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Mango enriched with sucrose and isomaltulose (Palatinose®) by osmotic dehydration: Effect of temperature and solute concentration through the application of multilevel statistical models

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Abstract

Osmotic dehydration (OD) is useful for the enrichment of mangos with interesting solutes. Isomaltulose has healthier properties than sucrose and its use is still scarce in OD processes. The OD of mangos with isomaltulose and sucrose was evaluated, and the effect of solute concentrations (25%, 30%, 35%) and temperatures (25, 35, 45°C) was estimated by multilevel statistical analysis in order to find the best conditions for a greater water loss (WL) and solid gain (SG). In sucrose OD, the highest concentration (35%) had the greatest effect than the temperature for WL and SG. For isomaltulose OD, the concentration provided greater WL and SG, but the effect of temperature was slightly more expressive for SG than WL. The maximum working conditions (35% of isomaltulose or sucrose and 45°C) promoted greater WL and SG for both carbohydrates, and with the OD it was possible to enrich mango with isomaltulose by taking advantage of the osmotic gradient, getting an osmodehydrated product with low glycemic and isulinemic indexes.

Novelty impact statement: Through the osmotic dehydration, it is possible to enrich mango samples with isomaltulose due to its healthy attributes. Instead, a traditional statistical analysis, the multilevel statistical modeling was applied, which was suitable for evidence that the highest solute concentration and temperature conditions promoted the greatest water loss and solid gain, favoring the enrichment process.

1 | INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most popular tropical fruits. It is a source of fiber, phenolic compounds and vitamins, such as C and pro-vitamin A (betacarotene), and minerals such as calcium, phosphorus, and iron (Lebaka et al., 2021). Despite its considerable nutritional value, mango is an extremely perishable fruit, which needs specific care for its conservation (Kumar & Sagar, 2014). One of the main strategies is the use of appropriate dehydration techniques to obtain a microbiologically stable product with decreasing physicochemical and sensory quality reduction (Mello et al., 2020).

Osmotic dehydration (OD) consists of immersing the food in a hypertonic solution, with consequent water loss (WL) and solid gain (SG) in simultaneous isothermal flows without any phase change. In OD, three types of counter-current mass transfer occur: (i) water flows from the product to the solution, (ii) a solute transfer from the solution to the product and (iii) leaching out of the native solutes (sugars, organic acids, minerals, vitamins, etc.). The OD process offers the possibility of modifying food properties, especially in relation to taste and structural characteristics (Abrahão & Corrêa, 2021).

Sucrose is the most common solute used in osmotic solutions (Fernandes et al., 2019). Its advantages are its low-cost and availability. However, it is considered a highly cariogenic sugar. This carbohydrate is rapidly digested, inducing a high glycemic and insulinemic responses. One way around these disadvantages is to replace sucrose with other carbohydrates that do not induce glycemic and insulinemic peaks and are slowly digested by the body (Mendonça et al., 2016).

Isomaltulose, commercially known as Palatinose®, is naturally present in honey and sugarcane juice. Although isomaltulose has a half of the sweet taste and similar caloric value of sucrose (~4 kcal/g), it can be considered a healthy, since it is a non-cariogenic carbohydrate and presents low glycemic and insulinemic indexes (Sawale et al., 2017). Due to it, this disaccharide is becoming increasingly used by sportsmen and disease people, such as diabetic, obese and heart diseases (Maeda et al., 2013). In this regard, isomaltulose could be added in fruits and vegetables by OD for enriching and obtaining a healthy product, as has been recently studied (Lopez et al., 2020; Macedo et al., 2021).

Apart from the proven influence of the type of solute and its concentration in OD processes, the temperature is another relevant factor (Jiménez et al., 2020). These factors can interfere with OD efficiency (ratio WL/SG). High efficiency can favor dehydrating processes in the fruit, whereas lower efficiency favors the process of enriching the fruit (Kvapil et al., 2021). Therefore, to evaluate the best dehydration or enrichment condition, strategic statistical methods must be used, such as those that work with observations nested in groups, that is, they can evaluate the simultaneous effect of individual characteristics as collective characteristics and their interactions on a response of the osmotic dehydration, that is, studying the role played by OD process factors (solute concentration and temperature) and their influence on dehydration or enrichment (WL or SG) of samples subjected to different osmotic solutions and tend to have a hierarchical or nested structure.

