Optimization methods as a tool for the reduction of salt on meat products. Case study for cooked ham

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RESUMEN:
Estudios recientes han demostrado que el consumo de carne está cada vez más influenciado por consideraciones de salud, nutricionales y ambientales. Un elevado contenido de sal en productos cárnicos genera impactos negativos para la salud. Por lo tanto, las empresas buscan constantemente tecnologías y métodos para reducir la sal en los productos cárnicos y mejorar su vida útil. Una de las alternativas para estudiar la disminución de sal en productos cárnicos y su efecto en los parámetros de calidad es el uso de modelos matemáticos. El objetivo de esta revisión fue comparar los métodos de diseño Box-Behnken y diseño de mezclas (múltiples factores) como herramientas de optimización para la reducción de sal en productos cárnicos. Para ello, se analizaron los datos reportados en la literatura por algunos autores en un caso de estudio de optimización de la formulación de jamón cocido reducido en sal y añadido con aromatizantes (extracto de glicina y levadura). Los resultados de la revisión del caso de estudio fueron comparados con una nueva optimización realizada en nuestro trabajo, utilizando un diseño de Box-Behnken.

Palabras clave: Optimización, Box-Behnken design, Reducción de sal

ABSTRACT
Recent studies have shown that meat consumption is influenced by health, nutritional and environmental considerations. A high salt content in meat products has a negative impact on health. Therefore, companies are constantly looking for new technologies and methods to reduce salt in meat products and improve shelf life. One of the alternatives to study the salt reduction in meat products and its effect on quality parameters is the use of mathematical models. The objective of this review was to compare Box-Behnken design and mix design (multi-factor) methods as optimization tools for salt reduction in meat products. The data reported in the literature by several authors were analyzed for a case study of optimization in the formulation of reduced cooked ham in salt and added with flavorings (glycine extract and yeast). The results of the review of case study were compared with a new optimization performed in our work, using a Box-Behnken design.

Keywords: Optimization, Box-Behnken design, Salt reduction

Área: Desarrollo de nuevos productos

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1. INTRODUCTION

Currently, consumers do not consider cured meat products as healthy meat products due to their high level of fat and salt. In relation to the salt content in these products, a high level of sodium chloride has been related to negative impacts on human health .The Food Standards Agency and the World Health Organization have published guidelines for daily salt intake recommending a reduction of approximately 50% in average salt intake per day (Grossi, et al., 2012). As an improvement to this recommendation, at the 66th World Health Assembly (2013), Member States adopted an overall target for salt intake: by 2025 a 30% reduction should be achieved (WHO, 2013). Therefore, the reduction of salt in meat products through strategies to reduce this component has become an important area of research over the past two decades and has received additional attention around the world. Meat products contribute between 15 and 25% of the salt/sodium of the diet; efforts have focused on the development of reduced salt analogues (Delgado-Pando et al., 2019). However, in the meat industry, the addition of various salts to meat products not only plays a role in the typical salty taste and taste, but is used with the aim of improving food functionality and ensuring food safety, so reducing salt in these products poses a major challenge for the meat industry. The addition of salts (commonly 1.5 to 2.5% sodium chloride) to meat batter is essential in the proper development of the desired physicochemical characteristics: improves gelling, water retention capacity, fat retention, cooking loss (Grossi, et al., 2012), and in addition, salt acts as a preservative agent (Barat & Toldrá, 2011; Desmond, 2006), causing an immediate decline in water activity to values of 0.96-0.97 (Whiting, 1994).

Regarding the high fat content in cured meat products these meat products are one of the main sources of saturated fats in the diet, so changes in their fat content and fatty acid profile (AG) may help to increase their nutritional quality. Recommendations on lipid consumption state reduction of saturated fats and increase of unsaturated fats (Marchetti et al., 2014).

In order to improve consumer health, different approaches have been applied to reduce the sodium and fat content in meat products, for instance, replacing sodium chloride with other types of salt (Baso et al., 2020; Da Silva et al., 2020; Grossi et al., 2012), the use of lean meats (which increases the cost) (Utrilla et al., 2014), reducing the fat and calorie content by adding water and ingredients that provide less or no calorie (increases exudative losses, affects the texture and juiciness of the product) (Abbasi et al., 2019), or newer processing techniques (Zuhaib et al., 2020, O'Flynn et al., 2014). Aaslyng et al., (2014) found that through product reformultion the salt in cooked ham can be reduced from 2.3% to 1.8% without altering the sensory properties, sliceabilty, production yield, shelf life and safety; however, further reductions affected significantly product quality and would therefore require other measures such as the substitution of salt with other functional ingredients such as salt replacers. Current trends suggest that novel non-meat ingredients can be added to meat products to achieve a lower content of fat, cholesterol, sodium, nitrites/nitrates, while providing the additional benefits of functional ingredients such as plant proteins, antioxidants and symbiotics (prebiotics and probiotics).

