THE EFFECTS OF POTATO AND RICE STARCH AS SUBSTITUTES FOR PHOSPHATE IN AND DEGREE OF COMMINUTION ON THE TECHNOLOGICAL, INSTRUMENTAL AND SENSORY CHARACTERISTICS OF RESTRUCTURED HAM

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ABSTRACT

The effects of sodium tripolyphosphate (STPP), two sources of starch (potato starch: PS and rice starch: RS) and comminution degree (CD) on the technological, instrumental and sensory characteristics of reformed hams were studied using response surface methodology. Both starches reduced cook loss and decreased ham flavour intensity, but RS had stronger effects on instrumental measures of texture, while PS was associated with improved juiciness when low/no added STPP was included. Coarsely ground meat, processed 100 % with the kidney plate was associated with slightly increased cook loss, reduced texture profile analysis parameters and a more intense ham flavour compared to the other treatment (80 % ground with a kidney plate plus 20 % with a 9 mm plate). STPP was the sole factor affecting overall liking. If starch is included in the formulation, the standard level of STPP (0.3%) can be reduced by half with no increase in cook losses, but some decline in sensory quality cannot be avoided.

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KEYWORDS

Reformed ham, potato/rice starch, phosphate, comminution, response surface methodology

1. INTRODUCTION

The preparation of reformed cooked ham, also known as sandwich ham, can help add value to cheap cuts and trimmings from e.g. pork shoulder, through their incorporation into a relatively uniform and convenient cold ready-to-eat product. The correct binding of meat pieces is important in the manufacturing process of these hams, as is the retention of the brine added, as these parameters help to define the yield and the structure of the product. Optimal binding can be achieved through mechanical and thermal processing plus the addition of functional ingredients, which either enhance the functionality of the meat proteins (i.e., salt and phosphates) or have a direct functional effect in the meat system, such as starches (Boles & Shand, 1998; Petracci, Bianchi, Mudalal & Cavani, 2013).

The use of phosphates offers some remarkable advantages as they are cheap, effective and easily handled. Additionally, they permit a reduction in the use of salt whilst maintaining technological quality and they can improve the sensory quality of meat products (Moiseev & Cornforth, 1997; Ruusunen, Niemistö & Puolanne, 2002). However, their use in meat processing is in decline due to the negative perception of consumers- for example, phosphates have been shown to be generally considered an artificial, unhealthy and unfamiliar ingredient in cooked ham (Petracci et al., 2013; Resconi, Keenan, Barahona, Guerrero, Kerry & Hamill, 2016) - and due to the increased focus on clean label ingredients in food processing in general.

It is well known that starch helps to retain water and can also affect other quality characteristics of meat products, such as texture, sensory, and colour. However, the magnitude of these effects differs according to several factors such as the botanical origin of the starch, chemical/physical processing and concentration, the matrix in which it is acting, the technological process, cooking temperatures, and salt concentration (Li & Yeh, 2002; Skrede, 1989; Teye & Teye, 2011; Zhang & Barbut, 2005). For example, a reduction in hardness and other texture parameters has been observed with starch inclusion in whole meat and restructured products (Motzer, Carpenter, Reynolds & Lyon, 1998; Resconi et al., 2015; Schilling, Marriott, Acton, Anderson-Cook, Duncan & Alvarado, 2003), whereas conflicting results were found in comminuted meat products, such as meat batters and sausages (Fernández, Cofrades, Solas, Carballo & Colmenero, 1998; Hughes, Mullen & Troy, 1998; Pietrasik & Janz, 2010).

In reformed meat, a product is generally considered to be of higher quality, the larger the pieces are, and the lower the level of extension (Feiner, 2006). However, when large particle sizes are used, it is more appropriate to use meat with less connective tissue (and fat) in order to offset any potential adverse consequences in the visual appraisal of the product. Hence, raw meat pieces are generally reduced with plates of different diameters or just passed through a mincer worm (Feiner, 2006). Nonetheless, the shape and size of the meat pieces could further affect the characteristics of the reformed product such as yield, instrumental texture and eating quality (Berry, Smith & Secrist, 1987; Cofrades, Serrano, Ayo, Solas, Carballo & Colmenero, 2004). This may be further complicated by action of non-meat ingredients that could interact differently according to the particles size (Boles et al., 1998; Cofrades et al., 2004; Nielsen, Høegh & Møller, 1996).

Due to the complex nature of the product and the interactions between influential parameters, more studies are required to enhance the understanding of the effects of starch in different meat matrices and to study possible interactions between ingredients, modulated by technological factors. Information generated could facilitate more straightforward optimization of ingredient usage levels in reformed products and permit a streamlining of new product development. Response surface / mixture design methodologies represent useful approaches to assess those aspects (Amini Sarteshnizi, Hosseini, Bondarianzadeh, Colmenero & khaksar, 2015; Keenan, Resconi, Kerry & Hamill, 2014; Resconi et al., 2015). The objective of the present study was to analyze the possibilities for phosphate substitution with two types of starch (potato and rice) in reformed hams prepared with meat with different comminution levels, considering technological, instrumental and sensory aspects in a response surface design.