Multilevel modeling is a generalization of regression methods, and can be used for several purposes, as prediction, data reduction, and causal inference from experiments and observational studies. It can be essential for prediction multilevel modeling, useful for data reduction and helpful for causal inference (Gelman, 2006). An advantage of using the multilevel methodology is attributing random effects to other elements of the model, not only to the experimental error as occurs in traditional analysis. Another advantage is that it is possible to answer questions focusing on random effects, which are limited to other tests. Studies about that have been applied the multilevel statistical models on OD processes were not found in the literature. In this context, this work aimed presenting data on the enrichment of the mangos with isomaltulose through the evaluation of the WL and SG variables on mangos submitted to OD in a 25%, 30% and 35% sucrose or isomaltulose solutions at 25, 35 and 45°C with the performance of the multilevel statistical analysis. This analysis evaluated the effect of solute concentration and temperature for the studied conditions for each osmotic solute evaluated, which the best condition was sought to have a greater WL and one greater SG.

2 | MATERIAL AND METHODS

2.1 | Material

Mango fruits (*Mangifera indica* L. cv. Tommy Atkins) were purchased in a local market (Lavras, Minas Gerais, Brazil) (21°14′43 S and 44°59′59 W). The fruits were selected in a similar degree of maturation (half-ripe) and with the general characteristics of reddish-green skin color, 85.14 ± 0.55% moisture; 12.3 ± 0.6 °Brix; 4.72 ± 0.16 °Brix/acidity (ratio), 3.60 ± 0.04 pH and 47.50 ± 5.55 N firmness. The mango fruits were washed with a disinfectant solution (chlorinated water at 200 ppm) during 5 min. After, the seed and peel were removed and the experimental samples were obtained from the fruit pulp. The samples were sliced into pieces of 4.00 ± 0.01 × 2.00 ± 0.01 × 0.40 ± 0.01 cm (long×wide×thickness) employing a stainless-steel mold.

2.2 | Preparation of osmotic solution

The osmotic solutions were prepared with distilled water and commercial sucrose (União, São Paulo, Brazil) or isomaltulose, commercially known as Palatinose® (Beneo, Mannheim, Germany). The solution concentrations chosen were 25, 30 and 35 w/w. They were based on osmotic solutions properties (solubility, density, heat specific, thermal conductivity and viscosity) investigated recently by Carmo et al. (2022). The water activity (a_w) of the osmotic solutions was determined at 25°C with a digital thermohygrometer (AquaLab 3TE, Decagon, USA).

2.3 | Osmotic dehydration

The OD experiments were carried out with samples immersed into a glass container without recirculation and with the osmotic solutions with a ratio of solution/sample of 10:1 (v/w) to avoid dilution of the solution (Tiroutchelvame et al., 2019). The experiments were performed at different temperatures (25, 35 and 45°C) in a thermostatic chamber (Eletrolab EL111/4, São Paulo, Brazil) at atmospheric pressure, during 300 min, and then samples were removed from the solution and immediately immersed in a water and ice bath for 10 s to stop dehydration and to remove the remaining osmotic solution on the surface. Then, they had their surface dried with absorbent paper (Viana et al., 2014). The OD time (300 min) was chosen based on preliminary tests that showed that the osmotic equilibrium was reached at that time period. Other authors also used similar time periods (Grzelak-Blaszczyk et al., 2020; Junqueira et al., 2018; Prithani & Dash, 2020).

The moisture content of fresh and osmotically treated samples was determined according to Association of Official Analytical Chemists (2010).

For each condition of osmotic process, the water loss (WL) and SG (%) were determined according to Equations (1) and (2), respectively (Viana et al., 2014):

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

$$SG(\%) = \frac{w_t S_t - w_0 S_0}{w_0} \times 100 \quad (2)$$

where w is the sample weight (kg), S is the solid content (kg solid/kg fruit) and x is the moisture content based on a wet basis (w. b.) (kg water/kg fruit). Sub-indexes “0” and “t” refer to the fresh samples and the samples after osmotic treatment, respectively.

All analyses were performed in triplicate and the results were presented as the replicates mean.

2.4 | Statistical analysis

Multilevel statistical models are used when the data structure is hierarchical with elementary units. It is an increasingly popular approach to substitute classical regression in predictive accuracy. One feature of multilevel models is the ability to separately estimate the predictive effects of an individual predictor and its group-level mean, which are sometimes interpreted as “direct” and “contextual” effects of the predictor. It has been replaced traditional statistical methods, which ignore the correlation of outcomes within clusters and tend to underestimate standard errors. This artificially increases the significance of hypothesis tests, increasing the risk of falsely concluding that significant associations exist. The analysis type is common for data in health research and population studies (Austin et al., 2001).

Therefore, in the present work, multilevel models at two hierarchical levels were created for the first time for food data and these were defined as first level = Temperature and second level = Solute concentration for WL and SG variables. Considering the above, four models (Table 1) were taken in order to select the one that most closely matches the real conditions of the experiment and to assess where the random effect should be attributed – for WL and SG variables. Then, the selection of the appropriate model to explain the variation of WL and SG was made initially by means of the probability of significance, obtained as function of the chi-square statistic. Thus, models that were not significant were selected and subsequently evaluated using as a criterion the model that had the highest intraclass correlation coefficient, being possible to justify the hierarchy between the factors, as well as, the imposition of random parameters. Statistical software R Core Team (2021) was used to analyze the data.

