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Edible coating based on modified corn starch/tomato powder: Effect on the quality of dough bread

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A R T I C L E I N F O

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A B S T R A C T

The ascorbic acid modified starch coating solutions were developed based on the Central Compound Rotational Design (CCRD) and the variables were ascorbic acid and tomato powder. The dough was immersed in the coating solution to be analyzed for maximum expansion factor, bread crumb and crust color, specific volume, crumb image and Scanning Electron Microscopy (SEM). The results show that the corn starch with ascorbic also contributed to the expansion of the bread. The crust browning index decreased when the levels of ascorbic acid increase up to 1.6%, correlated with 4.0% of tomato powder; the best specific volume results for the breads samples were run 7 (4.25 cm^3/g) and run 2 (3.84 cm^3/g). In the data obtained, the inclusion of up to 7.5% of tomato powder in the solutions presented a browning index of crumb superior compared with others samples promoting a good quality bread. The use of ascorbic acid in the modification of the starch contributed to the increase of the specific volume of bread. The results were analyzed by second-order multivariate regression analysis and ANOVA with Tukey test at a significance level of 5% ($p \leq 0.05$).

1. Introduction

Edible coating formulas include biopolymers or biomass and various additives, such as plasticizers, antioxidants, and antimicrobial agents (Takala, Salmieri, Vu, & Lacroix, 2011). They enhance the quality of food products by extending shelf-life and preventing physical, chemical, and biological deterioration (Pranoto, Rakshit, & Salokhe, 2005). Further addition of antioxidants and antimicrobial compounds impart microbial barriers and avoid volatile loss, etc. (Lee, Park, Lee, & Choi, 2003). Edible biological components, such as, polysaccharides, proteins and lipids or a mixture of these were successfully used for the preparation of coatings and films (Bertuzzi, Armada, & Gottifredi, 2007).

Modified starches have been used to develop a biodegradable coating for food packaging, because they present better physical, visual, morphological, mechanical and barrier properties when compared to the native starch films (Fonseca et al., 2015).

In the bread industry, several additives are used to improve dough properties, food quality and tolerance processes, in particular the optimization of shelf life (Benejam, Steffolani, & León, 2009). Thus, new alternatives to increase the shelf life of products, while maintaining characteristics similar to those of a freshly prepared product, are of great interest to industries (Saraiva et al., 2016). However, the addition of an edible coating on the dough can increase the positive effects on the gluten network.

Gliadins and glutenins can interact to form a protein network (gluten) in dough making, which provides the essential viscoelastic properties for producing most of the wheat based foods consumed by humans (Lagrain, Goderis, Brijs, & Delcour, 2010). This effect it's important to provide functional properties, which are of industrial importance for food and not-food applications. Wheat gluten is widely used to fortify flours for the improvement of their dough baking properties (Day, Augustin, Batey, & Wrigley, 2006).

The structure and the physicochemical properties of native corn starches of various botanical cultivars are relatively well researched and documented. Modified starches are used in the food industry as food additives that allow the acquisition of desirable texture and functional properties. They are valuable additives to such products, such as sausages, spreads or ready meals (soups, sauces) (Włodarczyk-Stasiak, Mazurek, Jamroz, Hajnos & Sokolowska 2017).

The consumption of tomato and tomato-based products has been associated with a lower risk of developing certain types of cancers, such as digestive tract and prostate cancer, which may be due to lycopene and other components with antioxidant abilities (Tapiero, Townsend, & Tew, 2004). The increasing interest in the antioxidant activity of lycopene (the most abundant carotenoids in tomatoes) and other functional components has promoted the consumption of tomato and

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tomato-based products (Liu, Cao, Wang, & Liao, 2010). In this manner, the inclusion of tomato powder in edible film formulas can improve the nutritional and antioxidant dough capacity.

The objective of this work was to develop and apply an edible coating produced from modified corn starch with ascorbic acid and added tomato powder, as well as to evaluate its effect on the bread dough and quality.