The great impact of reducing salt and fat on the sensory properties of the product is evident, so it is important to consider the possible consumer response to the reformulation of meat products mainly when wanting to generate adequate optimized formulations. In fact, optimization can be defined as the different steps necessary to obtain the best result in a particular set of circumstantial (Delgado-Pando et al., 2019). For the correct formulation of meat products aimed at current trends, the type and quantity of meat are important factors for the health of the consumer, the technological properties of the product, which will be reflected in the quality of the product; however, in the development of new products, techniques are suggested to assess the effectiveness of new product developments, including the use of experimental blend designs to study ingredient functions and interactions in processed foods. To systematically determine what is best in the relevant environment, several sensory factors, such as taste, color, texture, etc. (Delgado-Pando et al., 2019) should be taken into account.

2. OPTIMIZATION METHOD

Reducing salt in meat emulsions is a complicated task. Salt not only plays an important role in the taste and salty taste typical of foods, especially meat sausages, but also acts as a preservative and is essential in the proper development of the desired physicochemical characteristics. The great impact of salt reduction on the sensory properties of the finished product is evident, so it is vital to take into account the consumer's response to reformulation, throughout the entire product optimization process.

Gacula (1993) defines optimization as the different steps necessary to obtain the best result in a particular set of circumstances. Applied in reduced meat sausages in salt, it is understood that the circumstances are both the level of salt and ingredients necessary to achieve the most acceptable product within its category, in this case among analogues with reduced salt content.

Delgado-Pando et al. (2019) point out that in order to systematically determine what is best in the relevant environment, several sensory factors, such as taste, color, texture, among others, should be taken into account. Response Surface Methodology (RSM) is a simulation modeling tool, widely used to predict process conditions in various scientific and industrial processes, for the optimization of processing operations. The advantages of this methodology are that it provides robust but intuitive and easy-to-use statistics, provides us with a graphical solution and helps to achieve a single formulation, optimized simultaneously combining multiple attributes.

This methodology was chosen as the optimization method for pork sausages because it is a powerful mathematical and statistical technique that allows testing multiple process variables and their interactive and quadratic effects, which helps to investigate the interactive effect of several variables and to construct a mathematical model that accurately describes the general process. In addition, this methodology has been used effectively to optimize formulations in a variety of food products, such as low-fat Frankfurt sausages, mortadella and sausages or pork battered (Carballo et al., 1995, Murphy et al., 2004, Pietrasik and Li-Chan, 2002), so it is ideal to apply in this research project. Specifically, the Response Surface Methodology (RSM), which uses a Box Benkhen design, allows us to evaluate the effects of various processing parameters and their interactions on response variables.

Ferreira, et al. (2007) mention that the first step of multivariate optimization is accomplished screening the factors studied (full factorial or fractional factorial design) in order to obtain the significant effects of the analytical system. After determining the significant factors, the optimum operation conditions are attained by using more complex experimental designs such as Doehlert matrix (DM), central composite designs (CCD) and three-level designs such as the Box-Behnken design (BBD). During the multivariate optimization procedure, there are two types of variables: the responses and the factors. The responses are the dependent variables. Their values depend on the levels of the factors, which can be classified as qualitative or quantitative.

In the present work, the data reported by Delgado-Pando et al. (2019) were analyzed, the authors study optimization of cooked ham reduced in salt and added with flavorings (glycine extract and yeast) using a mix design (multi-factor). The results of the review of this study case were compared with a new optimization performed in our work (see section 4), using the Response Surface Methodology (RSM) with a Box Benkhen design.

3. SELECTED HAM FORMULATION

In the study carried out by Delgado-Paldo et al. (2019) formulations of cooked ham with low salt content were prepared using different mixtures of sodium chloride (0.82 to 1.23%) and two flavor enhancers: glycine (0.70 to 0.27%) and yeast extract (0.11 and 0.14%). Ham recipes also contained dextrose, phosphates, sodium ascorbate and sodium nitrite.

