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Extrusion process of maize grits used for nixtamalization

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Abstract: The aim of the paper was to seek optimum conditions of extrusion cooking and follow-up processing to produce high-quality tortillas with good sensory properties. Sixteen samples of maize flour were prepared by extrusion with and without alkaline treatment. The extrudate diameters depended primarily on the moisture content of the premix and the temperature in the extruder. Alkaline treatment with calcium hydroxide [$Ca(OH)_2$] had a strong effect on water absorption index (*WAI*), water solubility index (*WSI*), pH, and colour of the extrudates. Besides, *WAI* was influenced by the moisture of the premix and by the temperature in the second zone of the extruder. Soluble dietary fibre (*SDF*) in the samples with the addition of $Ca(OH)_2$ increased more than in the samples without alkaline treatment. In addition, a higher screw speed influenced *SDF*. The texture of the tortillas was very dependent on the addition of $Ca(OH)_2$, on the moisture of the premix and the temperature in the second zone of the extruder.

Keywords: extrusion cooking; extrusion process parameters; tortilla

To prepare tortillas, maize grains are classically processed through a thermo-alkaline process called nixtamalization, which changes the structural, morphological, and rheological properties of the flour. Historically, wood ash was the first calcium source used to cook maize in this process; the ash was later replaced by lime.

Nixtamalization causes the loss of the waxy layer in a pericarp. Higher porosity enables the diffusion of calcium ions into the internal structures of the maize grain. Additionally, solubilisation of starch, pectin, and lipids occurs (Santiago-Ramos et al. 2018).

The importance of nixtamalization for human nutrition is undeniable since it increases the availability of niacin, lysine, and tryptophan, as well as calcium content, which has contributed to preventing pellagra, rickets, and osteoporosis (Bressani 1990). Nevertheless, there are also some disadvantages of the classical process: it needs a large amount of water and a longer time for cooking, and it also causes highly polluted wastewater, in which part of the nutrients is lost.

Lime-cooking extrusion is an alternative process that can make dough suitable for tortillas with similar characteristics to those prepared by the traditional process (Milán-Carrillo et al. 2006). Extrusion cooking involves a combination of various operations, such as mixing, conveying, heating, kneading, shearing, and shaping, which is achieved in continuous production. The heat generated during extrusion, combined with the shearing effect, induces physicochemical reactions in the raw material (Ye et al. 2018). This new method of nixtamalization by extrusion enables to save the main part of the nutrients in the product without any wastewater. Besides, tortillas prepared by both traditional nixtamalization and extrusion from yellow maize show great carotenoid profile and lipophilic antioxidant activity when compared to raw kernels. Bioactive compounds such as lutein have the best stability retained above 60% in traditional and extruded tortillas (Corrales-Banuelos et al. 2016). During extrusion cooking in combination with calcium hydroxide [$Ca(OH)_2$], complexes of starch are formed. They affect the structure and properties of the starch granules. Starch granules swell and become more compact (Zazueta-Morales et al. 2002). Extrusion cooking also promotes the formation of amylose-lipid complexes, which are classified as resistant starch that behaves as a fibre having health benefits (hypoglycaemic effects and the potential to reduce colon cancer) (Panyoo and Emmambux 2017). On the other hand, extrusion cooking also affects the content of some vitamins and phenolic compounds (Šárka et al. 2021).

The aim of the work was to seek suitable conditions for extrusion cooking using a laboratory single-screw extruder and follow-up processing to produce tortillas having good nutritional and sensory properties.

MATERIAL AND METHODS

Preparation of premixes, extrusion process and baking of tortillas. Fine maize grits (particle size in the range of 465–752 µm; KONKORDIA Ltd. Maize Mill, Mrzkovice, Czech Republic) were combined in a kitchen mixer without or with $Ca(OH)_2$ addition (0.21% or 0.30%). The input mixtures differed in water content of the premix W (%) (25, 28, 29, or 35%). A laboratory extruder (Kompaktextruder Brabender KE 19/25; Brabender, Germany) was used for extrusion. The single-screw extruder had a 19 mm barrel diameter and a 25 : 1 ratio of the barrel length to diameter. The transporting screw had a compression ratio of 2 : 1 and its speed was set at 100 rpm or 150 rpm. The diameter of the die was 3 mm.

The tortillas were prepared by mixing 200 g of extruded maize flour with 200 mL of water and 1.5 g of NaCl to achieve an adequate consistency of dough. The fresh dough was divided into 35 g pieces/balls and then formed into flat disks using a manual machine.

The resulting tortillas were cooked on a Teflon pan.

Analytical methods and processing magnitudes. Specific mechanical energy (*SME*) (kJ kg^{-1}) of the extrusion cooking was determined from the torque on the drive motor at a constant screw speed and mass flow rate:

$$SME = \frac{\tau_{\max} \times 0.01zN}{1\,000\dot{m}} \tag{1}$$

where: $\tau_{\max}$ – maximum torque (150 J); N – screw speed (rpm); $\dot{m}$ – feed rate (kg min^{-1}); z – motor load (%).