2. Materials and methods

2.1. Tomato powder preparation

Freshly harvested tomato (*Solanum lycopersicum* L.) fruit at the mature-green stage of ripening were purchased from a local market in Fortaleza. The fruits were chosen considering uniformity in color, size, and absence of blemishes, mechanical damages and fungal infection. After washing, the tomatoes were dried (Quimis Corporation, São Paulo, Brazil) in an oven at 45 °C for 24 h. The dried tomatoes were then finely pulverized using an electric grinder and particles smaller than 149 μm were separated by passing through a standard sieve (U.S. No. 100). The tomato powder obtained was used to make the edible coating solution.

2.2. Corn starch modification

Corn starch (100.00 g) was dissolved in 100 mL of distilled water until complete homogenization, containing different concentrations of ascorbic acid P.A through a Central Compound Rotational Design (CCRD), Table 1. The solution was dried at 60 °C for 4 h in the forced air circulation oven.

2.3. Preparation of coating solutions

Coating solutions were prepared according to Choulitoudi et al. (2016). Briefly, Modified Corn Starch (MCS) was dissolved in distilled water (15 g/L) under magnetic stirring at 80 °C. The MCS solution was mixed by magnetic stirring with glycerol 20.2% (v/v). Emulsions were obtained by adding tomato powder in MCS solutions according to CCRD. Homogenization of the emulsions was performed by a high-speed homogenizer (CAT Unidrive 1000, Paso Robles, California) at 200 rpm, for 5 min, at room temperature. The emulsions remained for 15 min at room temperature to exhaust air bubbles formed during homogenization. The amounts of ascorbic acid and tomato powder used in the preparations of each formula were selected according to Table 1.

2.4. Bread preparation

For the control bread, the test baking formula used was: flour (300 g, 14% moisture basis), fat (30 g), refined sugar (15 g), compressed yeast (11 g) and salt (6 g). Yeast was added in the form of suspension. The dough formed after mixing was placed in a baking pan and proofed for 90 min at 28 °C and 75% relative humidity (RH). The dough was molded in dough molder. After molding the mixtures were immersed in the edible coating solutions according to the experimental design, where they remained for 3 min. The excess solution was removed by gravity for 1 min. After immersion, the dough was placed in lightly greased pans and set for final proofing for another 36 min at 28 °C and 75% RH. After final proofing, the bread dough was baked at 220 °C for 20 min. The loaves were removed from the pans and cooled at room temperature. Bread characteristics were tested two hours after the loaves were removed from the oven.

Table 1
Coded and uncoded variables for Central Compound Rotational Design (CCRD).[a]

Formulation	Variables	
	Ascorbic Acid (%)	Tomato Powder (%)
1	1.0 (−1)	5.0 (−1)
2	1.0 (−1)	10.0 (+1)
3	2.0 (+1)	5.0 (−1)
4	2.0 (+1)	10.0 (+1)
5	0.80 (−1.41)	7.5 (0)
6	2.20 (+1.41)	7.5 (0)
7	1.5 (0)	4.0 (−1,41)
8	1.5 (0)	11.0 (+1,41)
9	1.5 (0)	7.5 (0)
10	1.5 (0)	7.5 (0)
11	1.5 (0)	7.5 (0)

[a] Corn starch basis (100%).

2.5. Maximum expansion factor of dough

Maximum Expansion Factor of dough was determined according to Gabric, Ben-Aissa, Le-Bail, Monteau, and Curic (2011), considering dough shape as a truncated ellipsis.