For the optimization study, the authors made use of Design Expert v10 (Stat Ease Inc., USA) which built the I-Optimal experiment mix with 3 lack of fit points. The model comprised 12 different points (Table I) with sample H9 replicated twice (H10 and H11), and sample H12 was the control (1.63% salt without flavorings). The minimum and maximum levels were: 0.82 to 1.63% for salt, 0 to 0.7% for glycine and 0 to 0.3% for yeast extract. For validation study, Delgado-Paldo et al. (2019) produced three different ham samples: an optimized control ham (CO) where the salt content was 1.63% (with glycine and yeast, both 0%) and two optimized HO1 products (1.33% salt, 0.3% yeast extract) and HO2 (1.27% salt, 0.16% glycine and 0.20% yeast extract).

Delgado-Paldo et al. (2019) reported that the differences in formulation significantly affected both sensory and physicochemical properties with the exception of instrumental colour characteristics. Instrumental lightness ($F = 1.61$, $P = 0.16$), redness ($F = 1.94$, $P = 0.09$), yellowness ($F = 2.15$, $P = 0.06$) and cured colour ratio ($F = 1.11$, $P = 0.39$) were not significantly affected by formulation. For the purposes of the optimization project, the variables to be evaluated will be flavour (%), overall acceptability (%), hardness (N) and chewiness (N). These authors performed a variance analysis and discarded the non-significant terms and recalculated the ANOVA. The models that the authors selected were those of mayor statistical power, lower factor of variance inflation for coefficients and proper noise ratio. Because the blend model doesn´t contain an intercept term, linear terms incorporate the global response media and are tested together. With regard to general acceptance, the model shows that yeast was the ingredient with the greatest relative impact, meaning that it provided more acceptability to hams compared to the other two ingredients alone.

The salt concentration was also important, as for the same amount of yeast extract the overall acceptability increased when the salt concentration was higher, meaning a lower glycine content. Delgado et al. (2019) emphasize that maximum acceptance levels are in the highest salt content ranges, but not at the highest point, as yeast extract had a greater impact, indicating that salt reduction could be possible with the use of flavorings. The maximum value for overall acceptability corresponded to a binary mixture of 1.33% salt and 0.3% yeast extract (R^2=0.42).

The pure salt mixture produces the hams with a better taste of flavor, whereas yeast extract appeared to exert a negative impact when used alone. However, when the yeast extract was in combination with salt or glycine, a synergistic effect was observed as reflected in the positive and significant quadratic terms (R^2=0.71). This means that the media response values were higher when combinations of these two ingredients were used that when using the mean of each pure mixture. The maximum taste for flavor (>70%) appeared at around 1.45% salt and 0.18% of yeast extract. Delgado et al. (2019) point out that the model had a significant lack of fit. Although alternative models were tested, no improvement was found. The residual plot against values cannot be seen in particular, so the model was accepted by them.

With regard to textural parameters, the authors report that the harder and chewier hams were the ones with the mayor proportion of glycine. For the same glycine concentration, hardness values rarely varied with salt concentrations and yeast extract. For the same amount of glycine, lower salt content and higher yeast extract, produced higher chewiness. Maximum chewiness appears at 0.82% salt, 0.7% glycine and 0.11% yeast extract (R^2=0.59).

4. RSULTS COMPARISON

Optimal levels of the predictor for flavour, acceptability, and texture were performed using response surface plots with the Box-Benken design. The effects of 3 factors (concentration of NaCl, glycine, yeast extract) on the acceptability and textural properties of formulated cooked ham were studied.