3 | RESULTS AND DISCUSSION

3.1 | Osmotic dehydration

The results obtained for WL and SG of mango slices at different temperatures and solute concentrations of sucrose and isomaltulose are showed in Figure 1.

The WL results showed that this variable increases for a constant temperature, as the concentration of the sucrose solution increases (Figure 1a); therefore, an effect of the solutes is eminent during the OD, also, the highest moisture loss (42.48%) was reached at the highest processing conditions (35%, 45°C). In the case of the samples treated with the isomaltulose solution (Figure 1c), it could only be observed that the 35% of concentration obtained an increase of

TABLE 1 Description of the models with identification of the fixed and random effects attributed to the parameters and levels of the factors

Model	Code	Number of the parameters	Fixed effects parameters	Random effects parameters
Random intercepts	Mod0	3	Intercept	Intercept for each factor level (solute concentration) and residual
Random intercepts and fixed slopes	Mod1	4	Intercept for each factor level (temperature)	Intercept for each factor level (Solute concentration) and residual
Random intercepts and slopes	Mod2	6	Intercept for each factor level (temperature)	Intercept for each factor level (solute concentration) with random slopes for each factor (temperature) and residual
Intercepts and slopes random with inclusion of variable SG at the second level	Mod3	8	Intercept for each factor level (temperature), SG and interaction temperature × SG	Intercept for each factor level (Solute concentration) with random slope, for each factor level (temperature) and residual

Abbreviations: Mod0, model 0; Mod1, model 1; Mod2, model 2; Mod3, model 3.