2.6. Bread crumb and crust color

The bread crumb and crust color were determined using the CIELAB parameters (L*, a*, b*). The visual sensations that are sent to the brain create the three dimensions of color judgment response that is often referred to as three-dimensional color space. The crumb color analysis was conducted with the central part of the bread slice with the thickness of 20 mm. Forty measurements were averaged for each formula using the Minolta CR-300 Colorimeter (Osaka, Japan), with a measurement area of 8 mm and geometries d/0°, 10° viewing angle and standard illuminant D65. The browning index (BI) was expressed according to the following equations (Buera, Retriella, & Lozano, 1985; Saricoban & Yilmaz, 2010):

$$BI = 100\,x\,((X - 0.31))/0.172 \quad (1)$$

$$X = (a^* + 1.75L^*) / (5.645L^* + a^* - 3.012b^*) \quad (2)$$

2.7. Bread specific volume

The bread was weighed after cooling and its volume (cm^3) was determined by the rapeseed displacement method. The specific volume (cm^3/g) was calculated as loaf volume/bread weight.

2.8. Bread crumb image analysis

The bread was sliced transversely with a slicing machine. The images were captured using a color camera (NIKON P610, Nikon Inc., Japan) with a resolution of 4272 × 2848 pixels. The camera was located at 20 cm overhead on the sample platform to obtain the best image of the samples of bread slices throughout the experiment. The samples were illuminated with two 36 W fluorescent lights (model: T8 G13, Phillips, Brazil) and enclosed in a black cardboard box with a door (Al-Rahbi, Manickavasagan, Al-Yahyai, Khriji, & Alahakoon, 2013). The inside wall of the box was concealed with black paper to reduce the reflectance, and the roof was covered with white paper to enhance light scattering and reduce the shadow (Al-Ohali, 2011). The sliced bread samples were positioned on a black background to provide higher contrast between the background and the sample. The camera was connected to a computer, which contained remote shooting software Nikon Wireless Mobile Utility (WMU) (version 1.5.0, Nikon INC, Japan) through which the digital images were acquired.

The digital images were made using ImageJ software (National Institute of Health, Bethesda, MD, USA). The image was split into color channels. The contrast was enhanced and, finally, the image was binarized after applying a grey scale threshold. This was performed with the aim of dividing images into regions of cells and surrounding cell wall material. The analysis was performed on a slice area of 15 × 17 mm. Porosity measurements were run in triplicate (Martínez, Román, & Gómez, 2018).

2.9. Scanning Electron Microscopy (SEM)

The surface of dough and bread were observed using a Quanta FEG 450 Scanning Electron Microscope (at a low energy of 10 kV). The samples were deposited on carbon tapes and coated with gold, using vapor deposition techniques. The surface was scanned using magnification between 5.000 and 40.000×.

2.10. Statistical analysis

The CCRD was performed to obtain a second order model to predict the quality of the dough and bread as a result of ascorbic acid and tomato powder addition in the edible coating formulas. This model can be observed in the following equation:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_{11}X^2 + \beta_{22}X^2 + \beta_{12}X_1X_2 + \varepsilon \quad (3)$$

Where y is the predicted response (dough and bread quality variables), β_0 is the global mean, β_1 and β_2 is the linear coefficient, β_{12} is the coefficient of interaction, β_{11} and β_{22} is the quadratic coefficient, ε is the error of the model, and X_1 and X_2 are the coded values of the independent variables, such as, ascorbic acid and tomato powder, respectively.

The experimental data were analyzed using Statistica software, version 8.0 (Statsoft, Inc., Tulsa, OK, USA). Analysis of variance (ANOVA) tables was generated, and the effect and regression coefficients of individual linear, quadratic and interaction terms were determined. The significances of all words were judged statistically according to the p-value, which was set at a 5% significance level. The quality-of-fit of the equation model was expressed by the coefficient of determination (R^2), and its statistical significance was determined using the F-test. For validation of the statistical results, the observed values of bread dough and quality variables were compared with the predicted values obtained by the experimental models. The independent variables optimized were X_1 (Ascorbic Acid), X_2 (Tomato Powder) for dependent response, Y_1 (Maximum Expansion Factor), Y_2 (Specific Volume), Y_3 (Crust Browning Index) and Y4 (Crumb Browning Index). The complete design consisted of 11 combinations performed in standard order (Table 1).

3. Results and discussion

3.1. Quality parameters of dough and bread

The amount of ascorbic acid used in the corn starch modification to the edible coatings and tomato powder levels significantly influenced ($p < 0.05$) the parameters of the quality of the dough and bread (Table 2).

