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Study of IVDV as a texturizing pre-treatment for roasting maize and its effect on quality parameters

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ABSTRACT

Intensification of Vaporization by Decompression to the Vacuum (IVDV) is proposed as a pre-treatment for texturizing maize in order to prepare it for further roasting. A central composite rotatable design was adopted to study the effect of three operating parameters (initial water content (W), steam pressure (P) and processing time (T)) on the response parameters: Total Polyphenols Content, Expansion Ratio, Hardness, Work Done and color. After expansion, the polyphenols content increased due to the liberation of bound polyphenols. The hardness decreased due to modification of the kernel's structure by the creation of internal alveolation. Expansion ratio was studied after expansion and after roasting. P had the most important effect, it was followed by T. Pressure drop and rheological equilibrium were responsible for the kernels expansion. A pressure of 6 bars was required for the kernels to start expansion. Expanded and roasted kernels showed higher expansion than non-expanded roasted ones. Interactions between the variables had interesting effects on color and mainly b*. A decrease in luminance and yellowing and an increase in redness was observed after IVDV treatment.

Keywords: Decompression; expansion; color; polyphenols; RSM

Introduction

Maize (*Zea mays* L.) is a worldwide consumed cereal providing food to the populations but also consumed as snack after roasting. Its world production was estimated about 872 million tons in 2012 (FAOSTAT, 2014). In addition to its high content in starch and oil (Courtois, 1991; FAO, 1992), it is known to be a rich source of phytochemicals among which phenolic compounds (Lopez-Martinez *et al.,* 2009; Hu and Xu, 2011). Many studies have shown the important functional role of these molecules as antioxidants, antimutagens, inducers of detoxification enzymes such as glutathione transferase and quinone reductase and cancer inhibitors (Thomasset *et al.,* 2006; Pedreschi and Cisneros-Zevallos, 2007; Rajha *et al.,* 2013).

Worldwide, maize is processed in many different ways. In the Mediterranean region, it is consumed raw or grilled directly on the cob, boiled, processed as maize grits, maize flour, corn bread or transformed into crunchy products such as corn flakes, popcorn and snacks. Recently, demand on crunchy snack products is increasing and competition for better products is growing in the industrial sector. The most known way to produce crunchy maize as snack is deep frying. However, fried products are being often considered as too calorific rendering the food product not healthy. Moreover, they cause the degradation of the phenolic substances in food products (Tokusoglu and Yildirim, 2012; Seveg *et al.,* 2012). Roasting is another technique known to produce healthy crunchy snacks. Nevertheless, some trials reported that roasting requires a series of pre-treatments and doesn't always provide maize with the sought crunchiness due to the hard texture of the kernels. In order to alleviate these drawbacks, a well-controlled texturizing pre-treatment can be applied for the production of crunchy snack maize while preserving the grains integrity and its nutritional values.

Food texturizing by expansion has played a fundamental role in improving the quality of dried foodstuffs. Expansion first appeared in the early fifties via a process called Explosion puffing. It consisted in providing a better texture in terms of crunchiness by self-vaporization of the moisture contained in a partially dried product. The product is subjected to steam pressure for a certain time, then a sudden decompression to the atmospheric pressure takes place inducing a partial evaporation of the water within the product (Sullivan and Craig, 1984; Clark, 1986). The steam thus formed provokes mechanical constraints within the viscoelastic product, creating thereby a porous structure. During this phenomenon, the product undergoes an irreversible adiabatic transformation. Therefore it must be suitably prepared to the expansion regarding its rheological properties mainly determined by temperature and water content (Louka and Allaf, 2002, 2004).

The expansion-puffing underwent many modifications with time until a new expansion process with a sudden decompression towards the vacuum "Détente Instantanée Contrôlée" (DIC) has been developed in the nineties (Allaf *et al.,* 1992). DIC consists in carrying out a decompression towards a vacuum of 0.1 bar instead

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of the atmospheric pressure. The amount of steam generated by self-vaporization is therefore greatly sufficient with a lower treatment temperature (e.g. from 150°C to 30°C instead of 220°C to 100°C where the decompression is towards the atmospheric pressure), (Louka and Allaf, 2002). These milder conditions, followed by a rapid and intensive cooling, were suitable for expanding heat sensitive products while preserving very satisfactory final organoleptic qualities (shape, texture, color and flavor), (Louka, 1996).

