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Vacuum enrichment of mango slices with isomaltulose

Enriquecimento de fatias de manga com isomaltulose

Juliana Rodrigues do Carmo[1], Jefferson Luiz Gomes Corrêa[1*], Mariana Resende[2], Marcelo Ângelo Cirillo[4], Javier Telis-Romero[3], Rosinelson da Silva Pena[4]

ABSTRACT

Vacuum is efficient for incorporating solutes of interest into fruits. In this study, the low glycemic and insulinemic index carbohydrate, isomaltulose, was incorporated into mangos slices by immersion with a vacuum pulse (VP). The influences of the combination of pulsed vacuum time at the beginning of the process (5, 10, 15, and 20 min) and vacuum pressure (24 kPa and 48 kPa, absolute pressure) in the incorporation were evaluated with the multidimensional scaling (MDS) statistical technique. Water loss (WL), solid gain (SG), water activity (a_w), and color were also studied. The MDS effectively indicated that the vacuum incorporation (VI) with 10 min of VP at 48 kPa provided a product with higher SG (more enriched), WL, lightness, and lower a_w and total color difference. Thus, the VI with intermediate conditions resulted in a high incorporated mango with good quality.

Index terms: Tommy atkins; PVOD; palatinose.

RESUMO

O vácuo é eficiente para incorporar solutos de interesse às frutas. Neste estudo, o carboidrato de baixo índice glicêmico e insulinêmico, isomaltulose, foi incorporado em fatias de manga por imersão com pulso de vácuo (VP). As influências da combinação do tempo de pulso de vácuo no início do processo (5; 10; 15 e 20 min) e pressão de vácuo (24 kPa e 48 kPa, pressão absoluta) na incorporação, foram avaliadas com a técnica estatística de escalonamento multidimensional (MDS). A MDS foi eficaz em indicar que a incorporação com 10 min de pulso de vácuo a 48 kPa proporcionou um produto com maior SG (mais enriquecido), maior WL e luminosidade; e menor a_w e diferença total de cor. Assim, VI em condições intermediárias resultou em uma manga com alta incorporação e boa qualidade.

Termos para indexação: Tommy atkins; PVOD; palatinose.

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[1]Universidade Federal de Lavras/UFLA, Departamento de Ciência dos Alimentos/DCA, Lavras, MG, Brasil
[2]Universidade Federal de Lavras/UFLA, Departamento de Estatística/DES, Lavras, MG, Brasil
[3]Universidade Estadual Paulista Júlio de Mesquita/UNESP, Departamento de Engenharia e Tecnologia de Alimentos, São José do Rio Preto, SP, Brasil
[4]Universidade Federal do Pará/UFPA, Faculdade de Engenharia de Alimentos, Belém, PA, Brasil

Corresponding author: jefferson@ufla.br

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Introduction

Isomaltulose, commercially known as Palatinose®, is a low glycemic and insulinemic index carbohydrate (Shyam, Ramadas, & Chang, 2018). It is slowly digested by α-glucosidase in the small intestine, controlling the postprandial glucose profile in humans (Maeda, Miyagawa, & Miuchi, 2013). Due to these characteristics, isomaltulose is suggested to be used in diets for athletes and diabetics (Lazaridou, Kotsiou, & Biliaderis, 2022; Onuma et al., 2023).

Mango is an important fruit in the human diet. It is a source of macronutrients (carbohydrates, proteins, lipids, and organic acids), micronutrients (vitamins and minerals), and non-nutrient compounds (flavonoids, phenolic compounds, carotenoids, chlorophyll, and volatile compounds) (Lebaka et al., 2021).

The immersion of a food in a hypertonic solution is known as osmotic dehydration. In such a process, soluble solids come from the solution to the food, whereas moisture content is partially removed from the food to the solution (Abraão & Corrêa, 2023, Lopes et al., 2024). The use of a vacuum in the osmotic process usually increases the interchanges between the solution and matrix food (Junqueira et al., 2021; Macedo et al., 2022). It is indicated for the enrichment of foods with functional ingredients in the pores of the product, such as texture-retaining agents, antioxidants, and antimicrobials, which increase their quality and shelf life. In this context, the enrichment of foods with healthier carbohydrates, such as isomaltulose, has been investigated (Carmo et al., 2022a; Macedo et al., 2021; Shyam, Ramadas, & Chang, 2018).