All bread presented specific volumes higher than 3.42 cm^3/g. The solutions with 2.0% or 1.5% of ascorbic acid in the modification of the corn starch correlated to the tomato powder in the concentrations of 4.0% or 5.0%, respectively. This conditions contributed to increase the specific volume of the bread. It is an important parameter to analyze the bread quality involving loaf volume and weight.

The results showed that the acid treatment of corn starch also contributed to the expansion of the bread even though applied as an edible coating, that is, its addition is not necessarily directly in the bread formula. This expansion was verified after the baking, since the influence of the maximum expansion factor was not noticed with the same intensity. The hydration of recipe components such as corn and wheat starch can be seen as one of the driving forces of bread structure formation.

In wheat dough, a late start of starch gelatinization is associated with higher bread volume since a delayed transition from the liquid dough phase to the solid wheat crumb structure was said to allow volume increase for a longer period (Wilderjans, Pareyt, Goesaert, Brijs, & Delcour, 2008). There are four phases in transport processes during bread baking, i.e., solid, liquid water, water vapor and CO_2. Water vapor and CO_2 are the dominant gases in the bread (Fan, Mitchell, & Blanshard, 1999). Transport includes heat transfer, liquid water transport, and water vapor as well as CO_2 transport. Deformation is driven by internal pressure buildup, a result of steam and CO_2 generation and their transport. Mechanical properties of bread change with temperature. In turn, deformation affects transport through changes in characteristic dimension, porosity and sufficient conductivity, etc. Therefore, transport, deformation and their combination form a very complex picture in bread baking (Zhang & Datta, 2006).

The browning index of the crust was higher when compared to that of the crumb. This result was expected since the edible coating was incorporated to the dough surface; however, due to the mass transfer by diffusion, the penetration of part of the solution into internal regions of the dough during the proofing process may result in the browning crumb as evidenced in run 8 (55.63), for example. Thus, formulas of edible films that used amounts greater than 7.5% of tomato powder presented a browning index of crumb superior to the others.

3.2. Influence of edible coating on the dough and bread quality responses

Response surface analysis was performed to study the experimental data. The statistical significance of the model terms was examined with analysis of variance (ANOVA). Lack of fit test (F-values) for all the models were observed insignificant which describe the adequacy of models to predict responses. R^2 values for all the models were more than 0.82 (except for browning index $R^2 = 0.78$) which further validated the adequacy of the model. All the models were statistically adequate and were used for studying the influence of processing variables on the various responses. The result of the regression analysis and analysis of variance (ANOVA) for all the models is reported in Table 3.

3.3. Maximum bread dough expansion factor

The effect of ascorbic acid on starch modification and tomato powder levels on the maximum expansion factor of the dough is shown in Fig. 1a. This indicator increased with a decrease in tomato powder and ascorbic acid levels. An increase in tomato powder level decreased the maximum expansion factor of the dough due to the diluting of gluten. At low tomato powder levels ($< 4.0\%$) there were no significant effects of starch treatment with ascorbic acid in the maximum expansion power of the dough. The results agree with the previous finding in which bread was fortified with barley flour (Al-Attabi, Merghani, Ali, & Rahman, 2017).

The effect of ascorbic acid starch modification level on the maximum expansion factor of dough with higher tomato powder levels was more prominent than with the lower tomato powder levels. With lower tomato powder levels, the maximum expansion factor of bread dough first increased and then decreased, with an increase in ascorbic acid level. With higher tomato powder levels ($> 10.0\%$), the maximum expansion of dough remained almost unchanged up to 2.0% ascorbic acid, but beyond 2.0%, maximum dough expansion increased with an increase in tomato powder. This may be due to the increase of the starch swelling power through ascorbic acid action, as Singh and Adedeji (2017) suggested.