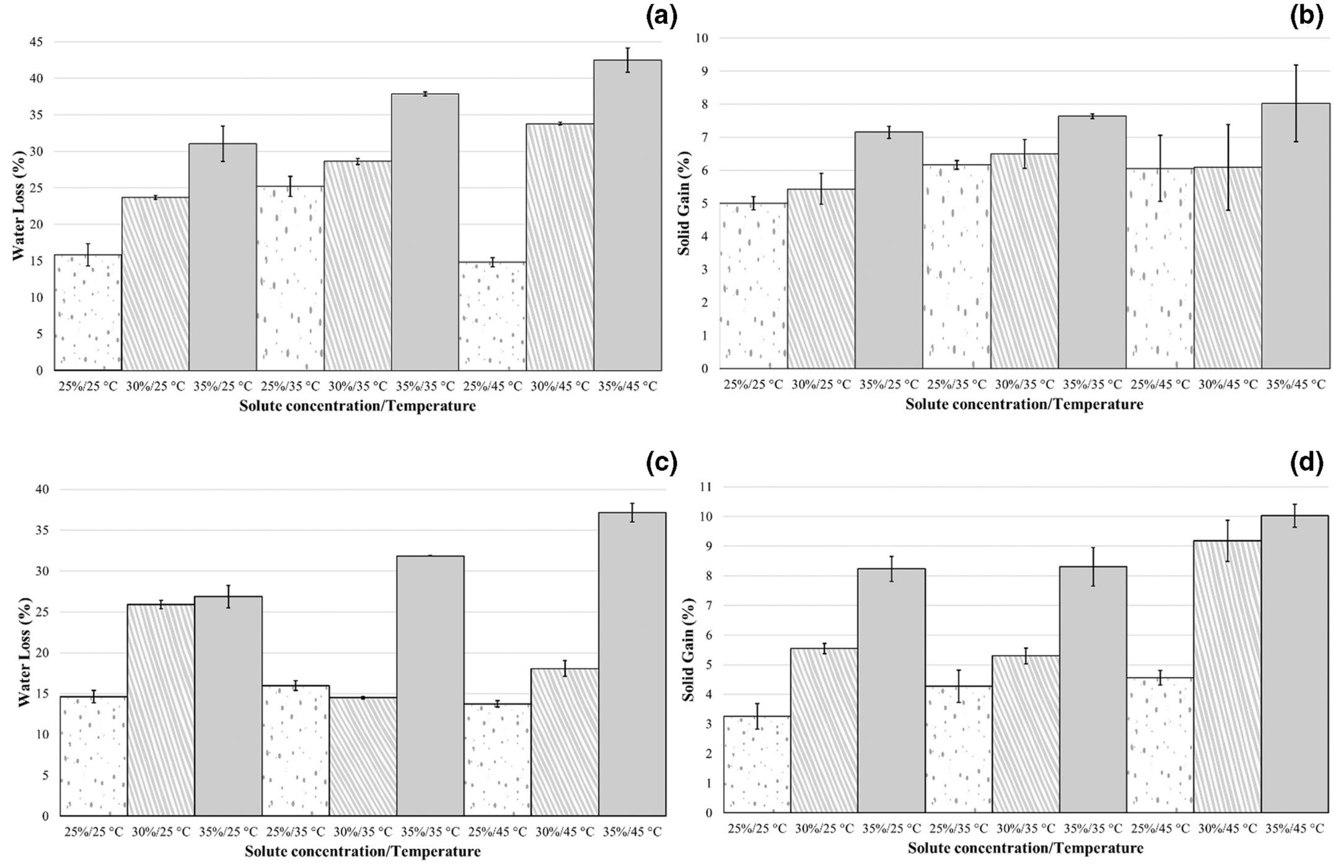

FIGURE 1 Water loss (%) and solid gain (%) of osmodehydrated mangos in sucrose solutions (a and b, respectively) and isomaltulose solutions (c and d, respectively) at different solute concentrations and temperatures for 300 min. Means ± standard deviation ($n = 3$).

WL values due to the effect of the temperature and only at 45°C a trend of increased by the presence of the solutes was showed, obtaining the greatest loss of water (37.15%) at 35% of concentration and 45°C of temperature, in a similar way than samples subjected with sucrose. The rest of the concentrations and temperatures did not show a clear trend.

On the other hand, the SG results showed that there was a trend in its increase due to the effect of the increase in the presence of solutes, the behavior being more evident in the samples subjected to the isomaltulose solution. However, such a clear effect of temperature was not observed, only at the highest study temperature. The highest solids gain for both cases (sucrose and isomaltulose) was at the highest process conditions (35% and 45°C), with the isomaltulose samples (10.02%) having a higher solute enrichment than the sucrose samples (8.02%).

In a general way, the results of mango slices osmodehydrated with sucrose solution presented WL values from 14.81% to 42.48% and SG from 5.00% to 8.02% in temperature range studied (25–45°C), while for the samples with isomaltulose solution, the WL was from 13.73% to 37.15% and the SG, from 3.25% to 10.02%, under the same conditions. Therefore, the results showed that the samples subjected to a sucrose solution obtained a greater loss in the amount of water than those that were osmotically dehydrated with isomaltulose, so the latter showed partial dehydration. However, the samples treated with isomaltulose presented a greater number of solutes, so there was an enrichment of the sample with this osmotic agent. Although the solubility of aqueous sucrose solution is greater than isomaltulose solution (Galdino et al., 2021), the a_w of both solutions are close (0.979, 0.974 and 0.970 for sucrose solutions and 0.978, 0.978 and 0.972 for isomaltulose solutions for 25%, 30% and 35% solute concentration, respectively) and this causes similar osmotic pressure gradients and, consequently, WL and SG values are of the same order of magnitude for all conditions studied (Figure 1). In spite there are no studies about OD of mango in isomaltulose solutions in literature, for sucrose solutions, the results obtained for WL and SG were similar to those previously reported in other works of OD under similar dehydration conditions (Galdino et al., 2021; Zongo et al., 2021).

In this way, the present work shows that under the conditions studied, the use of isomaltulose is interesting as an osmotic agent and it may turn out even more promising because it can be a partially dried and enriched food with low glycemic and insulinemic indexes agent, as mentioned previously (Macedo et al., 2021, 2022).

According to Fernandes et al. (2019), fruits like apples, pineapples and strawberries have a porous tissue structure with thin cell walls. Thus, for these fruits, water and soluble solids mass transfer from the fruit to the solution and vice versa suffers little resistance at the border of the fruit samples. Mangos are denser and much less porous (porosity = 0.04 to 0.05) than most fruits (pineapple porosity = 0.16 to 0.25; apple porosity = 0.18 to 0.22; strawberry porosity = 0.47)

(Ozcan & Haciseferogullan, 2007). Thus, the use of healthy carbohydrates in the process of OD in a less porosity fruit with satisfactory incorporation opens the way for further studies in this area.

3.2 | Multilevel statistical modeling for sucrose

3.2.1 | Selection criteria for modeling of sucrose solutions

Table 2 shows the selection criteria for the tested models for sucrose solutions. The comparison was performed according to the chi-square criterion. Three replicates were used for each level that served to give more accuracy in the mean response and the models were adjusted by the mean. The selected model was one whose chi-square statistic is not significant. Therefore, for the WL variable, none of the models was discarded according to the criteria used. For the SG variable, model 2 (with intercept and slope, both random) and model 3 (with intercept and slope, both random, and inclusion of a variable at the second level) were discarded. The covariate introduced in the second level was the SG, in order to investigate the effect of the SG with the WL. For WL, model 3 was selected as it presented a higher intraclass correlation coefficient. For the SG, model 1 was selected (random intercept and fixed slope), since among the models tested, it was the only one that did not show significance in the chi-square statistic.