The NIS-Elements V2.3 imaging system (Laboratory Imaging Ltd., Czech Republic) was used for the observation and size evaluation of the measured extrudates (Šárka et al. 2017). The expansion ratio (*ER*) of the puffed product was calculated according to Frame (1995):

$$ER = \frac{d}{D} \tag{2}$$

where: d – diameter of the extrudate (mm); D – diameter of die opening (mm).

The dry matter content was determined at 130 °C for 90 min [ČSN EN ISO 1666 (1996)].

To analyse pH, a sample of 5 g was dissolved in 50 mL distilled water at 25 °C and left to stand for 1 h.

Total dietary fibre (*TDF*) content, soluble dietary fibre (*SDF*) content, and insoluble dietary fibre (*IDF*) content were analysed according to Association of Official Analytical Chemists (AOAC) 991.43.

A Rapid Visco Analyser (RVA 4500; Perten Instruments, Sweden) tested the rheological properties of the extrudates. The profile was as follows: 160 rpm, ramp up to 95 °C, 2–7 min; hold at 95 °C, 7–10 min; cooling to 25 °C, 10–15 min; hold at 25 °C, 15–20 min.

Water absorption index (*WAI*) and water solubility index (*WSI*) were analysed according to Gogoi et al. (1996) and Ding et al. (2005).

Physical parameters for the sensory evaluation of the tortillas were (Pappa et al. 2010): appearance, aroma, colour, texture/residual particles (smooth to grainy), manual texture (flexible to rigid), degree of fragility, flavour, and bite texture (soft to hard).

Sensory evaluation. The appearance, colour, aroma, texture (manual and residual particles), crispness, taste, and chewability of the fresh tortillas were tested by 12 non-professional consumers (6 men and 6 women) according to an internal method having a scale of 0–10 points for each feature. Every analysis and every baking process were done in duplicate.

Evaluation of data from the extrusion process. The design and results of sixteen extrusion experiments (independent and dependent variables) are shown in Table 1. The design was similar to the design in the Taguchi method. Extrusion process variables were coded at 2–3 levels and correlation coefficients r were calculated as published in our previous work (Šárka et al. 2015). The significance of the correlation coefficient was evaluated from the F-criterion calculated according to the following equation:

$$F = \frac{r^2}{1-r^2}\frac{n-k-1}{k} \tag{3}$$

where: r – correlation coefficient; n – number of experiments; k – number of evaluated variables; $\alpha = 0.05$.

Table 1. Composition of premixes and process parameters of the extrusion

Sample	Concentration $Ca(OH)_2$	*W*	*T1*	*T2*	*T3*	*T4*	Motor load	Revolutions of screw	Revolutions of dosing screw	Flow rate	*SME*
	(%)	(%)	(°C)				(%)	(min^{-1})		($kg\ h^{-1}$)	($kJ\ kg^{-1}$)
K1	–	35	60	50	75	81	35	100	12	1.40	224.31
K2	0.30	35	60	60	84	80	30	100	12	1.56	173.23
K3	–	29	60	62	98	80	35	100	12	1.72	182.65
K4	0.30	29	61	63	101	80	35	100	12	1.82	173.39
K5	–	35	60	61	70	79	30	150	15	1.72	235.17
K6	0.30	35	60	60	70	80	30	150	15	1.91	211.91
K7	–	29	60	60	80	84	40	150	15	2.06	262.09
K8	0.30	29	60	60	82	90	35	150	15	2.22	212.55
K01	0.21	25	44	85	91	85	45	100	12	1.65	245.45
K02	–	25	45	85	88	85	45	100	12	1.49	271.45
K03	0.21	28	44	84	83	85	35	100	12	1.38	228.59
K04	–	28	45	85	95	86	40	100	12	1.73	208.57
K05	–	28	44	85	91	85	40	150	12	2.12	254.96
K06	0.21	28	44	85	84	85	30	150	12	1.85	219.39
K07	–	25	45	85	92	86	35	150	12	2.08	227.38
K08	0.21	25	45	85	92	85	35	150	12	2.18	217.14

W – water content of the premix; *T1*–*T4* – temperature of the 1^{st} to 4^{th} extruder zone; *SME* – specific mechanical energy

The correlation coefficients were calculated by the CORREL function in the Microsoft Excel 2016 program. For this article, we present only revealed important dependences.

RESULTS AND DISCUSSION

Influences on *ER*. The porosity of an extrudate is connected with its formed diameter. The diameter of an extrudate *d* (mm) and thus its *ER* increased by decreasing feed water ($r = -0.78$) (Figure 1). This trend is in line with the statement of Ye et al. (2018). The diameter *d* and *ER* also increased by increasing temperatures in the extruder (Figure 2). This could be attributed to the decrease in viscosity as the temperature increases, which allows the dough to expand more readily and the increased vapour pressure at higher temperatures causes increased puffing (Šárka et al. 2015). According to Ye et al. (2018), increasing revolutions of the screw also increases the *ER*. However, this trend was not confirmed.