Multidimensional scaling (MDS) is a tool for evaluating the similarity between groups of variables. It can reduce the complexity of a dataset, allowing visualization of the underlying relational structures. When similarity estimates are subjected to MDS analysis, plots of the relationships between a set of variables are generated. This plot reduces the complexity intrinsic to a large table of closeness. The major purpose of MDS analysis is to disclose the relational structures between the variables evaluated.

This work aimed to evaluate the influence of the combination of different time (5, 10, 15, and 20 min) and pressure (24 kPa and 48 kPa, absolute pressure) conditions on the vacuum enrichment of mangos with isomaltulose, as well as other process variables like water loss (WL), solid gain (SG), water activity, and color of the product through the use of the MDS statistical technique.

Material and Methods

Material, sample, and solution preparation

Mango fruits (Tommy Atkins cultivar) were obtained in a local market (Lavras, Minas Gerais state, Brazil). The fruit selection was based on the degree of ripeness (half-ripe) and presented the following characteristics: peel color of 50% red and 50% green, firmness of 47.50 ± 5.55 N, moisture content on a wet basis (w.b.) of 85.14 ± 0.55%, pH of 3.60 ± 0.04, °brix of 12.3 ± 0.6, total acidity (citric acid) of 2.86 ± 0.21 %, and brix/acid ratio of 4.72 ± 0.16.

The mango fruits were sanitized with chlorinated water at 200 mg/L for 5 min. Then, the fruits were peeled, and the samples were obtained in a rectangular format (4.00 ± 0.01 cm in length, 2.00 ± 0.01 cm in width) with 0.40 ± 0.01 cm in thickness with the assistance of a stainless-steel molder. The fresh mango presented the following color parameters: L^* = 77.58 ± 0.96, a^* =-5.15 ± 0.41, b^* = 56.16 ± 7.35, C^* = 56.41 ± 7.28 and h° = 95.35 ± 1.20.

The 35% (w/w) osmotic solution was prepared with isomaltulose (Palatinose®) (Beneo, Mannheim, Germany) and distilled water. The isomaltulose solution presented water activity (a_w) of 0.972 (± 0.001) and viscosity of 2.405 (± 0.024) mPa·s at 45 °C (Carmo et al., 2022b).

Vacuum impregnation (VI)

The VI of the mango slices was performed in a temperature-controlled oven (Solab SL104/40, Piracicaba, Brazil) coupled to a vacuum pump (model DV95, Dosivac, Buenos Aires, Argentina). The mango slices were immersed in glass bottles containing the osmotic solution at a ratio of 1:10 (w/v) at 45 °C for 300 min. Such conditions were previously determined (Carmo et al., 2022a). Different periods of vacuum application at the beginning of the process were assessed (5, 10, 15, and 20 min) and two absolute pressures (24±1 kPa and 48±1 kPa) according to Table 1. After the vacuum application, the atmospheric pressure was resumed (997 hPa). Five samples were subjected to each process condition and analyzed.

Table 1: Vacuum incorporation conditions.

Code	Vacuum pulse	
	Time (min)	Absolute pressure (kPa)
t5P24	5	24
t10P24	10	24
t15P24	15	24
t20P24	20	24
t5P48	5	48
t10P48	10	48
t15P48	15	48
t20P48	20	48

The mass transfer parameters (WL and SG) of each sample subjected to the different VI conditions were calculated by Equation 1 and Equation 2 (Souza et al., 2023). The moisture content of the fresh and osmodehydrated samples was determined according to the Association of Official Analytical Chemists (AOAC, 2023).

$$WL(\%) = \frac{x_0^w M_0^o - x_t^w M_t^o}{M_0^o} \times 100 \quad (1)$$

$$SG(\%) = \frac{x_t^{ST} M_t^o - x_0^{ST} M_0^o}{M_0^o} \times 100 \quad (2)$$

where WL is the water loss (%), SG is the solid gain (%), x_0^w is the initial moisture content on w.b. (kg of water kg^{-1} of fruit), x_t^w is the final moisture content on w.b. (kg of water kg^{-1} of fruit), M_0^o is initial sample weight (kg), M_t^o is final sample weight (kg), x_t^{ST} is final solids content (kg solids kg^{-1} fruit), and x_0^{ST} is initial solids content (kg solids kg^{-1} fruit).