To proceed with the analysis, the structure of the design was evaluated in both variables. The intraclass correlation coefficients for temperature (ρ_1) was 0.18% and 8.02% and for solute concentration (ρ_2), was 99.82% and 91.98% for WL and SG, respectively Then, it was concluded that the temperature depends on the solute concentration of the selected models.

Thus, greater intraclass correlation (ρ_2) indicated greater dependence between individuals in the same group and it justifies the use of a regression model that respects the structure and the aggregation structure of the data. In addition, for sucrose solutions, means that the variance in WL and SG can consequently be attributed to the solute concentration level. Thus, there are several temperature levels considered homogeneous for each level of solute concentration, giving rise to a hierarchy structure. The relatively high value of intraclass correlation justifies the use of a multilevel approach to analysis instead of a traditional regression.

TABLE 2 Models selection criteria for mango OD in sucrose solutions

Model	Df	χ^2	Pr (>χ^2)
Water loss			
Model 0	3		
Model 1	4	0.9650	0.32594
Model 2	6	2.2805	0.31974
Model 3	8	5.1626	0.07567
Solid gain			
Model 0	3		
Model 1	4	2.3168	0.127984
Model 2	6	6.1554	0.046066*
Model 3	8	10.2819	0.005852*

Abbreviations: χ^2, chi-square; Df, degrees of freedom; Pr, probability of significance.

*Indicates the chi-square statistic is significant.

3.2.2 | WL modeling of sucrose solutions – Effect of solute concentration

Model 3 for WL is represented in Figure 2a, in which the random intercept and random temperature with inclusion of covariate (SG) in the second level are showed. The inclusion of the covariate implied the difference between the solute concentration, because as can be seen in the plot, the intercepts are quite different indicating a significant difference between the different levels of solute concentrations. So, it is possible to observe that 35% sucrose concentration has an initial value with an intercept with a greater difference from the others (25% and 30%).

3.2.3 | SG modeling of sucrose solutions – Effect of solute concentration

Figure 2b shows model 1 for SG, with random intercept and fixed temperature. In this sense, considering fixed intercept implies zero temperature, that is, all levels have the same mean. In this plot, the temperature was placed as a fixed effect and the effect of the solute concentration was considered random. So, it is possible to observe that 25% of sucrose concentration has an initial value with a greater difference intercept from the others. The others sucrose concentrations (30% and 35%) were statistically similar, since their intercepts started close together. Therefore, it can be said that 25% sucrose concentration is statistically different from 30% to 35% sucrose concentration.

3.2.4 | WL modeling of sucrose solutions – Effect of temperature

Figure 3 shows the behavior of the random effects of the selected models, in which the lines represent the fixed levels and the points are the mean of the replicates. The plot for WL (Figure 3a) presents different behavior for different solute concentrations, that is, the inclusion of the covariate SG had a great influence on the results. It is observed that WL increases with an increase of temperature for 25% and 35% sucrose concentration, being more expressive at 25% sucrose concentration, since the slope of the line is slightly stronger than the 35% sucrose concentration, which has a more linear effect. On other hand, at 30% sucrose concentration there was a decrease in WL with increasing temperature. Thus, for WL there is a difference between solute concentrations, being 35% sucrose concentration one that has the greatest effect on this variable since its estimates are highest than others.