Influences of motor load and *SME*. These variables are important not only for energy consumption but also they influence the quality of tortillas produced from extruded flour. Increased water content *W* (%) of the premix coming into the extruder increased the motor load *z* (%) of the extruder (Figure 3). This feature can be explained by the lower viscosity of the mixture in the extruder. Specific mechanical energy *SME* is connected with motor load according to Equation 1. This was influenced by $Ca(OH)_2$ addition *y* (%; $r = -0.51$); the higher the variable *y*, the lower the *SME*:

$$SME = -108\ y + 236 \tag{4}$$

Influence of revolutions of the screw on flow rate in the extruder. Generally, revolutions increase the flow rate in an extruder, but this is not valid for

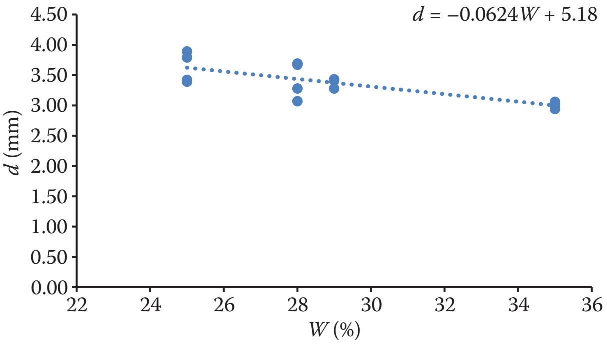

Figure 1. The dependence of the extrudates' diameter (*d*) on water content of the premix (*W*)

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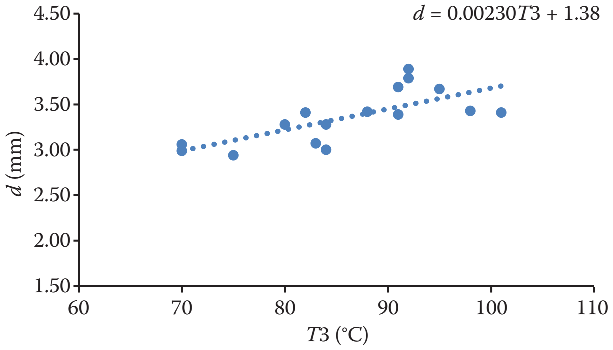

Figure 2. The dependence of the extrudates' diameter (d) on the temperature in the 3rd zone of the extruder ($T3$) ($r = 0.72$)

all materials and conditions because backflow occurs in the barrel as well. As to our premixes, the flow rate $\dot{m}$ (kg h^{-1}; $r = 0.80$) increased with an increase in revolutions N:

$$\dot{m} = 0.00846N + 0.748 \tag{5}$$

Influence of Ca(OH)$_2$ on pH and colour of extrudates. A higher concentration of Ca(OH)$_2$ caused an increase in the pH of nixtamalized maize flour and is related to its colour intensity (Sefa-Dedeh et al. 2004). The samples with a higher concentration of Ca(OH)$_2$ (K2, K4, K6, K8) were darker compared with the samples with lower concentration (K01, K03, K06, K08). The pH values of the samples having the concentration of 0.00, 0.21, or 0.30% Ca(OH)$_2$ were in the range from 6.22 to 6.61 and from 8.21 to 8.45. A higher concentration of Ca(OH)$_2$ caused an increase in the pH of nixtamalized maize flour. With the addition of 0.21% Ca(OH)$_2$, the pH of the extrudates ranged from 8.21 to 8.34.

Influences on *WAI* and *WSI*. According to Ye et al. (2018), *WAI* and *WSI* of extrudates depend on extrusion processing conditions. Water, as a plasticiser, probably reduces shearing and starch degradation during extrusion, and thus high feed moisture results in higher *WAI* and lower *WSI*. However, our results (Table 2) did not confirm this trend – *WAI* decreased with increasing water content ($r = -0.71$) and the dependence *WSI* on *W* was not statistically significant ($r = 0.03$). Neither were the expected influences of revolutions on *WAI* and *WSI* (Ye et al. 2018) statistically proved (for *WAI*: $r = 0.23$; for *WSI*: $r = 0.25$).

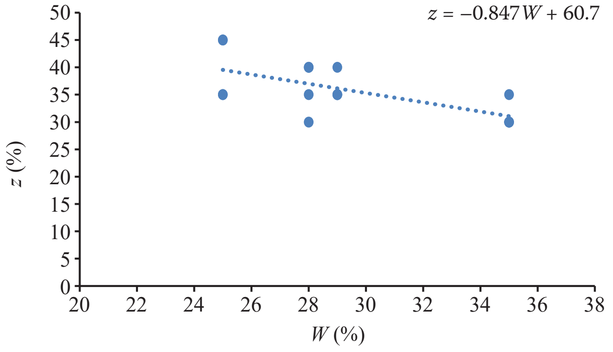

Figure 3. The dependence of the motor load (z) on water content of the premix (W) ($r = -0.64$)