Sample analysis

The following analyses were performed in the fresh and processed samples:

Water activity (a_w)

The a_w of the samples was determined in a digital thermohygrometer (AquaLab 3TE, Decagon, USA) at 25 °C.

Color evaluation

The instrumental color was performed in a digital colorimeter (Konica-Minolta, CR 400, Tokyo, Japan). The operating conditions of the equipment were a D65 light source and diffuse light/viewing angle of 2° (specular component included). The lightness (L^* = 0 indicates black and L^* = 100 indicates white) and the chromaticity coordinates (negative a^* indicates green and positive a^* indicates red, and negative b^* indicates blue and positive b^* indicates yellow) were used to calculate the chroma value (C^*) (C^*= 0 indicates the neutral color and C^*= 60 indicates intense color) (Equation 3), and the hue angle (h°) (0° and 360° = red, 90° = yellow, 180° = green and 270° = blue) (Equation 4) (McLellan, Lind, & Kime, 1995). Equation 5 was used to calculate the total color difference (ΔE) of the osmodehydrated samples relative to the fresh fruit.

$$C^* = \sqrt{\left(a^*\right)^2 + \left(b^*\right)^2} \quad (3)$$

$$h° = \cos^{-1} \frac{a^*}{\sqrt{\left(a^*\right)^2 + \left(b^*\right)^2}} \quad (4)$$

$$\Delta E = \sqrt{\left(L_0^* - L_t^*\right)^2 + \left(a_0^* - a_t^*\right)^2 + \left(b_0^* - b_t^*\right)^2} \quad (5)$$

where subindexes "0" and "t" indicate the fresh and vacuum-incorporated samples, respectively.

Statistical analysis

The statistical analysis was performed by transforming the data (Equation 6), limiting the responses to a continuous scale from 0 to 1. It made possible the interpretation as indexes, represented by x_{ij}, since the variables under study had different scales.

$$x_{ij} = \frac{x_i - \text{minimum } (x._j)}{\text{maximum } (x._j) - \text{minimum } (x._j)} \quad (6)$$

The similarity between the VI treatments was determined by the MDS technique, which obtained the coordinate vectors represented by $x_{ij} = (x_{i1}, \ldots x_{iq})$, given the Euclidean distance matrix $D = [d_{ij}]$ of order n x n formed from the dataset for all variables. Each element of this matrix was calculated using the Euclidean distance, which is defined by $d_{ij}^2 = \left\| x_i - x_{ir} \right\|^2 r$ for i ≠ i', with i = 1,…, n, where n is the number of treatments. The variables represented in each axis are independent; therefore, it is a favorable case to determine the similarity between the treatments defined by the combination of vacuum pulse pressure and time; that is, they are variables considered as if they were a factor and not as a response variable. Subsequently, the correlated variables were excluded, and a new dissimilarity matrix ($\Delta = [\delta_{ii'}]$) was adjusted to consider a smaller number of variables. Thus, considering the closeness of each element, i.e., $d_{ii'} \approx \delta_{ii'}$, the stress function configuration was used as a validation criterion (De Leeuw, 1988). The nonmetric MDS explored by Jaworska and Anastasova (2009) and based on this algorithm considers the selection of a monotonic function to represent the relationship between δ_{ij} and d_{ij} distances, which was applied. The algorithm used to minimize the stress function was studied (Kruskal, 1964) and better detailed by Cirillo and Barroso (2014).

It must be emphasized that the MDS technique was treated in the absence of any model, according to Cox and Cox (2008). Those authors suggest that the transformation of dissimilarity based on spline regression makes the model very complicated, computationally and in terms of inference. Therefore, it has been assumed that the transformation on a 0–1 scale and performed the MDS, in essence, treating it as a dimension reduction method, considering the dissimilarity matrix of the response variables. Here, it should be noted that the objective is to determine the combination of the response variables, eliminating redundant information (highly correlated variables).