Recently, an even better improvement has been added to the DIC, resulting in a new process called « Intensification of Vaporization by Decompression to the Vacuum » (IVDV), (Mrad *et al.,* 2014 a, b). IVDV consists in a very rapid compression to high pressures (reaching 15 bars) in less than 1 sec. The great advantage of this rapid compression is the possibility to treat heat-sensitive products that cannot withstand more than few seconds under high pressure.

In the present work, maize kernels were expanded by IVDV and roasted. The aim was to study the effect of the operating parameters (initial water content (W), steam pressure (P) and processing time (t)) of the IVDV treatment. This study was done by measuring the polyphenols content and the physical properties (expansion ratio, texture and color) of the expanded and/or roasted kernels. The aim was to prepare well-expanded maize kernels, without excessive deformation, for further processing such as roasting, while preserving their nutritional properties. The expansion is supposed to preserve, as much as possible, the original shape of the kernels without popping or disintegration. Response surface methodology was used to study the different response parameters.

Materials and methods

Chemicals and reagents:

All chemicals and reagents used in the experiments were of analytical grade. Folin-Ciocalteau reagent, gallic acid (GA), acetone, ethanol and methanol were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA). Sodium carbonate was obtained from Fluka (Buchs, Switzerland).

Sampling:

Maize (*Zea mays* L.) of the following variety “Chulpe Country Gentleman Corn”, designated by Maize C, was studied in this work. Samples were supplied from a local industry (Al-Kazzi). They were all purchased from the same source. Only whole healthy kernels were selected. The initial moisture content was 14.13 ± 0.54 g/100g DM.

Rehydration and homogenization:

Sample rehydration was carried out as a pre-treatment for IVDV processing. This operation was done by soaking the kernels in distilled water at 25°C with a ratio of 1/5 g of kernels / ml water. The soaking time necessary to obtain the required water contents was determined by preliminary testings. The hydrated samples were then kept for three to four days at 4°C for a better homogenous redistribution of water. These conditions were set by our laboratory after a series of trials.

IVDV reactor:

Experiments were carried out in a processing reactor consisting of the following main components:

I. A treatment chamber having an internal volume of 100 L where the samples are treated with high steam pressure. Pressure is reached within 1 sec using a steam generation system. II. A vacuum system consisting of a vacuum tank with a volume 100 times greater than the treatment chamber. The vacuum in the tank is ensured by a combination of mechanical (vacuum pump) and cooling effect (cooling water that circulates in the double jacket of the tank). III. A decompression system where a pneumatic valve (200 mm diameter) operating in less than 0.5 sec separates the treatment chamber from the vacuum tank.

Sample preparation:

Having carried out the rehydration and homogenization, the maize kernels were placed in the treatment chamber in which an initial vacuum was established. This primary vacuum will improve the heat transfer and make the material more accessible for steam. After that, saturated steam at a pressure "P" (which could attain 15 bars) and a temperature “Θ” was generated quickly into the treatment chamber for a fixed processing time "t" (from 1 to 200 sec). This high-temperature/short time stage was followed by an instant pressure release towards a vacuum that could reach 1 mbar. The abrupt pressure release, at a rate $\Delta P/\Delta t$ higher than 12 bar/ sec, simultaneously produces a self-vaporization of a part of the water in the product, and an instantaneous cooling of the product, which stops thermal degradation (Louka, 1996). A porous structure is attained. The treated product is then subjected to an atmospheric air injection under vacuum to ensure its rapid cooling before returning back to atmospheric pressure. After, expanded maize kernels underwent dehydration in a forced-convection oven at 50°C for 24 h. Finally expanded samples were roasted in a laboratory tumble-like mini-roaster heated by gas flame. Optimal roasting time and temperature were set after a series of trials. They were 3 min at 220°C.