We confirmed that *WAI* and *WSI* are influenced by Ca(OH)$_2$ addition (Zazueta-Morales et al. 2002; Ye et al. 2018). *WAI* was found for different extrusion conditions and for Ca(OH)$_2$ addition 0.00, 0.21, and 0.30% in the range from 3.379–7.013, 5.022–6.787, and 3.610–5.012, respectively, having bigger values of *WAI* in the range from 0.1–0.2% Ca(OH)$_2$. *WSI* for Ca(OH)$_2$ addition 0.00, 0.21, and 0.30% was in the range of 0.040–0.065, 0.033–0.045, and 0.032–0.035, respectively. The *WSI* trend decreased with the increased addition of Ca(OH)$_2$. This can be explained by the formation of Ca starch complexes.

As to *WAI*, the temperature of the extruder second zone ($T2$) was also important ($r = 0.72$):

$$WAI = 0.063T2 + 0.802 \tag{6}$$

Table 2. The dependence of *WAI* and *WSI* on feed moisture, concentration of Ca(OH)$_2$ and revolutions

Sample	*W* (%)	*WAI*	*WSI*
K1^{a}	35	3.422	0.044
K2^{*a}	35	3.669	0.032
K3^{a}	29	4.816	0.040
K4^{*a}	29	5.012	0.032
K5^{b}	35	3.379	0.065
K6^{*b}	35	3.610	0.033
K7^{b}	29	4.764	0.040
K8^{*b}	29	4.976	0.035
K01^{*a}	25	6.120	0.040
K02^{a}	25	6.336	0.042
K03^{*a}	28	5.022	0.033
K04^{a}	28	6.329	0.051
K05^{b}	28	5.792	0.052
K06^{*b}	28	5.555	0.033
K07^{b}	25	7.013	0.046
K08^{*b}	25	6.787	0.045

*Ca(OH)$_2$ added; ^{a}100 rpm; ^{b}150 rpm; *W* – water content of the premix; *WAI* – water absorption index; *WSI* – water solubility index

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This feature is connected with starch gelatinisation. *WAI* characterises water absorption in the gel; therefore, when *T*2 is high and also *WAI* is high, the gelatinisation is more complete.

Influences of process parameters on soluble, insoluble and total fibre. The data of soluble, insoluble and total fibre in extrudates are surveyed in Table 3. Extrusion cooking increased the content of *SDF*, which is very important for the nutrition of the intestinal microbiome. *SDF* content of the extruded samples without $Ca(OH)_2$ addition was 0.19 ± 0.10%, but it was higher for the samples with $Ca(OH)_2$ addition. This is in agreement with the data of Ning et al. (1991) explaining it by chemical hydrolysis. Like starch changes, some transformation of cellulose and lignin could also occur. As to process parameters, revolutions of the screw had the highest influence on *SDF* content ($r = 0.73$); the higher the rpm, the higher the *SDF* content.

IDF was linked with *TDF* content (Figure 4).

Influence of process parameters on pasting properties. Pasting profiles measured by RVA are shown in Table 4. All the measured samples containing $Ca(OH)_2$ (K2, K4, K6, K8, K01, K03, K06, K08) had the typical time shift. Higher setback (the most consistent gel) was found for the samples K4 (1 562.0 ± 62.2 mPa.s) and K03 (1 391.0 ± 4.2 mPa.s). On the other hand, the samples K5 (1 234.0 ± 14.1 mPa.s) and K04 (986.5 ± 19.1 mPa.s) had the lowest setback.

Table 3. Content of insoluble dietary fibre (*IDF*), soluble dietary fibre (*SDF*) and total dietary fibre (*TDF*) [% dry substance (DS)] (mean ± SD; $n = 3$)

Sample	*W*	*IDF*	*SDF*	*TDF*
K1[a]	35	2.37 ± 0.22	0.33 ± 0.05	2.70 ± 1.44
K2*[a]	35	2.29 ± 0.13	0.79 ± 0.13	3.08 ± 1.06
K3[a]	29	2.98 ± 0.09	0.59 ± 0.10	3.57 ± 1.69
K4*[a]	29	2.84 ± 0.23	0.78 ± 0.10	3.62 ± 1.45
K5[b]	35	2.80 ± 0.23	0.74 ± 0.02	3.55 ± 1.46
K6*[b]	35	2.24 ± 0.54	0.97 ± 0.17	3.21 ± 0.90
K7[b]	29	2.90 ± 0.05	0.80 ± 0.08	3.70 ± 1.48
K8*[b]	29	2.56 ± 0.08	0.89 ± 0.05	3.45 ± 1.18
K01*[a]	25	2.34 ± 0.02	0.53 ± 0.01	2.86 ± 1.28
K02[a]	25	3.01 ± 0.08	0.40 ± 0.08	3.41 ± 1.84
K03*[a]	28	2.57 ± 0.00	0.54 ± 0.30	3.12 ± 1.44
K04[a]	28	2.69 ± 0.05	0.41 ± 0.06	3.10 ± 1.62
K05[b]	28	3.11 ± 0.08	0.87 ± 0.05	3.99 ± 1.58
K06*[b]	28	2.81 ± 0.08	0.88 ± 0.19	3.69 ± 1.37
K07[b]	25	3.00 ± 0.12	0.66 ± 0.11	3.66 ± 1.65
K08*[b]	25	2.40 ± 0.07	0.77 ± 0.03	3.17 ± 1.15