Borg and Groenen (2005) highlight the use of MDS as a technique that tests in what way certain criteria an individual can differentiate objects of interest considering a certain metric. Contextualizing this statement for this work, and as a result of each response variable presenting different magnitudes, the use of the technique is adequate.

To validate the results, the biplot technique was used to study the similarity between the treatment groups, considering a multivariate approach, using the BiplotGUI package of the software R (version 4.1.0, R Core Team).

One-way analysis of variance (ANOVA) was also employed by Statistica v.10.0 (StatSoft, Inc., Tulsa, USA) to determine whether the differences in the means were significant. Tukey's test at a 95% confidence interval has been chosen. The test of means to treatments, ± 1 standard error, was used precisely to complement the results obtained in the MDS. At this point, this inference considered only the variables selected in the MDS.

Results and Discussion

Vacuum incorporation (VI)

Table 2 and Table 3 show the results for the mass transfer (WL and SG) and physical properties (a_w and color parameters – L^*, a^*, b^*, C^*, h°, and ΔE) of the vacuum enriched mango slices. The results for WL variated from 41.97% (t20P24) to 50.28% (t15P48), and the treatments with higher vacuum pulse (24 kPa, absolute pressure) presented lower WL ($p \leq 0.05$). Regarding SG, the achieved enrichment variated from 7.06% (t5P48) to 9.54% (t20P24), but the values did not differ statistically ($p > 0.05$). According to the literature (Oliveira et al., 2021), the use of prolonged time and high vacuum levels is not recommended in osmotic dehydration because they could lead to cell collapse, causing irreversible deformation of the fruit tissue and leading to a reduction in porosity and a decrease in the free volume available for impregnation. In addition, the application of long vacuum time (> 15 min) leads to softening of the samples (Corrêa et al., 2010). Thus, the tissue structure can collapse, physically hampering the entry of solids into the fruit. This behavior is observed in Table 2, where the treatments with the highest WL show the lowest SG.

The a_w for the samples at 48 kPa did not differ statistically from those at 24 kPa ($p > 0.05$) (Table 2). High a_w (> 0.9) was observed in all samples obtained in the experimental domain. Lower a_w values are desirable for restricting biochemical and microbial changes, thus preserving the quality of fruits and vegetables (Khubber et al., 2020).

Table 2: Water loss (WL), solids gain (SG), and water activity (a_w) of mango slices submitted to different conditions of vacuum incorporation.

Treatment	WL (%)	SG (%)	a_w
t5P24	47.59±3.44^{ab}	8.51±1.26^{a}	0.954±0.001^{a}
t10P24	43.52±1.67^{ab}	9.26±0.33^{a}	0.954±0.004^{a}
t15P24	46.86±2.50^{ab}	7.68±1.07^{a}	0.959±0.001^{a}
t20P24	41.97±1.80^{b}	9.54±0.97^{a}	0.960±0.001^{a}
t5P48	49.31±0.52^{ab}	7.06±0.70^{a}	0.952±0.008^{a}
t10P48	48.30±1.32^{ab}	9.35±0.48^{a}	0.948±0.001^{a}
t15P48	50.28±0.31^{a}	7.35±0.65^{a}	0.947±0.001^{a}
t20P48	48.38±0.04^{ab}	7.35±1.46^{a}	0.945±0.004^{a}

The number after the letter t in the treatment corresponds to the vacuum pulse time (min), and the number after the letter P means pressures (kPa). Mean values of five replications ± standard deviation. Values with different uppercase letters in the same column differ statistically ($p \leq 0.05$) according to Tukey's test.

The color parameters (Table 3) indicated that the vacuum-enriched mangos show a strong tendency to yellow (positive b*) – typical of this fruit, and a slight tendency to green (negative a*). The C* values showed that the product had a saturated color. The hue values (h°) close to 90° confirmed the yellow color of the product. In general, the L* values showed that the samples treated at 24 kPa were darker than those treated at 48 kPa ($p \leq 0.05$). This behavior may be associated with the rupture of the cell structure at high vacuum levels, enabling the formation of the enzyme-substrate complex and thus favoring enzymatic browning (Tonolli, Franco, & Silva, 2021).

