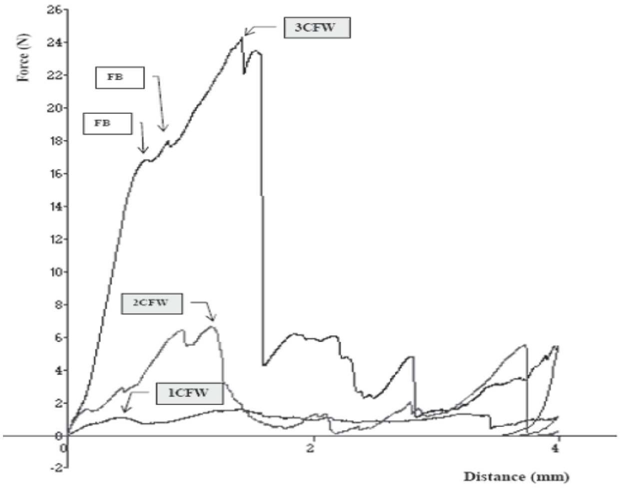


Fig. 8. Diagrams of hardness for samples 1CFW-3CFW in penetration mode

der same processing conditions within extruder but different composition of mixtures. In addition presented textural properties of that research indicate higher nutritional values but lower textural properties. Moreover when compare those two works pattern is similar but with better textural properties in this work. However, it is visible from the results in Table 4 how the samples withhold the force in both penetration and bending mode. Extrudates marked as 1 CF-3 CF are with greatest puffing properties and lowest BSI which is good, but without addition of any kind of proteins and because of that they were considered only in the means of control samples. Other samples 1 CFW-9 CFW is very similar in textural properties but enriched with WPC. Only samples 8 CFW and 9 CFW are with values of BSI over 3.0 in bending mode. Such a value determine this samples as to hard for consuming despite the fact that within this samples 15% of WPC is incorporated. It can be concluded how such amount of WPC under conditions of to high FMC intake gives product that withhold high force of mastication (chewing) and for that reason is not taken under consideration for further argumentation. On the other hand all other samples with WPC addition were entirely acceptable. Extrudates marked as 4 CFW-6 CFW showed BSI from 0.665-0.997 N/mm in penetration mode and 2.163-2.778 N/mm in bending mode. These results indicate how this ratio of CF and WPC is the most applicable ratio for mixing and extrusion processing under mentioned conditions within extruder. Smallest difference between results for BSI within that group of the same WPC intake (group 1: 1CFW-3CFW; group 2: 4 CFW-6 CFW; group 3:7 CFW-9 CFW) is shown in Table 4. Although hardening of the samples occurred within all samples with WPC it is shown during textural measurements that with optimal extruder setup, direct expanded extrusion gives product with well incorporated WPC that could be consumed at once.

Interactions that explain relationships between extruded starches (CF in this experimental work) and water intake (FMC) are WAI and WSI. Changes in WAI and WSI during extrusion processing occur rapidly in the beginning at the cooking zone of the device. It happens after the mixture is thrown in the extruder, than mixing and kneading. In other extruder zones changes in WAI and WSI are uniform.

Statistical analysis of process parameters influence on WAI and WSI is presented in Tables 5 and 6. Statistical significance of individual regression coefficients i.e. influences is determined by analysis of variance (ANOVA) and expressed over p values. In this study, the effect is considered significant if the p-value for each factor or interaction is less than 0.05. When these results are compared it is visible how water input has got higher influence than WPC. Values of correlation coefficients R^2 and adjusted correlation coefficients R^2_{adj}, which takes independent variables into consideration, are for WAI 0.9199 and 0.8093 and for WSI 0.9245 and 0.9007. Achieved empirical models are presented with equations 2 and 3.

s^2 – Variance

R^2 – Correlation coefficient

R^2_{adj} – Adjusted correlation coefficient that takes independent variables into consideration

p value differ significantly $p<0.05$

$$WAI = -0.2958 + 0.1124*WPC - 0.8814*Q_{H2O} \quad (2)$$

s^2 – Variance

R^2 – Correlation coefficient

R^2_{adj} – Adjusted correlation coefficient that takes independent variables into consideration

p value differ significantly $p<0.05$

$$WSI = 35.619 - 0.6698*WPC - 0.8567*Q_{H2O} \quad (3)$$

Conclusions

On the basis of the results achieved in this work it can be concluded how textural properties of the direct expanded extrudates are significantly influenced by interactions of CF and WPC. Hardening of the samples is occurred due to intake of WPC which influence change in textural properties. Higher force was needed to break the extrudates in bending than in penetration mode for each sample which is reasonable because of nature of the breaking point due to nature of simulation for texture analysis. Severe increase of the BSI was established within the extrudates with higher amount of WPC and FMC as well.

Extrudates with WPC addition were harder than pure CF extrudates but protein enrichment of food products is necessary due to lower protein content of raw material itself. It is also proved by recalculating of data points to BSI values. Determination of textural properties of various food products is good method to simulate the process that take place in mouth during chewing, and results are accurate. Statistical analysis shown that WAI and WSI were significantly influenced with FMC and WPC intake changes and their interactions.

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