*$Ca(OH)_2$ added, [a]100 rpm, [b]150 rpm; *W* – water content of the premix; SD – standard deviation

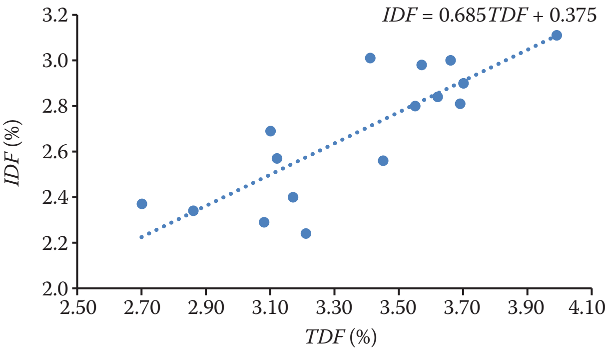

Figure 4. The dependence of insoluble dietary fibre (*IDF*) on total dietary fibre (*TDF*) ($r = 0.82$)

The lowest breakdown (the most stable gel) was found for the K5 (225.0 ± 1.4 mPa.s) and K04 (186.5 ± 0.7 mPa.s) samples, the highest one for K4 (384.0 ± 0.0 mPa.s) and K08 (505.0 ± 5.7 mPa.s). Hold viscosity characterises the degree of kneading of the sample: the lower the viscosity of the hot paste, the greater the kneading of the sample. Greater kneading of the suspension occurred in samples K6 (140.0 ± 0.0 mPa.s) and K08 (142.5 ± 0.7 mPa.s).

Ye et al. (2018) stated that extruded starches are characterised by a low peak viscosity. Compared to the maximum viscosity of the native sample (646.0 ± 4.2 mPa.s), this trend was confirmed.

According to Zazueta-Morales et al. (2002), the addition of $Ca(OH)_2$ increases RVA-pasting characteristics. The explanation of this feature could be in the formation of starch and calcium complexes.

Peak viscosity was influenced by the temperature in the 3rd zone (*T*3) of the extruder (Figure 5). The higher the *T*3 temperature, the higher the peak viscosity.

Influence of extrusion process parameters on sensory properties of tortillas. Extrudates containing $Ca(OH)_2$ and having good parameters were ground to prepare extruded flour (K2, K8, K03, K06, and K08) for the tortilla preparation. The samples were divided into two groups according to the lime addition (0.21% or 0.30%), and the samples inside any group had extreme parameters of WAI, different revolutions (100 rpm or 150 rpm) and water content of the premix (35, 29, 28, or 25%). The summary sensory results of the prepared tortillas are in Figures 6 and 7, discovered dependencies are in detail in the follow-up figures.

The effects on tortilla colour were tested; weaker correlations were found. The colour was influenced mainly by $Ca(OH)_2$ addition ($r = 0.73$) and by the temperature of the 2nd zone of the extruder ($r = –0.73$). Tortillas with

Table 4. Pasting properties of the samples (mean ± SD; $n = 3$)

Sample	Peak viscosity	Hold viscosity	Final viscosity	Setback	Breakdown	Time
			(mPa.s)			(min)
Maize grits	646.0 ± 4.2	647.0 ± 4.2	2 083.5 ± 23.3	1 436.5 ± 19.1	−1.0 ± 0.0	10.0
K1	529.5 ± 16.3	252.0 ± 7.1	1 720.5 ± 62.9	1 468.5 ± 55.9	277.5 ± 9.2	7.4
K2*	442.0 ± 2.8	174.0 ± 0.0	1 591.0 ± 14.1	1 417.0 ± 14.1	268.0 ± 2.8	6.8
K3	557.0 ± 5.7	295.5 ± 0.7	1 779.0 ± 9.9	1 483.5 ± 9.2	261.5 ± 4.9	7.3
K4*	565.5 ± 0.7	180.5 ± 0.7	1 742.5 ± 62.9	1 562.0 ± 62.2	384.0 ± 0.0	6.7
K5	380.5 ± 0.7	155.5 ± 0.7	1 389.5 ± 13.4	1 234.0 ± 14.1	225.0 ± 1.4	7.2
K6*	438.0 ± 1.4	140.0 ± 0.0	1 568.0 ± 11.3	1 428.0 ± 11.3	298.0 ± 1.4	6.6
K7	492.0 ± 2.8	185.5 ± 2.1	1 523.5 ± 48.8	1 338.0 ± 46.7	306.5 ± 0.7	7.2
K8*	539.5 ± 2.1	161.0 ± 0.0	1 637.0 ± 11.3	1 476.0 ± 49.5	378.5 ± 2.1	6.7
K01*	558.5 ± 7.8	155.0 ± 2.8	1 463.5 ± 20.5	1 308.5 ± 17.7	403.5 ± 4.9	6.7
K02	595.0 ± 9.9	313.0 ± 5.7	1 600.5 ± 24.7	1 287.5 ± 19.1	282.0 ± 4.2	7.3
K03*	400.0 ± 2.8	161.5 ± 0.7	1 552.5 ± 3.5	1 391.0 ± 4.2	238.5 ± 2.1	6.7
K04	542.5 ± 2.1	356.0 ± 1.4	1 342.5 ± 20.5	986.5 ± 19.1	186.5 ± 0.7	7.2
K05	511.5 ± 7.8	313.5 ± 3.5	1 377.5 ± 26.2	1 064.0 ± 22.6	198.0 ± 4.2	7.3
K06*	482.0 ± 4.2	154.5 ± 2.1	1 341.0 ± 7.1	1 186.5 ± 4.9	327.5 ± 2.1	6.8
K07	549.5 ± 14.8	330.0 ± 11.3	1 333.0 ± 63.6	1 003.0 ± 52.3	219.5 ± 3.5	7.2
K08*	647.5 ± 6.4	142.5 ± 0.7	1 187.5 ± 14.8	1 045.0 ± 14.1	505.0 ± 5.7	6.6