Regarding the ΔE values, the samples with higher quality were those whose colors were closer to the original color of the fresh sample; therefore, low total color difference values are desired. In the treatments at 48 kPa vacuum, the ΔE value was lower than that at 24 kPa ($p \leq 0.05$). The former treatment condition leads to a smaller difference from the color of the fresh sample.

Multidimensional scaling (MDS)

Figure 1 contains the following variables: WL, SG, a_w, and the color parameters L*, a*, b*, C*, h°, and ΔE, where the treatments were grouped in regions delimited by the variables under study. The t15P24 treatment was distinct from the others. It represents the use of a vacuum pulse in the first 15 min within an absolute pressure of 24 kPa. Such treatment did not differ concerning the following variables: a* chromaticity coordinate (-0.4 and -0.5) and SG (0.08). This indicates that the higher the SG, the lower the a* chromaticity coordinate.

The t5P48, t10P48, and t15P48 treatments were indistinguishable in terms of h° (0.004 and 0.006) and a* chromaticity coordinate (-0.2 and -0.3). The similar values for these samples indicate that a vacuum pulse pressure of 48 kPa is well accepted, regardless of the time used. This suggests that the vacuum pulse pressure more significantly reduces the a* chromaticity coordinate.

The t5P24, t10P24, t20P24, and t20P48 treatments produce data points grouped based on the values of the variables SG (0.06 and 0.08), h° (0 and 0.004) and a* chromaticity coordinate (0 and -0.1). This indicates that although the vacuum pulse pressure of 24 kPa improved the SG and h°, it decreased the a* chromaticity coordinate.

The similarity of the treatments is determined by considering all experimental variables. Figure 1 shows that the variables C* and b*, SG and L*, and WL, a_w, and ΔE strongly correlate. This means that the homogeneity of these treatments should also be assessed to consider only the independent variables. The results of this evaluation are shown in Figure 2.

Table 3: Lightness (L*), chromaticity coordinates (a* and b*), chroma (C*), hue angle (h°), and total color difference (ΔE) of mangos submitted to different conditions of vacuum incorporation.

Treat.	L*	a*	b*	C*	h°	ΔE
t5P24	66.99±1.48^{ab}	-2.04±0.18^{ab}	50.28±3.25^{b}	50.16±3.03^{ab}	92.30±0.28^{ab}	11.58±2.57^{ab}
t10P24	64.20±3.70^{b}	-1.97±0.01^{ab}	47.58±3.13^{b}	47.61±3.12^{b}	92.35±0.21^{ab}	15.13±4.72^{a}
t15P24	67.58±0.97^{ab}	-0.93±0.40^{a}	54.44±1.67^{ab}	54.44±1.67^{ab}	90.85±0.35^{b}	10.20±0.9^{ab}
t20P24	67.81±1.65^{ab}	-2.28±0.04^{ab}	52.23±3.89^{ab}	52.16±3.00^{ab}	92.60±0.42^{ab}	10.47±0.65^{ab}
t5P48	74.79±1.29^{a}	-3.68±1.16^{b}	55.23±0.14^{ab}	55.35±0.06^{ab}	93.75±1.20^{a}	3.33±1.55^{b}
t10P48	74.02±2.01^{a}	-2.13±0.50^{ab}	59.52±0.35^{a}	59.56±0.33^{a}	92.00±0.42^{ab}	5.82±1.69^{b}
t15P48	74.06±3.86^{a}	-1.61±0.42^{a}	55.62±0.23^{ab}	55.64±0.24^{ab}	91.60±0.42^{b}	5.37±2.83^{b}
t20P48	76.01±1.52^{a}	-3.88±0.04^{b}	54.49±0.29^{ab}	54.62±0.29^{ab}	94.00±0.14^{a}	2.77±0.68^{b}

The number after the letter t in the treatment corresponds to the vacuum pulse time (min), and the number after the letter P means pressures (kPa). Mean values of five replications ± standard deviation. Values with different uppercase letters in the same column differ statistically ($p \leq 0.05$) according to Tukey's test.