Experimental design:

Response surface methodology was employed to investigate the effect of expansion conditions on expanded and roasted maize. The response parameters were: Total Polyphenols Content (TPC), Expansion Ratio (ER), Hardness of the grains (HARD), Work Done (WD) and color (L*, a* and b*). They are assumed to be affected by three independent variables: W, P and t.

A Central Composite Rotatable Design was adopted. Twenty experiments were completed with eight (2^3) factorial points, six axial points (stars) and six center points for replications (Table 1). The range and the center points of the experimental parameters were chosen after preliminary trials (see Table 1). The 20 experiments were run in random order to minimize the effects of unexpected variability in observed responses. Experimental designs and data processing of the obtained results were performed using Statgraphics *Plus* 5.1 for Windows.

A second degree polynomial equation was assumed to approximate the true function:

$$Y = b_0 + \sum_{i=1}^{3} b_i X_i + \sum_{i=1}^{3} b_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=2}^{3} b_{ij} X_i X_j \qquad \text{with } j>1$$

where Y is the predicted response, X_i and X_j are the coded values of the factors, b_0 is the mean value of responses at the central point of the experiment; and b_i, b_{ii} and b_{ij} are the linear, quadratic and interaction coefficients, respectively.

Table 1: Independent variables and their levels used for central composite rotatable design.

Variables	Symbol	Coded variable levels				
		-α	-1	0	+1	+α
Initial water content (%)	W	16.6	20	25	30	33.4
Steam pressure (bar)	P	3.2	10	20	30	36.8
Processing time (sec)	t	5	6	7.5	9	10

Expansion ratio:

The expansion ratio was determined in order to quantify the volume increase of the final product. The method used was that of Louka and Allaf (2002). It consists in measuring the bulk density of raw (ρr) and treated (ρt) maize kernels. Experiments were repeated five times each. The expansion ratio was calculated from the following equation: $ER = \frac{\rho r}{\rho t}$.

Chemical analysis:

Water content determination:

Measured samples were dried in a drying oven until a constant weight was obtained (105°C for 24 h), (AOAC, 1990). The water content was expressed as a percentage of the dry matter (DM).

Sample extraction:

Extraction was done according to Serpen *et al.* (2008) and optimized in our laboratory to suit our case. Acetone at 85 % (v/v) was found to extract polyphenols better than methanol 50 % (v/v). Five grams of ground samples were extracted twice with 20 ml of acetone 85 % (v/v). Mixtures were shaken at 300 rpm for 24 h at room temperature and in the dark. Extracts were centrifuged at 3500 g for 10 min. The supernatants were pooled and concentrated at 40°C for 24 h. The residues were then reconstituted with water/Ethanol 8/2 (v/v) and stored at -20°C in the dark until further analysis within 2 days.

Total Polyphenols Content determination:

The TPC was determined based on the Folin-Ciocalteu colorimetric method described by El Darra *et al.* (2012). The absorbance was measured using a UV-VIS spectrophotometer (UV-9200, BioTECH Engineering Management, UK) at 765 nm wavelength against a negative control. Total phenols concentrations were expressed as mg gallic acid equivalents (GAE) per 100 g of DM based on a calibration curve of 0 - 500 µg of GAE / mL.

Textural analysis:

Compression tests were performed using a CT3 texture analyzer (Brookfield Engineering Labs. Inc.). A 10 kN load was applied to perform compression tests. The texture analyzer was out-fitted with a craft blade that cut the sample at a test speed of 2.0 mm/s. The measured textural parameters were hardness (maximum peak force required to shear the sample) and work done (work required to overcome the internal structural strength of the bonds within the grain). All bulk compression measurements were performed in 15 replicates and results were averaged.

Color determination:

The surface color of maize samples was measured using a chromameter (ADCI - 60 - C). The measurement was performed in CIE Lab, an international standard for color measurements, known for its uniform distribution of colors, and its closeness to human perception of color (Leon *et al.* 2006). L* is the luminance or lightness component, which ranges from 0 to 100, and parameters a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from -120 to 120. Five measurements were done for each sample and averaged.