*$Ca(OH)_2$ added; SD – standard deviation

higher addition of $Ca(OH)_2$ (K2 and K8) were darker than tortillas with lower addition (K03, K06, and K08).

Figures 8–10 are devoted to influences on manual texture which is an important parameter for consumers. Tortillas prepared with higher addition of $Ca(OH)_2$ were less flexible (Figure 8). Tortillas prepared from extrudates coming from premixes with higher water content were stiffer (Figure 9), while, on the other hand, those with lower water content were more flexible (which is better).

The higher the temperature in the 2nd zone of the extruder, the more flexible the tortillas (Figure 10); this is connected with the course of gelatinisation.

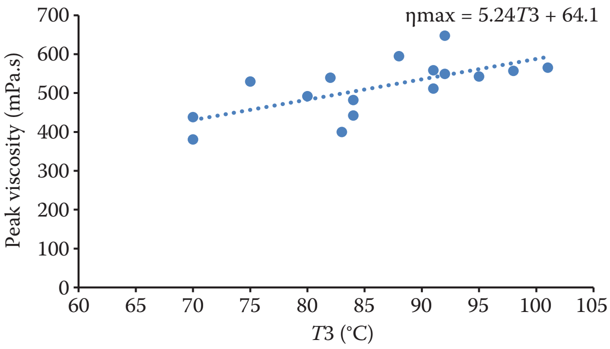

Figure 5. The dependence of peak viscosity on the temperature in the 3rd zone of the extruder ($T3$) ($r = 0.67$)

Figure 11 illustrates the in-mouth texture, i.e. how the texture and residual particles are perceived in the mouth. The extrusion process by higher revolutions (150 rpm) had a positive effect.

The aroma and flavour of the tortillas were influenced primarily by specific mechanical energy (Figure 12). The most intensive maize aroma was found in the torti-

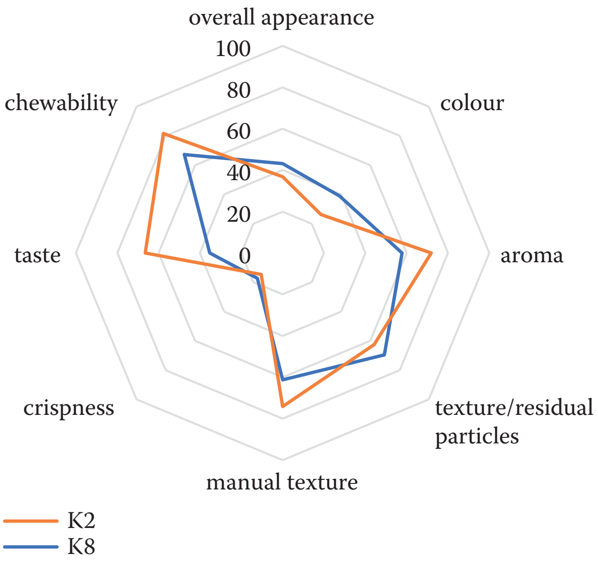

Figure 6. Results of sensory evaluation of tortillas prepared from samples K2 and K8 [addition of 0.30% $Ca(OH)_2$]

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lla prepared from K2 flour, the least from K8 flour. *SME* was positively influenced by $Ca(OH)_2$ addition. However, the addition cannot be too high; otherwise, this leads to a less pronounced taste.

The chewability (bite texture) was associated with the manual texture (r = 0.91) and water content of the premixes (Figure 13). As the moisture content of the extrusion mixture decreased, the chewability of the bite was easier. This feature can be explained by more porous and more digestible extrudates whose texture influenced positively chewability.