Acid hydrolysis is a chemical modification which is conducted with a controlled addition of acid in an aqueous suspension of starch, at a range from room temperature to a few degrees below gelatinization temperature, for a specified period (Hoover, 2000). Acid hydrolysis can

Table 2
Experimental design for dough and bread quality properties with respective variables (X) and response value (Y).

Run	X_1	X_2	Y_1	Y_2	Y_3	Y_4
1	1.0	5.0	1.56 ± 0.01[a]	4.16 ± 0.02[ab]	35.83 ± 0.83[fg]	23.30 ± 0.32[c]
2	1.0	10.0	1.35 ± 0.01[b]	3.84 ± 0.03[bc]	84.40 ± 0.28[a]	35.96 ± 0.90[b]
3	2.0	5.0	1.43 ± 0.01[ab]	4.26 ± 0.05[a]	51.37 ± 0.78[e]	25.83 ± 0.44[bc]
4	2.0	10.0	1.28 ± 0.01[bc]	3.42 ± 0.01[d]	65.66 ± 0.23[bc]	44.40 ± 0.28[ab]
5	0.80	7.5	1.34 ± 0.01[b]	3.55 ± 0.02[c]	43.65 ± 0.81[f]	12.73 ± 0.12[e]
6	2.20	7.5	1.41 ± 0.02[ab]	4.00 ± 0.06[b]	27.40 ± 0.28[g]	21.69 ± 0.25[d]
7	1.5	4.0	1.50 ± 0.01[a]	4.25 ± 0.05[a]	22.43 ± 0.24 [h]	10.66 ± 0.44[f]
8	1.5	11.0	1.20 ± 0.01[c]	3.25 ± 0.03[e]	72.03 ± 0.18[b]	55.63 ± 0.25[a]
9	1.5	7.5	1.34 ± 0.01[b]	3.95 ± 0.04[b]	50.85 ± 0.88[e]	16.69 ± 0.23[de]
10	1.5	7.5	1.32 ± 0.01[b]	3.96 ± 0.01[b]	54.16 ± 0.47[d]	16.62 ± 0.18[de]
11	1.5	7.5	1.32 ± 0.02[b]	3.97 ± 0.03[b]	52.93 ± 0.64[de]	16.59 ± 0.23[de]

X_1: ascorbic acid level (%); X_2: tomato powder (%); Y_1: maximum expansion factor (cm^3); Y_2: specific volume (cm^3/g); Y_3: crust browning index; Y_4: crumb browning index.
Average of three values with standard deviation, same letter in the line indicates that there is no significant difference between the means by Tukey test ($p < 0.05$).

Table 3
Regression analysis of second order polynomial models for various responses.

Regression coefficient	Maximum Expansion Factor (cm^3)	Browning Index Crumb	Browning Index Crust	Specific Volume (cm^3/g)
Intercept	1.328	52.405	16.539	3.953
X_1	- 0.011*	- 3.276*	2.968*	0.040*
X_2	- 0.096*	16.704*	11.892*	- 0.323*
X_1 X_2	0.015*	- 8.568*	1.475*	- 0.129*
X_1^2	0.035*	- 3.979*	2.133*	- 0.05*
X_2^2	0.023*	1.992*	10.264*	0.064*
ANOVA				
Model (F-value)	858.25	1289.48	12806.47	4504.48
Lack-of-fit (F-value)	0.69	1.93	0.95	1.58
R^2, %	0.8250	0.7837	0.8834	0.8376
c.v.%	7.12	5.85	9.12	8.36

*X_1: ascorbic acid level; X_2: tomato powder level.
Significant at $p < 0.05$.

change the structural and functional properties of starch. This process can intensify subsequent modifications, due to a greater substitution degree in the hydroxyl groups as reported by Klein et al. (2013).

The specific volume of bread decreases as the levels of tomato powder increases in the edible coating formulas (Fig. 1b). The effect of tomato powder levels on the reduction of specific bread volume was more prominent than ascorbic acid levels. This characteristic was intensified with the increase of ascorbic acid levels (> 1.6%), when the tomato powder was added in a maximum amount of 7%.