Results and discussion

Table 2 presents the experimental design and the data of the responses for non IVDV treated (raw or roasted without IVDV pre-treatment) and IVDV treated maize. It shows the values of ER, TPC, HARD and WD of Maize C after IVDV expansion and ER and color parameters (L*, a* and b*) after expansion and roasting. Fig. 1 illustrates the shape of the IVDV treated maize kernels according to the experimental conditions.

Expansion ratio:

Results of expansion ratio are shown in Table 2. Expansion ratio varied from 1.31 (run 2) to 2.14 (run 8) after IVDV treatment and from 1.47 (run 11) to 2.09 (run 8) after roasting. Runs 2 and 11, that presented the lowest values in the expanded and roasted plans respectively, corresponded to the treatments W = 30 %, P = 6 bar, t = 10 sec where P and t are at their [-1] levels and W = 25 %, P = 5 bar, t = 20 sec where P is at its [–α] level. In the expanded plan, run 13 also showed a low value of ER (1.32), very close to that of run 2 (1.31). It corresponded to the level [–α] of t. Run 8 showed the highest expansion ratios for both plans. It corresponded to [+1] levels of P, t and W simultaneously (run 8). Run 12, where P is at its [+α] level, also showed high ER for both plans even though a bit less than run 8. However, for runs 8 and 12, visual observations (Figure 1) showed that kernels were expanded to the degree of explosion. Such an expansion was not appreciated as it didn't preserve the shape and integrity of the grain.

On the other hand, Table 2 shows that samples which were roasted without IVDV pre-treatment presented a lower expansion ratio (ER = 1.4) than those roasted after IVDV expansion.

TPC, HARD, WD and color:

TPC varied between 59.21 and 81.29 mg/100 g DM. The minimum was attained for run 4 and the maximum for run 7 where the operating parameters were respectively at the following levels of [W, P, t]: [+1, +1, -1] and [-1, +1, +1]. In both cases P was at its high level [+1]. However, its combination with W and t was responsible for the extreme values of TPC.

As seen in Table 2, most of the runs had higher TPC values than that of raw maize before IVDV treatment (61.96 mg/100g DM). In fact, the bigger amount of polyphenols in maize was found to be bound to the cell walls (Lopez-Martinez *et al.,* 2009). The treatment seemed to help the extraction of polyphenols by the rupture of cell walls and the release of bound polyphenols in the cell matrix. Similarly, Debs-Louka *et al.* (1996) observed cell membranes degradation after microscopic examination of DIC treated products.

Runs 4 and 14 (t at [+α]) were the only runs that had values of TPC slightly lower than that of the raw grains. In fact, at combined high values of W and P (run 4), the big quantity of generated steam along with the high pressure denivelation could have caused an important explosion inside the kernel, resulting in an expulsion of the free and liberated polyphenols in the outside medium and thus their loss. On the other hand, in run 14, polyphenols might have gone a thermal degradation due to the prolonged processing time (Mrad *et al.,* 2014a, b). In both cases, the decrease in TPC was not so important as it was compensated by the liberation of bound ones.

Concerning hardness, after expansion, the values ranged between 1261 and 2685 g. All were far below the value of raw maize (4516 g).

The values of work done ranged from 17.55 to 71.66 mJ. The lowest and the highest values corresponded to the runs 13 and 14 where t was at its [-α] and [+α] levels respectively. Thus, the processing time seemed to be responsible for the variation in WD.

As already mentioned, hardness and work done are the parameters defining the grain's texture. A decrease in hardness is appreciated in order to obtain a consumable product easily chewable. A limited decrease in the work done is also appreciated indicating a decrease in the internal structural strength of the bonds within the grain. However, low WD could result from the destruction of the internal bonds and thus the formation of a brittle product having no crunchiness. In order to choose the Hard and WD that provide the best texture and thus crunchiness, a sensory analysis should be conducted.