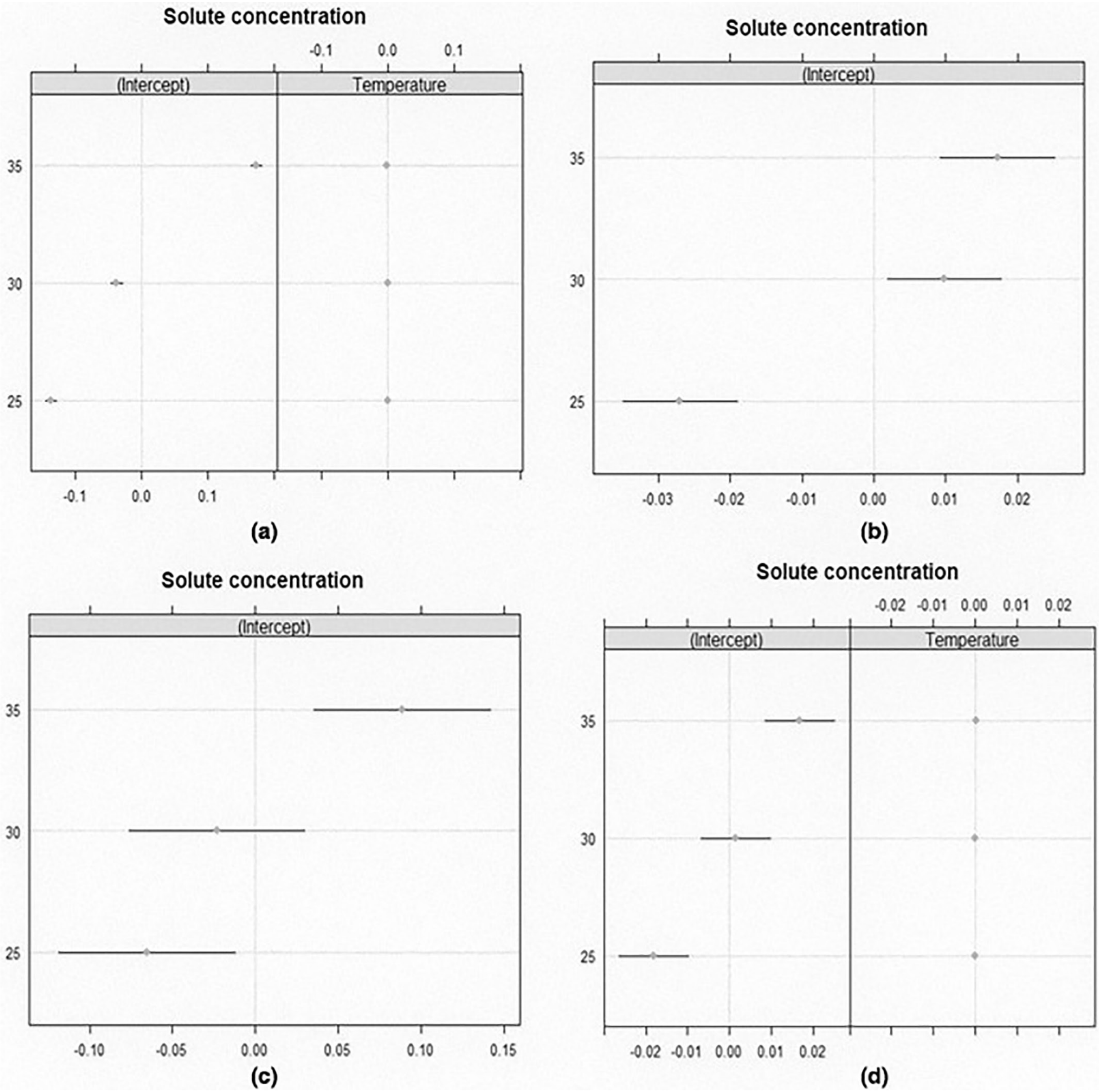

FIGURE 2 Dotplot plots representing the fixed and random variables of the selected model for water loss (%) and solid gain (%) in sucrose solutions (a and b, respectively) and isomaltulose solutions (c and d, respectively).

3.2.5 | SG modeling of sucrose solutions – Effect of temperature

In Figure 3b, the slopes of the temperature lines are the same, so it justifies keeping it fixed. In addition, the effect of the slope is extremely small, since it is a model with a fixed inclination. In practical terms, the effect of temperature on SG is considered constant for each solute concentration. So, it is possible to increase or decrease the temperature that the adjusted lines are indicating little evidence of SG. This plot can be understood and explored as an offshoot for each level of solute concentration in relation to temperature. In other words, statistically, the solute concentration had the greatest influence on this variable.

3.3 | Multilevel statistical modeling for isomaltulose

3.3.1 | Selection criteria for modeling of isomaltulose solutions

As for sucrose, the same four models (Table 1) were compared to select the one that most closely matches the real conditions of the