According to Elbadrawy and Sello (2016) and Acosta-Quezada et al. (2015) the tomatoes present a high content of fibers and minerals, components that have the ability to damage and dilute gluten, damaging the specific volume of bread, as evidenced by Waters, Jacob, Titze, Arendt, and Zanini (2012).

3.4. Browning index of bread crumb

The relationship between the crust browning index of bread, ascorbic acid and tomato powder level is presented in Fig. 1c. The tomato powder showed a greater influence on the crust browning index than ascorbic acid levels. The crust browning index decreases as the levels of ascorbic acid increase up to 1.6%, correlated with 4.0% of tomato powder. At > 1.6% levels of ascorbic acid, there was an increase in the browning index.

It was observed that increasing the amount of ascorbic acid added to the starch provided a modification of its coloration from white to slightly yellow. It may have corroborated to the increase of the browning index of tomato powder, due to the content of carotenoids and other pigments. The tomatoes are distinguished in five cultivar groups based on fruit color and shape: orange, orange pointed, red, red conical and purple, and considerable morphological diversity within each of the cultivar groups was found (Acosta-Quezada, Martínez-Laborde, & Prohens, 2011). The increase of crust browning index of bread can be attributed of the tomato powder presence.

Fig. 2 show the overall shape, crumb and crust structure. In the case of bread treated by run 7 (Fig. 2b), the number of pores was more significant, which demonstrates a less dense crust with rounded alveoli. This behavior can be verified when related to the specific volume obtained by bread produced from run 7 (4.25 cm^3/g) and run 2 (3.84 cm^3/g), according to Fig. 1b. This could be explained by the tomato powder action on the gluten network, promoting cracks, which reduces the carbonic gas holding capacity within the dough and expands the number of pores formed during the mixing step. The number and size of pores in the bread crumb was greatly increased and some of the pores became stacked, giving the dough a disrupted structure.

The morphology of bread crumb product is the result of a series of aeration occurring during the stage of mixing (generation of bubbles and their entrapment within the dough), fermentation (inflation of bubbles) and baking (expansion and breakage (Chiotellis & Campbell, 2003)).

The mechanical energy imparted during mixing induces the damage and formation of both covalent and noncovalent bonds which results in the formation of a viscoelastic gluten network (Belton, 2012). On top of this, mixing also introduces air bubbles into the dough, which serve as nucleation sites during proofing (Peighambardoust, Fallah, Hamer, & Van der Goot, 2010). Carlson and Bohlin (1978) demonstrated that up to 10% of gas gets occluded into the wheat flour dough during its mixing and Jha, Chevallier, Cheio, Rawson, and Le-Bail (2017) found 13% of gas gets occluded.

Cauvain and Young (2006) reported that during first proofing, yeast begins to produce carbon dioxide gas and as a result the porosity of the dough increases. The inclusion of tomato powder in 10.0% and ascorbic acid in 1.5% promotes the formation of nonporous areas at the left side of bread (Fig. 2a), characterized as a high density region. The pore reduction and the appearing of high density areas were caused by damage to the gluten network as can be seen in Fig. 2a, which shows 2D digital image of bread slice treated with the edible coating formula of 1.0% ascorbic acid and 10.0% tomato powder.

3.5. Gluten network integrity analyzed by the SEM

Also, a continuous gluten network characterized by thick gluten strands and the presence of distinct wheat starch granules bound with the protein network was observed (Fig. 3a). However, when the image magnification was high, it was possible to verify the presence of powdered tomato particles bound by glycerol and corn starch and cracks in the gluten network surface (Fig. 3b).