Generally, the appearance of the tortillas was acceptable. The most attractive appearance was found for the tortilla prepared from K08 flour, the least attractive from K8 flour. The overall appearance of the tortillas was influenced mainly by the motor load of the extruder (Figure 14). The motor load was related to the moisture (water) content of the premix. The more mechanical energy the extruder required, the less pleasant the appearance of the maize tortillas.

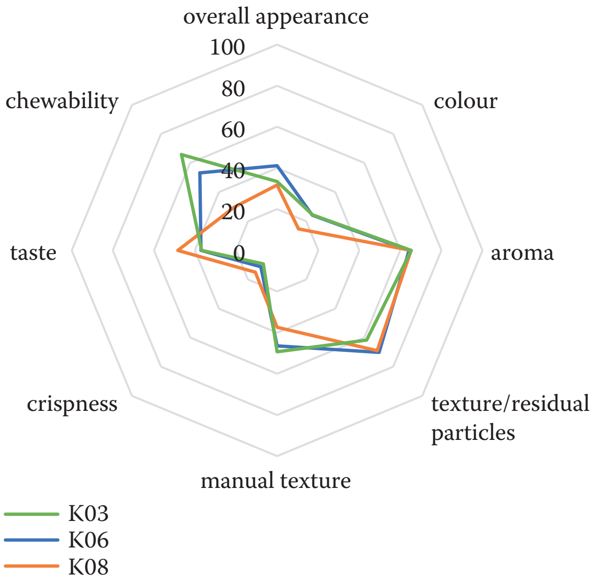

Figure 7. Results of sensory evaluation of tortillas prepared from samples K03, K06, and K08 [addition of 0.21% $Ca(OH)_2$]

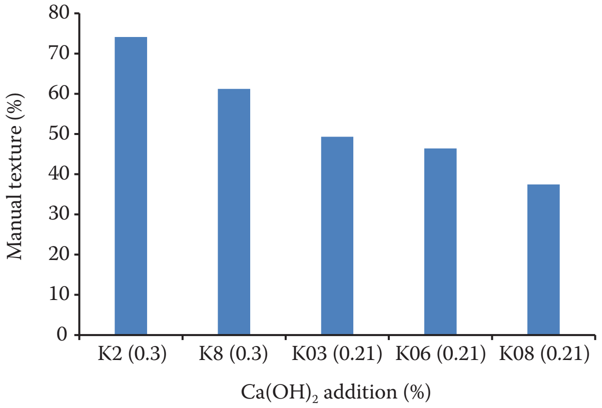

Figure 8. Dependence of manual texture on $Ca(OH)_2$ addition (r = 0.90)

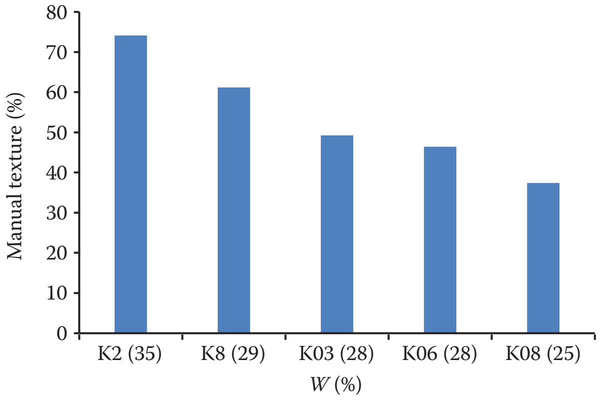

Figure 9. Dependence of manual texture of tortillas on water content of premixes (W) (r = 0.95)

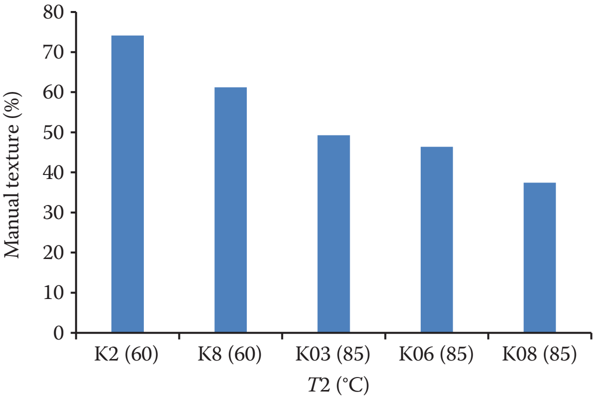

Figure 10. Dependence of manual texture on the temperature in the 2nd zone of the extruder ($T2$) (r = –0.90)

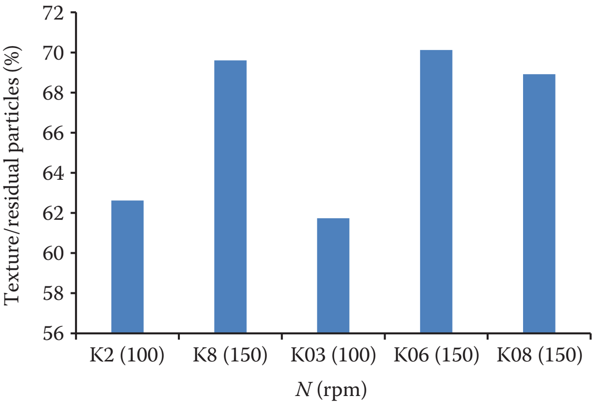

Figure 11. Dependence of texture/residual particles on screw speed (N) (r = 0.99)