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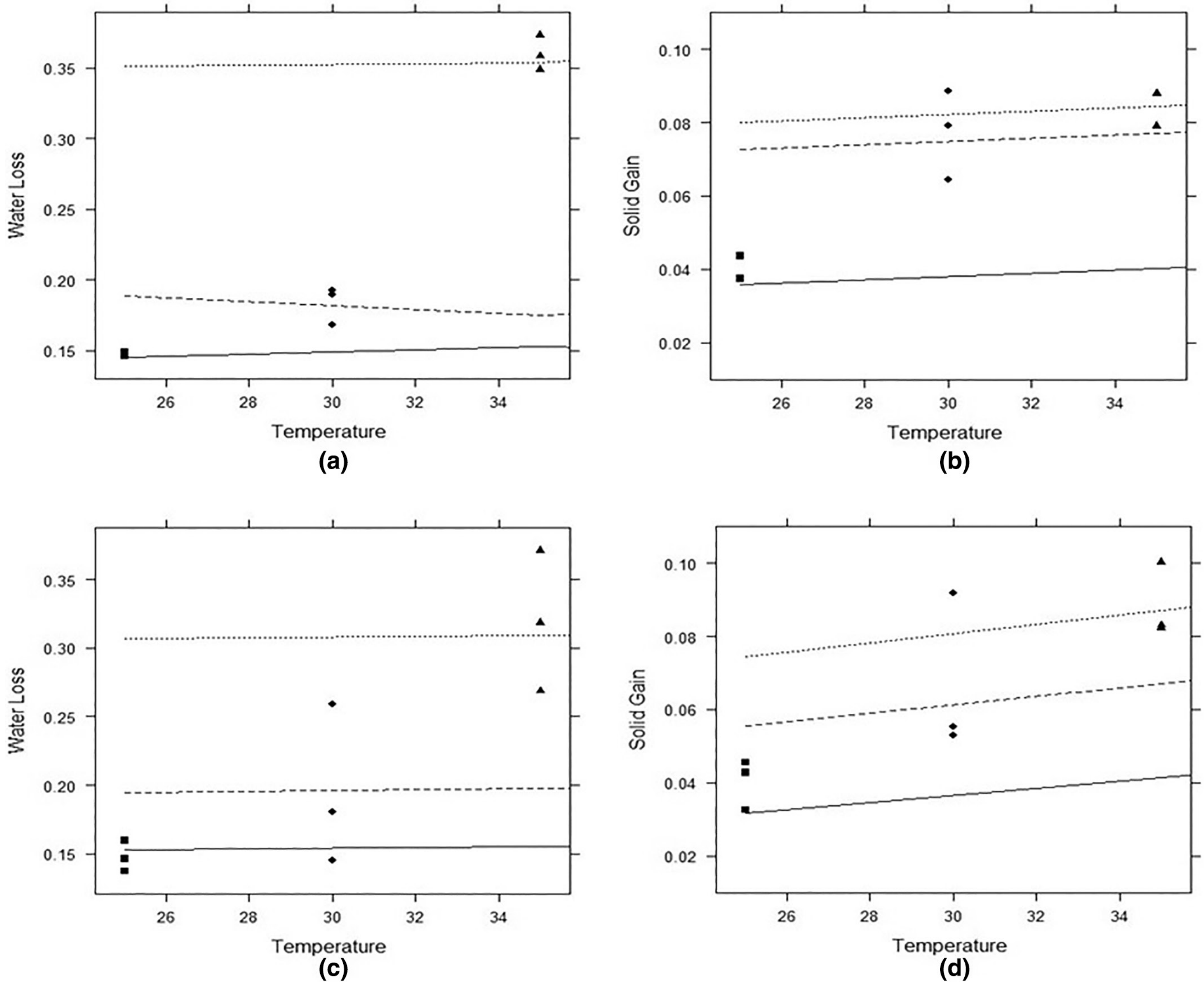

FIGURE 3 Behavior of random model parameters for water loss (%) and solid gain (%) in sucrose solutions (a and b, respectively) and isomaltulose solutions (c and d, respectively). Filled, dashed and dotted lines represent the fit of model 3 (a), model 1 (b), model 1 (c) and model 2 (d) to the experimental values of (■) 25%, (◆) 30% and (▲) 35% solute concentration, respectively.

experiment for the variables WL and SG for isomaltulose solutions. Table 3 describes the selection criteria for the tested models. The selection of the appropriate model was also obtained as a function of the probability of significance of the chi-square statistic. Three replicates were also used for each level that served to give more accuracy in the mean response and the models were adjusted by the mean.

As previously mentioned, the model selected was the one whose chi-square statistic was not significant. Therefore, for the WL variable the model 3 does not fit the data satisfactorily and should be discarded. For the SG variable the models 1 and 3, must be discarded.

For WL and SG, models 1 and 2 were selected, respectively, as they presented a higher intraclass correlation coefficient.

The intraclass correlation coefficients for temperature (ρ_1) was 25.77% and 23.13% and for solute concentration (ρ_2), was 74.23% and 76.86% for WL e SG, respectively. The greater intraclass correlation means that the variance in WL and SG in isomaltulose solutions can be attributed to the solute concentration level, as sucrose solutions.

3.3.2 | WL modeling of isomaltulose solutions – Effect of solute concentration

Figure 2C for WL shows that 35% isomaltulose concentration has an initial value with intercept with greater difference in relation to 25% and 30%, being statistically different from the latter, which in turn are statistically equal, as their intercepts started close.

3.3.3 | SG modeling of isomaltulose solutions – Effect of solute concentration

Figure 2D for SG is represented by model 2, which evaluation is made only in the intercept. It is observed in the plot that there is a difference between all intercepts, when temperature is fixed, since there is a noticeable difference in the place where their intercepts start, so there is a significant difference between them. For solute

TABLE 3 Models selection criteria for mango OD in isomaltulose solutions

Model	Df	χ^2	Pr (>χ^2)
Water loss			
Model 0	3		
Model 1	4	0.0198	0.8881
Model 2	6	3.2706	0.1949
Model 3	8	18.7299	$8.568\times10^{-5*}$
Solid gain			
Model 0	3		
Model 1	4	5.6161	0.0177959*
Model 2	6	0.1138	0.9447103
Model 3	8	17.8583	0.0001325*

Abbreviations: χ^2, chi-square; Df, degrees of freedom; Pr, probability of significance.