According to Martínez et al. (2018), the specific volume of white

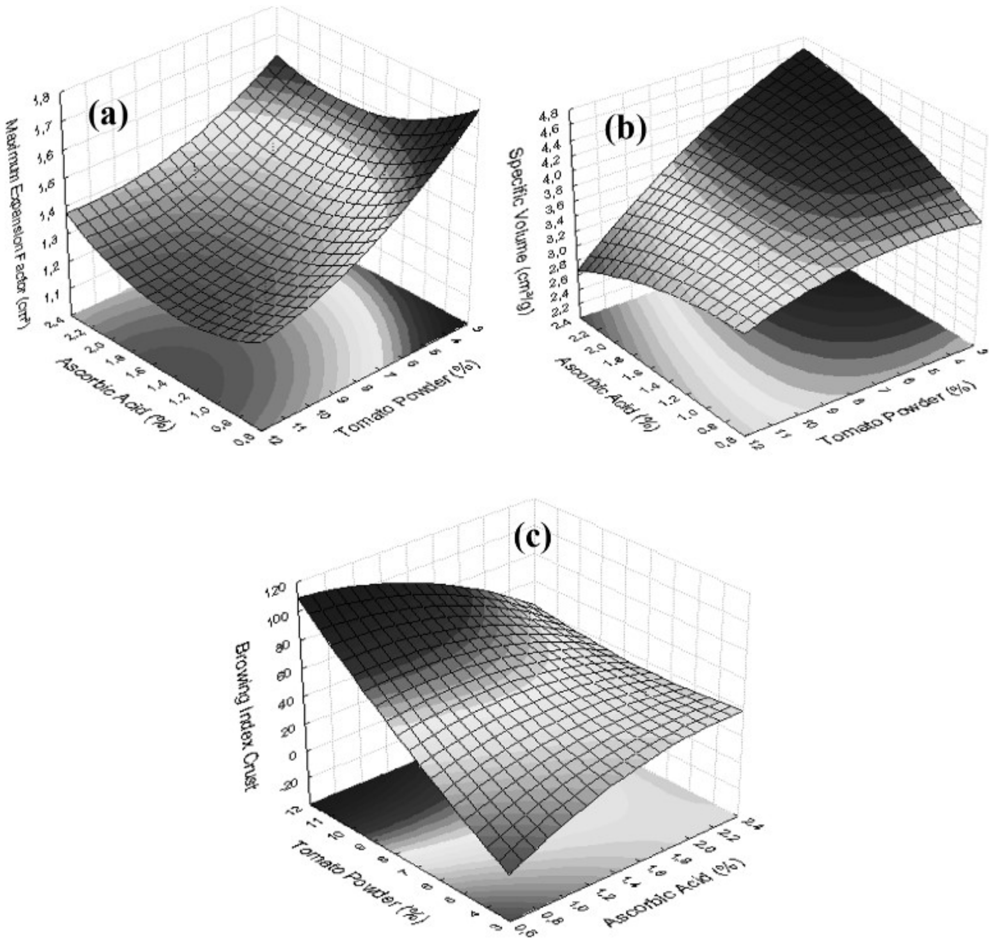

Fig. 1. Effect of ascorbic acid and tomato powder levels on **(a)** maximum expansion factor of dough **(b)** specific volume of bread and **(c)** crust browning index of bread.