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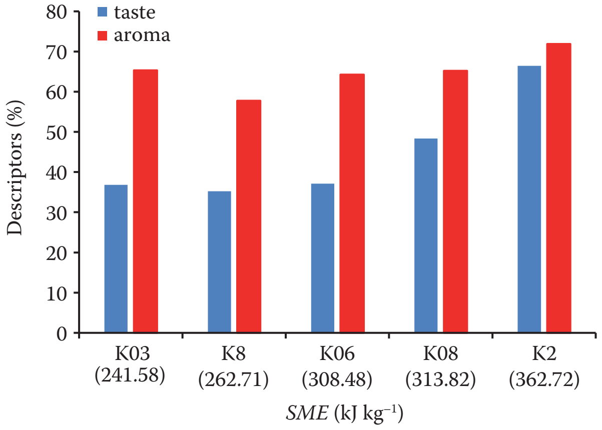

Figure 12. Dependence of flavour and aroma on specific mechanical energy (*SME*) ($r = 0.71$ for aroma and $r = 0.87$ for flavour)

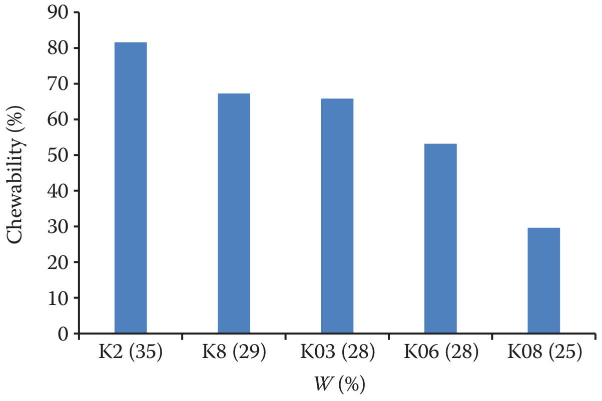

Figure 13. Dependence of chewability of the bite on the water content of the premix (*W*) ($r = 0.88$)

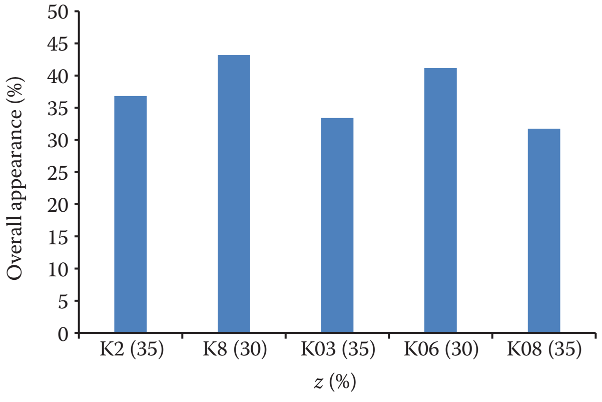

Figure 14. The dependence of overall appearance on motor load (*z*) ($r = -0.91$)

To have more reliable data, more evaluators would be required.

CONCLUSION

The paper seeks optimal parameters to produce tortillas from the flour prepared by extrusion nixtamalization. To have the suitable (medium) manual texture of tortillas, $Ca(OH)_2$ addition to an input mixture coming to extrusion should be less than 0.21%, less than 28% water content; the temperature in the extruder 2nd zone should be near 85 °C.

The lower the water content, the higher the power consumption but the more pleasant tortilla appearance (larger diameter of extrudates; their porosity and sensorial properties improved: tortillas were more flexible and chewable). Also, the *WAI* increased with the lower moisture content of the premix.

With a higher temperature set in the 2nd, 3rd, and 4th zone of the extruder, the diameter and *ER* of the extrudates, *WAI* and flexibility of tortillas improved as well.

Despite, the higher the $Ca(OH)_2$ addition, the lower the *SME*, but, the high addition caused an increase in pH of nixtamalized maize flour and negatively affected the colour, *WAI,* taste and aroma of the tortillas.

SDF in the samples with the addition of $Ca(OH)_2$ increased more than in the samples without alkaline treatment. *SDF* should have resulted in improvement of taste, but the negative influence of high $Ca(OH)_2$ addition on taste prevailed. A better possibility to increase *SDF* is by increasing the speed of the extruder screw (to 150 rpm).

All the samples with the addition of $Ca(OH)_2$ showed a characteristic shift of the maximum viscosity over time, most likely due to chemical modification by $Ca(OH)_2$ and easier swelling of starch granules. The maximum viscosity was affected by the temperature in the third zone of the extruder: the higher the temperature, the higher the maximum viscosity.

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