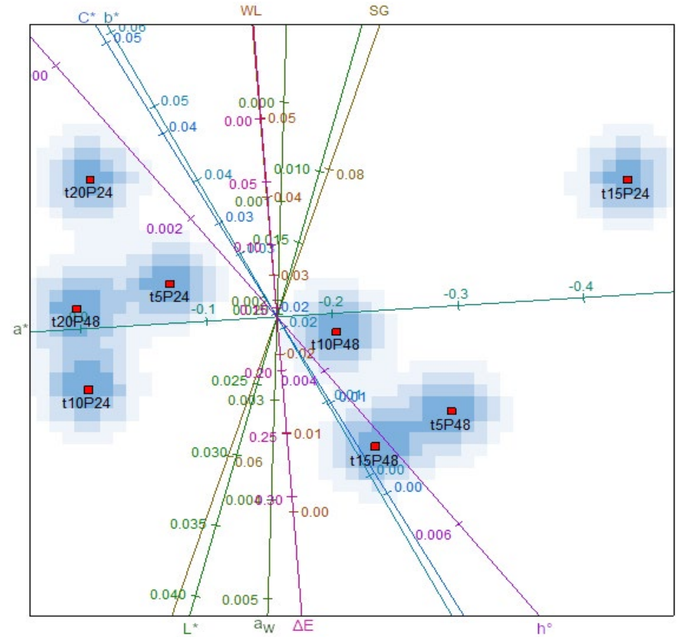

Figure 1: Biplots considering all variables in the vacuum incorporation treatments: water loss (WL), solid gain (SG), water activity (a_w), and the color parameters that indicate lightness (L^*), chromaticity coordinates for green–red (a^*) and blue–yellow (b^*), chroma (C^*), hue angle (h°), and total color difference (ΔE). The vacuum pulse times are 5, 10, 15, and 20 min, and the vacuum pulse pressures are 24 kPa and 48 kPa.

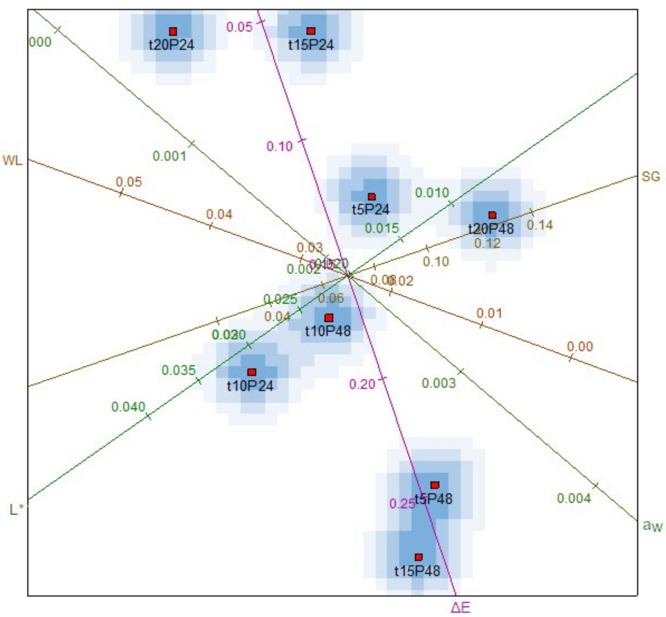

Figure 2: Biplots considering the independent variables: water loss (WL), solid gain (SG), water activity (a_w), color parameter indicating lightness (L*), and total color difference (ΔE). The vacuum pulse times are 5, 10, 15, and 20 min, and the vacuum pulse pressures are 24 kPa and 48 kPa.

Concerning the validity of ordering the treatments in different sets, a loss of information can occur when evaluating data based on all variables versus excluding correlated variables. The variable reduction is appropriate in this case, as the graph of the stress function (Figure 3) showed values closest to zero. Therefore, this fact reveals that the statistical grouping determined by the independent variables is validated, without loss of information, for all variables, as shown the Figure 2.