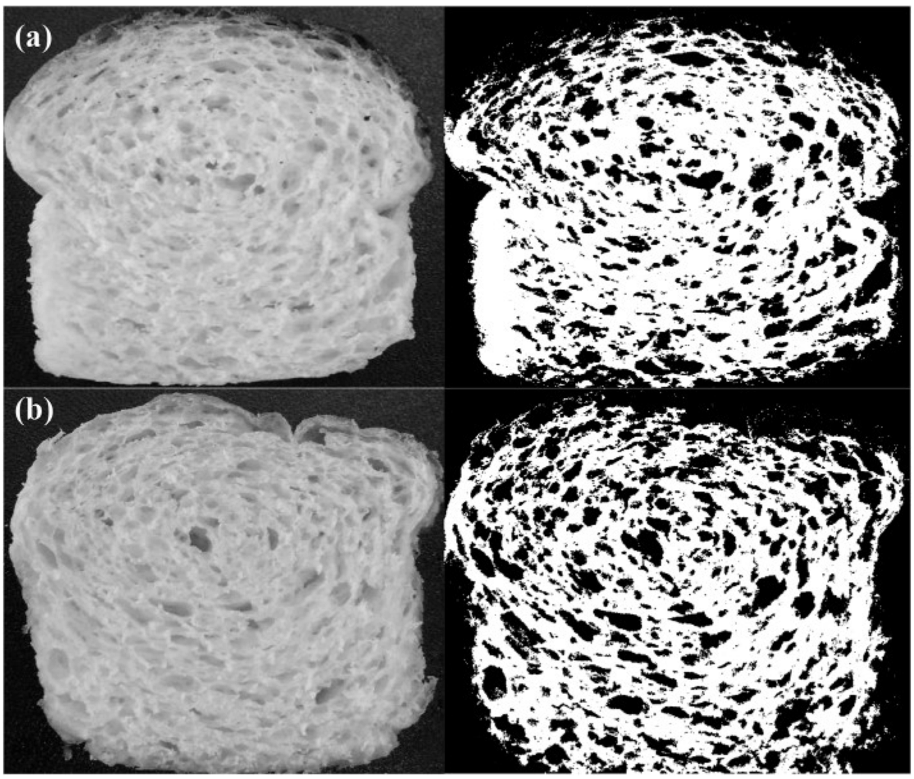

Fig. 2. The 2D images of bread crumb treated by **(a)** run 2–1.0% of ascorbic acid and 10.0% of tomato powder and **(b)** run 7–1.5% of ascorbic acid and 4.0% of tomato powder.

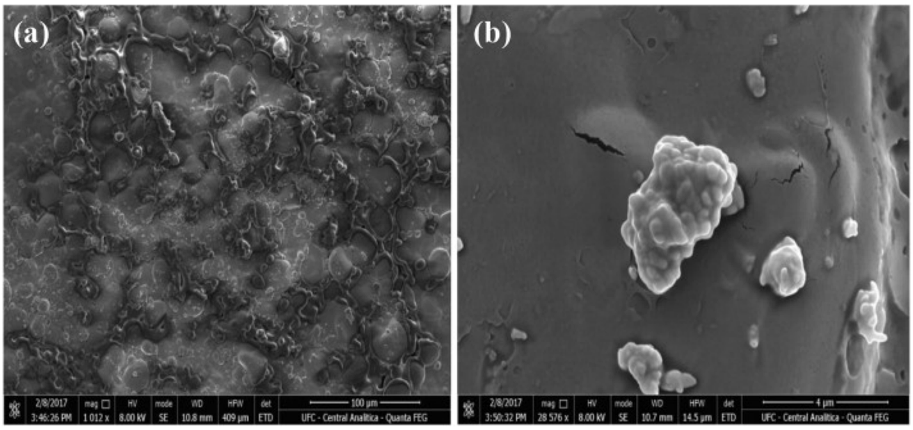

Fig. 3. Scanning Electron Microscopy of bread crumb structure treated with the edible coating run 7 **(a)** magnification 1012× and **(b)** magnification 28576×.

bread was inversely correlated with its hardness. This reciprocal relationship has been reported in previous studies (Gomez, Oliete, Pando, Ronda, & Caballero, 2008) and was attributed to the denser crumb (higher cell density) with more small cells affecting the volume of baking products, caused by gluten microstructure damage.

4. Conclusion

The ascorbic acid and tomato powder in edible coatings formulas contributed to increasing the physical properties of bread and the browning index of crust. The inclusion until of 7.5% of tomato powder in these solutions produces bread of good technical quality. The use of ascorbic acid on the starch modification contributed to the increase in bread specific volume.

Bread crumb structure was affected by the edible coatings formulas. However, with smaller amounts of tomato powder, there was a good distribution of the pores and low density of the breads. The same result was obtained in the presence of damage to the gluten network.

Thus, the use of ascorbic acid in the corn starch modification and tomato powder as edible coating presents extensive application capacity.

Conflicts of interest

The authors declare that they have no conflict of interest regarding this manuscript.

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