Concerning the color parameters, all runs showed lower L* and b* values than those of the grains roasted without having undergone a pre-treatment by IVDV. On the opposite side, they showed higher values of a* than those without IVDV, except for the runs 1 and 10. This indicates a decrease in luminance and yellowing after IVDV treatment and an increase in the redness of the grains.

Table 2: Experimental plan for IVDV expansion of maize C and results after expansion and roasting.

Run	W	P	t	After IVDV expansion				After roasting			
	(%)	(bar)	(sec)	ER	TPC mg/100g DM	HARD g	WD mJ	ER	L*	a*	b*
Non IVDV treated maize				1	61.96	4516	32.00	1.4	57.04	11.33	31.56
1	20	6	10	1.45	68.92	2073	33.03	1.52	49.63	11.26	25.69
2	30	6	10	1.31	67.10	2034	58.15	1.49	48.03	16.18	24.91
3	20	9	10	1.79	67.97	1541	25.1	1.70	51.43	18.05	27.7
4	30	9	10	1.45	59.21	2685	36.35	1.52	51.32	12.69	25.74
5	20	6	30	1.44	67.03	1590	41.3	1.52	53.7	11.61	26.48
6	30	6	30	1.46	71.58	2157	38.9	1.57	50.8	17.12	28.75
7	20	9	30	1.68	81.29	1441	32.06	1.76	48.81	15.29	26.4
8	30	9	30	2.14	77.97	1732	28.15	2.09	49.87	14.35	25.63
9	16.6	7.5	20	1.62	70.55	1470	28.24	1.63	51.98	15.98	24.88
10	33.4	7.5	20	1.44	72.23	2566	41.8	1.59	50.9	10.09	25.02
11	25	5	20	1.40	75.18	1579	42	1.47	50.8	12.06	25.81
12	25	10	20	2.01	70.65	1298	34.78	1.83	46.75	13.53	25.76
13	25	7.5	3.2	1.32	76.00	1261	17.55	1.53	54.19	15.17	29.15
14	25	7.5	36.8	1.55	67.10	2383	71.66	1.69	49.37	15.26	26.49
15	25	7.5	20	1.49	71.68	1622	34.18	1.65	48.59	13.95	25.7
16	25	7.5	20	1.50	65.24	2000	32.6	1.67	45.73	14.11	25.97
17	25	7.5	20	1.52	79.92	2015	23.78	1.56	49.26	15.04	25.63
18	25	7.5	20	1.50	71.29	2365	46.5	1.56	48.92	13.59	24.5
19	25	7.5	20	1.53	73.00	2018	24.28	1.60	49.24	13.68	25.02
20	25	7.5	20	1.50	76.29	1573	56.48	1.63	50.96	15.46	25

Center points are bold-faced

Fig. 1: Photos of IVDV treated maize C kernels.

Modeling and Statistics:

In this study, the Response Surface Methodology (RSM) was used in order to determine the experimental conditions for the optimal response parameters: ER, TPC, HARD, WD and color of the maize C. Response values were shown by statistical analyses to fit best the second order polynomial models (Table 3). These latter express the relations between the response variables and the test variables (W, P and t) obtained by the application of a multiple regression analysis on the experimental data. Only models showing R^2 equal or higher than 0.8 were cited in Table 3.

The significance of the parameters is clearly shown by Pareto charts in figures 2 to 4. The vertical line on the Pareto chart determines the effects that are statistically significant at the 95% confidence level. Some had positive effects (+) while others had negative ones (-). The response surfaces illustrate the general aspect of response parameters in function of two independent variables while the third is kept fixed. They illustrate linear and quadratic effects of the operating variables as well as interactions between them.

Table 3. Second order polynomial equations relating response variables to test variables (W, P and t).