*Indicates the chi-square statistic is significant.

concentration, the 35% isomaltulose has the greatest effect on the SG, as its estimates are the highest. Thus, this concentration provided greater WL and SG.

3.3.4 | WL modeling of isomaltulose solutions – Effect of temperature

In Figure 3c, the lines do not show evident inclination. It can be attributed due to the effect of the inclination is extremely small and the model has a fixed inclination. So, according to the adjusted lines, the increase or decrease in temperature has little effect on WL.

3.3.5 | SG modeling of isomaltulose solutions – Effect of temperature

The plot for SG (Figure 3d) shows that by increasing the temperature there is a slight increase in SG. However, as compared with WL, for the SG the effect of temperature was more expressive.

In general, greater WL and SG are obtained within higher temperature and solution concentration. The OD is performed through the semipermeable membranes of the food in order to balance the chemical potential of the system. Kushwaha et al. (2018) observed, in their study on the influence of the osmotic agent on guava, that higher concentrations of sucrose resulted in higher WL and SG. However, depending on the process conditions, high SG can affect the nutritional and sensory profile of the food (Oladejo et al., 2013).

In which concerns the temperature, its increase promotes the diffusion of water inside the food (Alabi et al., 2022; Dimakopoulou-Papazoglou et al., 2022; Dimakopoulou-Papazoglou & Katsanidis, 2020). Moreover, the fruits have a porous structure, so that the high temperature also releases the air retained from the tissue, resulting in more efficient removal of water by osmotic pressure (Ramya & Jain, 2016). The increase of temperature led to the swelling and plasticization of the cell membrane during osmotic dehydration, which increases its permeability and decrease the viscosity of the osmotic solution (Kumar & Singh, 2014; Ruskova et al., 2016). According to Ahmed et al. (2016), the mass exchange in plant cells follows two major pathways – apoplasmic and symplasmic. The apoplasmic pathway is made possible by the connection between the cell components (cell wall and middle lamella), while the symplasmic pathway occurs via linked protoplasm of the surrounding cells, thus allowing cell to cell mass transport. The loss of the cell membrane selectivity makes it easier for solute to diffuse from the solution into the product (Campos et al., 2012). This set of factors improves water removal and solids absorption. Another benefits can be observed. As example, Devic et al. (2010) verified greater retention of vitamin C at 45°C and that above this temperature, damage to the cell wall could occur, reducing mass transfer.

This knowledge is very important to aid in the choice of best osmotic process conditions for a dehydrating effect (SG is much less than WL), in order to facilitate the subsequent drying process; or the incorporating effect (SG is slightly less than the WL), in order to promote the food-enrichment with a solute of interest; or the both effects.

4 | CONCLUSIONS

The results of osmotic dehydration (OD) with both osmotic solutions showed that the highest solute concentration (35%) and the highest temperature (45°C) conditions, promoted the greatest WL and SG in both solutions. However, the sucrose solution resulted in greater WL than isomaltulose, showing a high dehydration of samples, while a slight influence of temperature on the SG for isomaltulose solution was observed and a significant enrichment of samples was obtained with this osmotic agent with a less WL. Moreover, the multilevel analysis was applied on OD processes analysis and it was feasible to be applied since it was possible to adjust a model that was closest to the actual conditions of the experiment in order to analyses the relationship between the studied variables. Thus, the performance of the multilevel statistical analysis was suitable to evaluate the effect of solute concentration and temperature for the studied conditions for each osmotic solute evaluated.

Hence, this study not only examined the application of multilevel analysis on OD processes in food science, but it also offered the possibility of determine adequate OD processing conditions for the enrichment of mango with isomaltulose for the obtention of healthy product.

Furthermore, through this work the application of multilevel analysis can be extended to other foods, besides opening way to evaluate other parameters of the process, as well as, other types of osmotic solutions.

AUTHOR CONTRIBUTIONS

Juliana Rodrigues do Carmo: Conceptualization; Writing – review & editing; Writing – original draft. **Jefferson Luiz Gomes Corrêa:**

Conceptualization; Funding acquisition; Writing – review & editing; Supervision; Formal analysis. **Mariana Resende:** Writing – review & editing; Formal analysis. **Marcelo Ângelo Cirillo:** Conceptualization; Supervision; Formal analysis; Writing – review & editing. **Edith Corona-Jiménez:** Writing – review & editing; Formal analysis. **Javier Telis-Romero:** Writing – review & editing; Supervision.

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CONFLICT OF INTEREST

The authors have no conflict of interest. The authors alone are responsible for the content and writing of the paper.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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