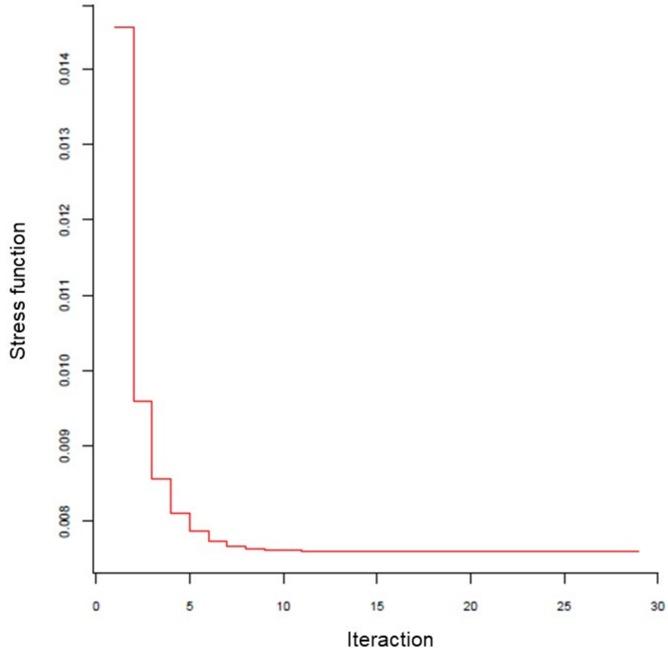

Figure 3: The plot of the stress function with only independent variables (water loss – WL, solid gain – SG, water activity – a_w, color parameter indicating lightness – L*, and total color difference – ΔE) from the vacuum incorporation data.

As a confirmation of the interpretations made previously, it is possible to observe that Figure 2 shows a trend toward clustering of the data points for t5P48 and t15P48 concerning ΔE and for t15P24 and t20P24 concerning ΔE, a_w, and L^*, considering that the variables a^*, h°, C^*, and b^* are excluded because ΔE implicitly represents them. This result shows the tendency of the variables to be grouped by the vacuum pulse pressure value. The t10P48 and t10P24 treatments showed great similarity in relation mainly to the variable ΔE (0.20 and 0.15) and similarity concerning the variable L^* (0.020 and 0.035).

Besides the larger SG, having higher WL and L^* and lower a_w and ΔE is interesting. According to Figure 2, the t20P24 treatment presented the lowest values for the variables ΔE and a_w; the t20P48 treatment for L^* and WL; and the t10P24 treatment for SG. On the other hand, higher values of ΔE and a_w were obtained for the t15P48 treatment, SG for the t20P48 treatment, L^* for the t10P24 treatment, and WL for the t20P24 treatment. So, in this study, to obtain the best values for the studied variables, intermediate values of time (10 and 15 min) and lower vacuum pulse pressure (48 kPa) are required.

The most appropriate treatment indicated for practical purposes is the t10P48 treatment, representing a vacuum pulse time of 10 min and a vacuum pulse pressure of 48 kPa. It is in terms of the studied variables considered in the selection; that is, this treatment presented the best values concerning the set of variables. The variables in question (Figure 2) showed intermediate values in treatment t10P48 since they are closer to the center of the graph. In contrast, other treatments show very high or low values for some variables. Selecting the treatment with intermediate values is more interesting because this treatment would not show losses in any of the variables under study. This is because the present study aimed to determine a VI that would provide a final product with a higher incorporation of solids (higher SG), higher WL, lower a_w, higher L^*, and lower ΔE, as discussed in the VI section. Thus, through the MDS analysis, it was possible to choose the treatment that spatially (center of the graph) satisfied this condition.

Conclusions

Although prolonged vacuum time and lower pressure seem to result in higher solute incorporation, an intermediate situation could even offer this scenario. The evaluation by the MDS technique indicated that 48 kPa pressure in the firs 10 min promoted great enrichment with high WL and lightness and lower a_w and ΔE. There was no significant difference for most of the studied parameters for 10 or 15 min and at 24 or 48 kPa, except for WL and ΔE.

Author Contribution

Conceptual idea: Corrêa, J. L. G.; Carmo, J. R. C. do, Methodology design: Cirillio, M. A.; Resende, M., Data analysis and interpretation: Corrêa, J. L. G.; Carmo, J. R. C. do.; Telis-Romero, J.; Rosinelson da Silva Pena, R. da. S., Writing and editing: Carmo, J. R.; Corrêa, J. L. G.

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