Response parameter	Model
ER exp	$5.27 - 0.11*W - 0.57*P - 0.072*t + 0.00059*W^2 + 0.004*W*P + 0.0024*W*t + 0.034*P^2 + 0.0037*P*t - 0.00019*t^2$
ER roast	$3.26 - 0.052*W - 0.19*P - 0.066*t + 0.00016*W^2 + 0.0022*W*P + 0.0015*W*t + 0.0081*P^2 + 0.0046*P*t + 0.000041*t^2$
HARD exp	$502.59 - 172.66*W + 634.11*P + 64.32*t + 2.55*W^2 + 15.11*W*P - 0.61*W*t - 62.79*P^2 - 5.77*P*t - 0.055*t^2$
a* roast	$-47.86 + 2.26*W + 9.95*P - 0.37*t - 0.01*W^2 - 0.28*W*P + 0.013*W*t - 0.15*P^2 - 0.02*P*t + 0.0052*t^2$
b* roast	$17.25 + 0.48*W + 1.36*P - 0.27*t - 0.0035*W^2 - 0.07*W*P + 0.01*W*t + 0.092*P^2 - 0.05*P*t + 0.0093*t^2$

Effect of IVDV expansion and roasting on the expansion ratio:

The pareto charts of Figure 2 shows the pronounced positive effect of P and t on ER after expansion (Figure 2a) and roasting (Figure 2e). P had the most important effect, it was followed by t. These effects are also seen on the response surfaces (Figure 2: c, d, g). Concerning W, it showed a slightly significant negative effect on expanded kernels (Fig. 2a). All the interactions were positively significant. They contributed to the increase of the expansion ratio. Only the interaction W-P was not significant after roasting. The quadratic effect of P exerted a positive significant effect after expansion (Figure 2a). Other quadratic effects were slightly or not significant (Figure 2: a, b).

When discussing the effects of the operating parameters and their interactions, it is important to mention that P and t are the parameters that define the treatment intensity. In fact, the level of the decompression ΔP (for a given final pressure) determines the extent of the fall in temperature $\Delta\Theta$ after the pressure drop. The difference in temperature $\Delta\Theta$ determines the amount of steam generated by self-vaporization and thus the intensity of the mechanical constraints which provoke the expansion of the products (Louka and Allaf, 2002; Louka *et al.,* 2004). The higher the steam pressure at a given final temperature, the more vapor is generated by self-vaporization and the higher is the expansion ratio, making P the most important parameter of the expansion. The expansion of the structure also depends on the rheological behavior of the product. Previous studies have shown that rheological properties of the product differ with the time of treatment (Louka and Allaf, 2002, 2004). During the first phase of the treatment, thermal equilibrium occurs. This is not sufficient for expansion. The achievement of a viscoelasticity sufficient for expansion requires more heating time (Louka and Allaf, 2002, 2004). More the product is rheologically equilibrated more it undergoes expansion. This explains the positive effect of t on ER.

The response surfaces illustrated the effects of the three operating variables and their interactions on the variation of ER. The negative effect of W is seen in Figure 2 b and d. The positive effects of P and t are observed on all the response surfaces. The interactions W-t (Figure 2: b, f) and P-t (Figure 2: c, g) are very clear. The interaction W-P (Figure 2d) is less important. With the simultaneous increase of operating parameters, the product attained more viscoelastic properties and, on the other hand, more steam was generated at the decompression what conferred better expansion to the product.

The quadratic effect of P appeared at lower values of P (Figure 2: c, d, g) indicating that a steam pressure above 6 bars is required in order to assure sufficient pressure / temperature denivelation to provoke the product's expansion. A pressure lower than 6 bars was not sufficient for expansion.

Finally, maize C seemed to have the same pattern for the expansion ratio after IVDV and roasting with some differences in the order of operating parameters.