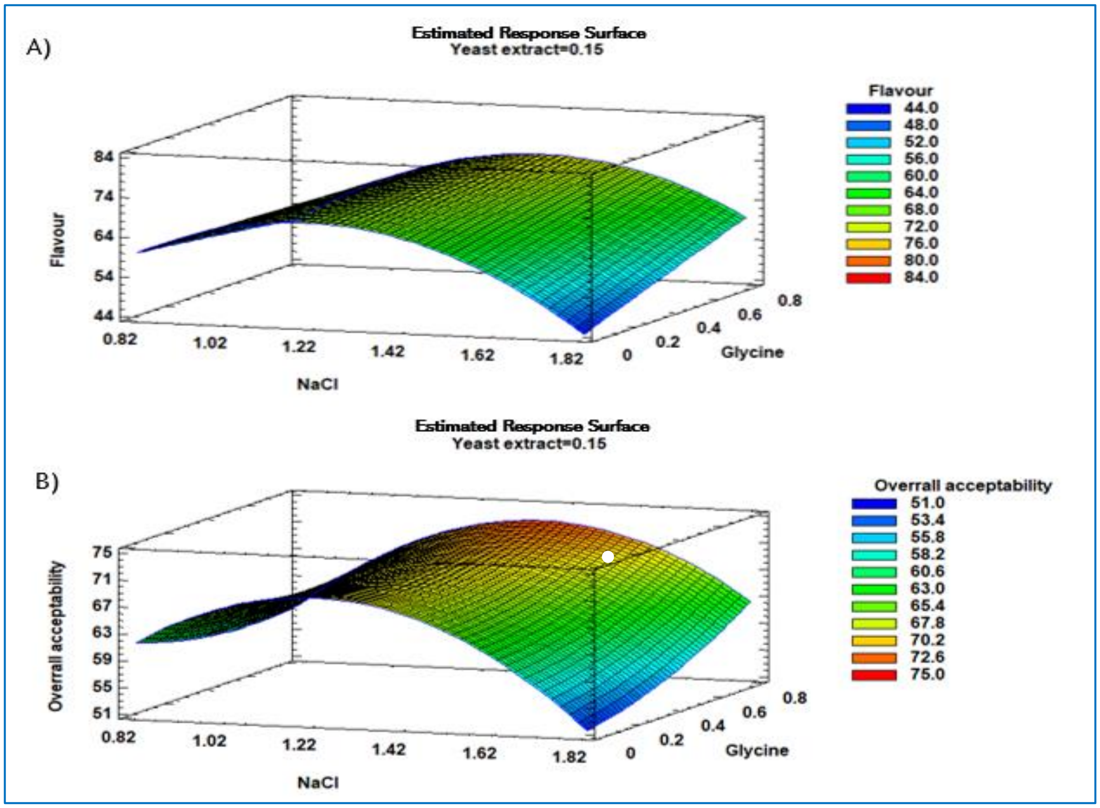

Fig. 1. Surface plot of the interaction effect between concentration of NaCl, glycine, yeast extract on hedonic parameters: (A) flavour; (B) overall acceptability.

4.1. Flavour

The optimum values of the variables were obtained by analyzing the response surface contour plots. Then, the ANOVA of the regression model showed the significance of the model. The value of R^2 (0.8759) indicated the good relation between the predicted and experimental values. The influence of the interaction between the concentration of NaCl, yeast extract and glycine can be seen in the response surface plots (Fig. 1 (A)). The response surface established as an optimum value for flavor 75.99%, which can be reached by having an optimal concentration of NaCl of 1.39801%, of glycine 0.7% and of yeast extract 0.3%.

4.2. Overall acceptability

The goodness of the model was checked by the determination coefficient (R^2 = 0.9581) which indicates good relation between the experimental and predicted values of the response. As demonstrated in Fig. 1 (B), overall acceptability is the response and the scaled estimates reflecting the influence of the term in the model. Concentration of NaCl, yeast extract and glycine have notably influenced the response with an antagonist interaction between these three factors. The Box-Behnken design established 74.2349% as an optimal value for overall acceptability, which can be achieved by having an optimal concentration of NaCl of 1.42741%, of glycine 0.685721% and of yeast extract 0.3%.