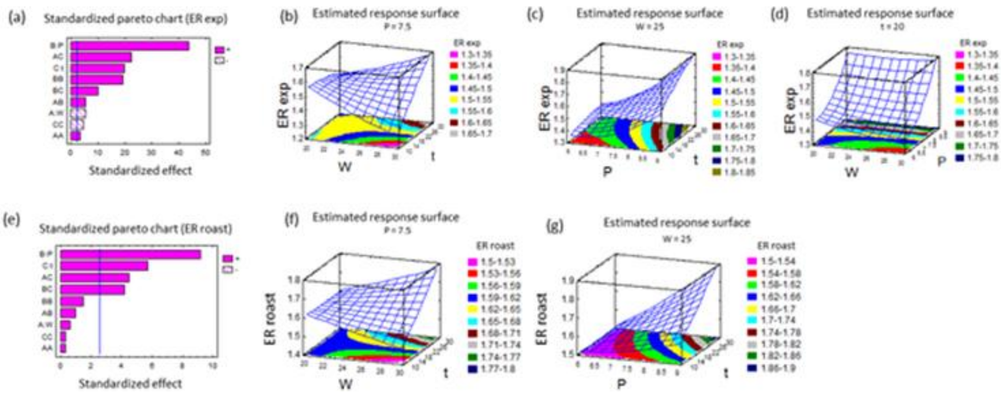

Fig. 2: (a, e) Standardized pareto charts and (b, c, d, f, g) Response surface plots of operating parameters (A = W, B = P and C = t) on the expansion ratio (ER) of Maize C after expansion (exp) and roasting (roast).

Effect of IVDV expansion on TPC, HARD and WD:

In the chosen domain of variation, TPC and WD were not significantly affected by any of the variables neither by their interactions (Figure 3: a, c). HARD was significantly (+) affected only by W (Figure 3b). Hardness increased with the initial water content. In fact, when W increased, a big quantity of generated steam accumulated inside the kernel. The small alveoli merged into bigger pores at the center of the kernel. Upon decompression, the steam exerted an internal pressure in the kernel and escaped while pushing endosperm particles from the center of the kernel to the inner wall of the pericarp. The center of the kernel was emptied while the pericarp became harder. Thus, the resistance of the kernel to the shearing blade, and then, the hardness increased while the crunchiness decreased.

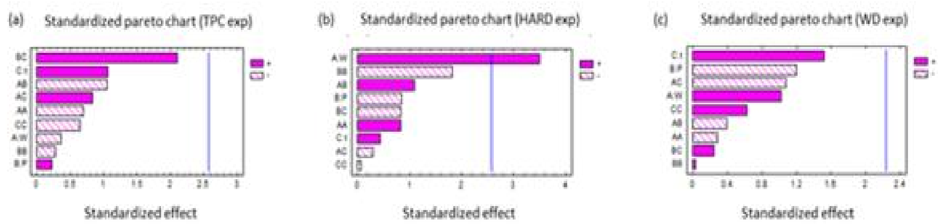

Fig. 3: Standardized pareto charts for total polyphenols content (TPC), hardness (HARD) and work done (WD) of IVDV treated Maize C (exp).

Effect of IVDV expansion on the color of Maize C after roasting:

Figure 4 shows the effect of the IVDV on the color of maize kernels after roasting. The operating parameters had no significant influence on luminance (L*) (Figure 4a). The interaction between W-P negatively influenced a* (Figure 4b). When both variables increased, a* decreased strongly (Figure 4c). W-P also influenced b* in the same way but to less extent (Figure 4f). At lower values of W, an increase in P caused a* and b* to greatly increase (Figure 4: c, f). In fact, water content had a protective role against thermal degradation. At low moisture content, the product was not protected and thus, a pressure increase caused a color development. With the elevation of W, the effect of P changed and the simultaneous increase in W and P caused a decrease in the product redness and yellowness. The interaction W-t had a positive effect on b* (Figure 4e). When both parameters were low or high, a yellowish coloration was developed. When one of the parameters decreased, b* decreased. The interaction P-t had an opposite pattern on b* in comparison to W-t, it had a negative effect (Figure 4: d, g). When one of the parameters (P or t) was high and the other low, b* increased amplifying by that the yellowness.

On the other hand, the quadratic effect of t strongly increased b* and thus the yellow coloration (Figure 4: d, e, g). The prolonged heat treatment causes Maillard products to appear conferring by that a brownish color to the kernels, which is characteristic of roasting.

When observing the different runs visually (see Figure 1), the color didn't seem to greatly differ between them. All were yellowish to brown and had an acceptable roasting color.