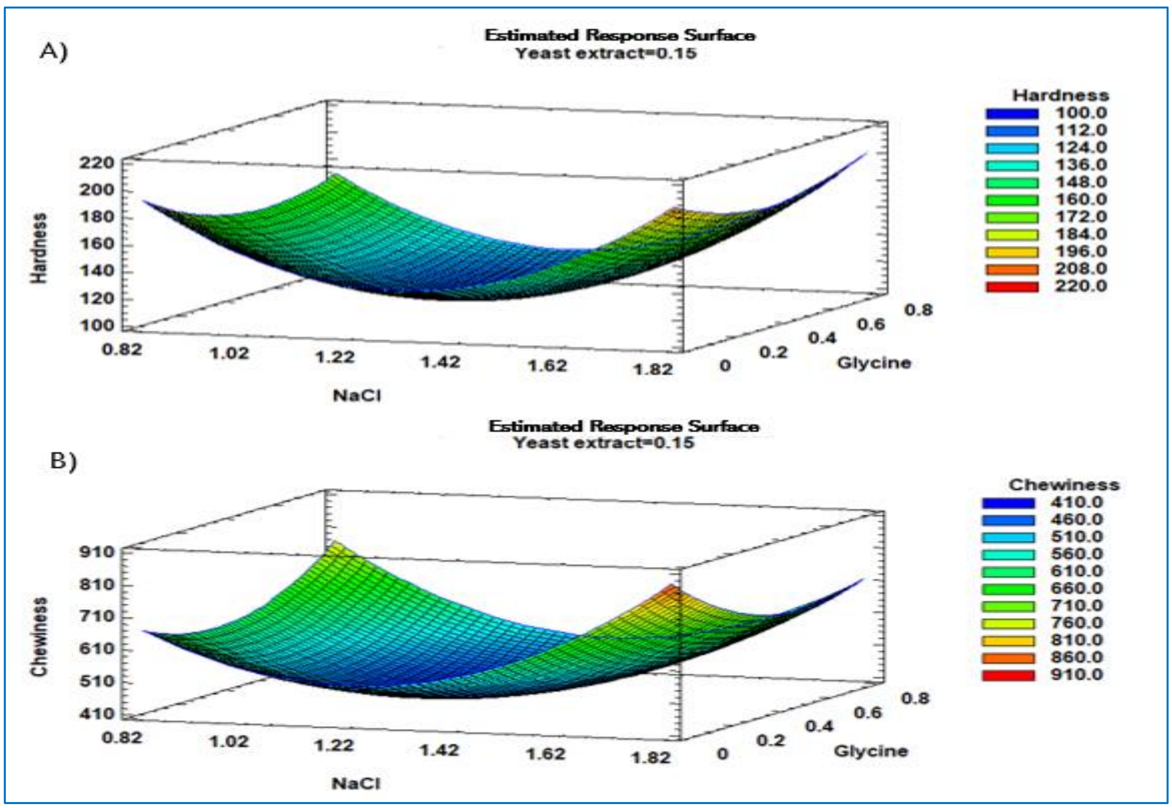

Fig. 2. Surface plot of the interaction effect between concentration of NaCl, glycine, yeast extract on hedonic parameters: (A) hardness; (B) chewiness.

4.3. Hardness

The value of R^2 (0.7881) indicated the good relation between the predicted and experimental values. The influence of the interaction between the concentration of NaCl, yeast extract and glycine can be seen in the response surface plots (Fig. 2(A)). The response surface established as an optimum value for hardness 197.974 (N), which can be reached by having an optimal concentration of NaCl of 0.82%, of glycine 0.000975392% and of yeast extract 0.281754%.

4.4. Chewiness

The determination coefficient (R^2) confirmed the goodness of the model. The value of R^2 (0.9426) indicated that 94.26% of all variations was explained by the model. The response surfaces method was used to visualize the interactions between NaCl, glycine and yeast extract concentration. As shown in Fig. 2 (B), that involves the interaction effect of these three factors. The Box-Behnken design established 760.371 (N) as an optimal value for chewiness, which can be achieved by having an optimal concentration of NaCl of 0.82279%, of glycine 0.7% and of yeast extract 0.3%.

The BBD allowed the evaluation of responses based on the concentrations of the three ingredients addressed in the research: NaCl, glycerin and yeast extract, and the adjustment obtained by this design was greater compared to those reported by Delgado et al. (2019) obtained from the methodology of optimization of mixture design (multiple factors) that they addressed in their study, whose model was reported with adjustment failures in the model. In addition, the optimal values based on taste, general acceptability, hardness and chewiness, determined by the BBD were higher than those reported by Delgado et al. (2019), so the BBD assumes a better optimization tool of cooked ham for obtaining desirable organoleptic properties.

5. CONCLUSION

Trends focus on reducing the salt content in meat products, this is caused by studies that show that a high salt intake is associated with negative health impacts. However, salt plays a significant technological role in processed meat because thanks to its antimicrobial properties it reduces water activity, developing a general bacteriostatic effect and affect their survival and growth. In addition, salt increases the binding properties of proteins, essential for taste and improve texture. Therefore, the reduction of salt in processed meat products is a challenge as quality can be compromised in the final product. In relation to the above, optimization is a final step that is performed in the optimal mix modeling system that is recommended to find a number of operating conditions that optimize all responses or keep them in a desirable range.

Moreover, the Response Surface Methodology (RSM) is an effective tool for finding these optimal levels of processing variables for the parameters studied, which is used to predict process conditions in various scientific and industrial processes, for the optimization of processing operations. The Box-Behnken design could be a useful tool for modeling and optimizing ingredient concentrations in meat product formulations, the adjustment of which turned out to be greater compared to RSM by multiple factors. The optimized condition determined by the BBD could improve the acceptability and texture of the final product.

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