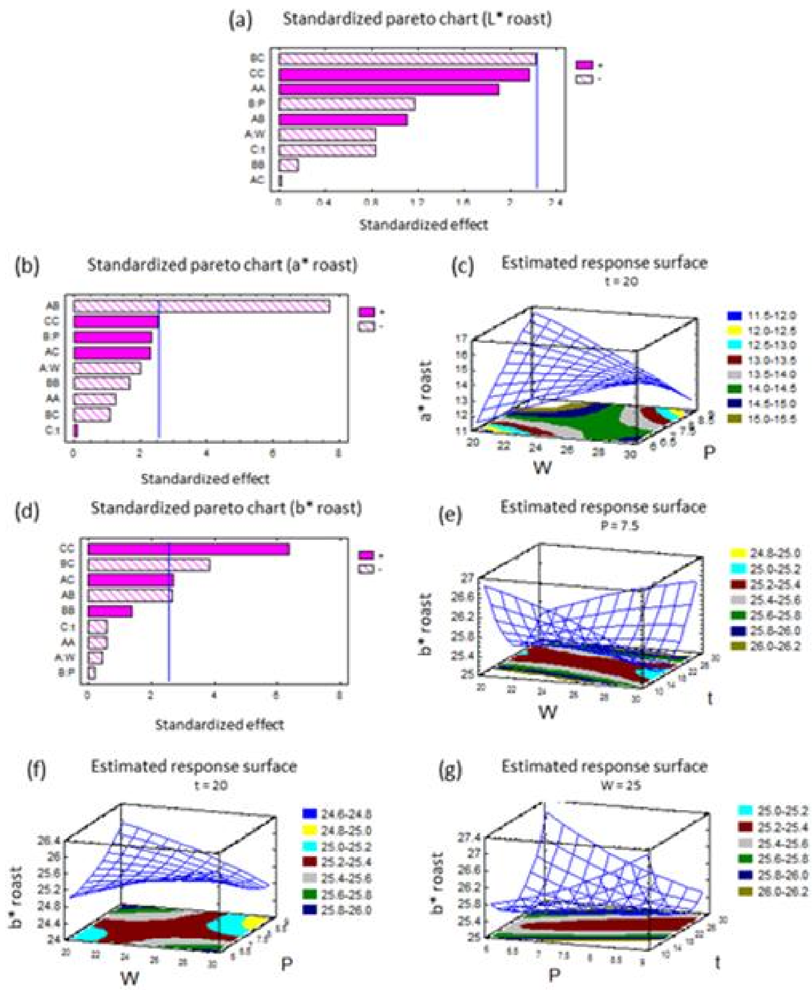

Fig. 4: (a, b, d) Standardized Pareto charts and (c, e, f, g) Response surface plots of operating parameters (A = W, B = P and C = t) on the color (L*, a* and b*) of Maize C after expansion (exp) and roasting (roast).

Conclusion:

High temperature high pressure treatments are considered relatively aggressive when used with heat sensitive biological products. Chemical components such as polyphenols are dramatically damaged by such treatments. Thermal treatments, applied to maize in order to improve their texture, highly alter the chemical composition and color. In this study, IVDV was adopted as a process that can be used in order to confer a new texture to maize kernels while preserving as much as possible the grain integrity and its nutritional potential. For this purpose, we studied the effect of three operating parameters (W, P and t) on texturizing maize kernels and on their polyphenols content and color after roasting. IVDV resulted in well-texturized kernels with more extractable polyphenols. After roasting, kernels were more expanded than un-texturized roasted ones. Their color was not altered. However, it turned to redness more than yellowness. IVDV is found to be a good texturizing process for expansion and texture modification of maize while preserving its polyphenols content. It is an important process that can be potentially applied before further roasting.

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Abbreviations

DIC: Détente Instantanée Contrôlée
ER: Expansion Ratio
HARD: hardness
IVDV : Intensification of Vaporization by Decompression to the Vacuum
P : saturated steam pressure
RSM : Response Surface Methodology
t : processing time
TPC: Total Polyphenols Content
W : initial water content
WD: Work Done
ϴ: temperature
ΔP : difference in pressure
Δϴ : difference in temperature

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