2. MATERIALS AND METHODS

2.1 Design of the experiment

A response surface methodology (RSM) based on d-optimal experiment was designed using Design Expert software (v. 7.6.1, Stat-Ease Inc.). Four factors were studied:

- STPP, sodium tripolyphosphate, at 0 - 0.3% w/w in the brined muscle (Carfosel™, supplied by Redbrook Ingredient Services Ltd., Mulhuddart, Ireland);
- PS, modified potato starch, at 0 - 2% (AllinAll Ingredients Ltd., Dublin, Ireland);

- RS, rice starch, at 0 - 2% (Remyline XS, Beneo, supplied by Healy Group, Dublin, Ireland); and
- CD, comminution degree, with two levels: 100% coarsely ground meat using a kidney plate (100/0), and 80% ground with a kidney plate plus 20% of meat ground with a 9 mm plate (80/20).

A constraint (PS + RS $\leq$ 2%) and a block effect were included in the experimental design, and 28 runs were generated by Design Expert software (18 model points, five points to estimate lack of fit and five replicates) within five blocks or weeks of processing. Each run represents a combination of the three ingredients for the brine formulation with one of the two comminution levels studied (Table 1).

2.2 Processing of hams

The experiment was conducted over five weeks with five or six ham formulations (runs) prepared each week, according to the design presented in Table 1. Each week, pork shoulders from female pigs, 4 d after slaughter (Rosderra Irish Meats Group, Edenderry, Ireland), were transported to the pilot scale abattoir and meat processing facility at Teagasc Food Research Centre Ashtown. Shoulders were excised and trimmed of excess fat (90-95% lean). The meat was ground with different plates: kidney and a 9 mm plate were used to prepare the two level of comminution studied (100/0 and 80/20), as explained in the section 2.1. Brines were prepared with levels of STPP, RS and PS specified by the design. Brines also contained pickling salt (0.5-0.6% $NaNO_2$, ESCO - European salt company, Hanover, Germany) and sodium ascorbate (Aland Nutraceutical Co. Ltd., Jiangsu, China) at 2.5% and 0.05% of the brined meat weight, respectively. The ground meat and the brine, yielding 120% of green meat weight, were mixed (MAINCA, Equipamientos Cárnicos SL, Barcelona, Spain) for 30 min (15 min clockwise and 15 min anti clockwise). After mixing, 2.5 kg of the mixture was vacuum packed using cooking bags (Food Processing Technology LTD, Dublin, Ireland), placed in metal rectangular casings and stored over night at 2-4 ºC. The following day, hams were steam cooked in a Rational® oven (Germany) at 100% relative humidity at 85 ºC to a core temperature of 72 ºC. Hams were subsequently chilled (2-4 ºC, 24 h) before being sub-sampled and vacuum packed for subsequent analyses [expressible moisture (day 1), colour, texture profile analysis (day 5), composition (days 7) and sensory (days 2 and 9)].

2.3 Weights and pH

pH (Thermo Orion Multimeter 250A, Orion Research Inc.) of brine, raw meat (4 d *post mortem*), and brined meat was recorded in duplicate. Meat weights were recorded after brining and cooking from which cook loss was calculated.

2.4 Composition analysis

Two 20 mm thick samples were homogenised in a Robot Coupe (R101, Robot Coupe SA, France). Intramuscular fat and moisture concentrations of minced samples were determined using the Smart System 5 microwave moisture drying oven and NMR Smart Trac rapid Fat Analyser (CEM Corporation USA) using AOAC Official Methods 985.14 & 985.26, 1990. Protein concentration was determined using a LECO FP328 (LECO Corp., MI, USA) Protein analyser based on the Dumas method and according to AOAC method 992.15, 1990. Salt (NaCl) was determined by titrating chloride ions in ashed (by furnace) samples with silver nitrite using the Mohr method (Kirk & Sawyer, 1991). All analyses were performed in duplicate, although further repetitions were made when a high standard deviation was obtained. Carbohydrate content was calculated [100- (moisture + ash + crude fibre + fat + crude protein)].

2.5 Colour

Ham colour (CIE L*a*b* system) was measured using a dual beam xenon flash spectrophotometer (Ultrascan XE, Hunterlab), with light illuminant D65, standard observer angle (8°) and a 25 mm port size. All values were the average of six independent measurements collected at random from duplicate ham slices (20 mm thick). Reflectance measurements were obtained at wavelengths of 570 and 650 nm, from which the cured colour ratio = 650 nm/570 nm (Sindelar, Cordray, Sebranek, Love & Ahn, 2007) was calculated.

2.6 Texture profile analysis and expressible moisture

Texture profile analysis (TPA) and expressible moisture were carried out using an Instron Universal Testing Machine (5542) using a 25 mm circular flat disk equipped with a 500N load cell (Instron Ltd., High Wycombe, UK). For TPA, eight cores (diameter 25 mm) from the two slices (20 mm thick) were axially compressed (5 cm min^{-1}) to 50% of the original height in a two cycle compression (Bourne, 1978). For expressible moisture, four cores (19 mm diameter x height 12.7 mm) were weighed and individually placed between two filter papers (12.5 cm Whatman No.1) to absorb expressed moisture (Schilling, Marriott, Acton, Anderson-Cook, Alvarado & Wang, 2004b). Cores were axially compressed (100 mm min^{-1}) between plates at a height of 3.2 mm (75% compression), held for 15s and then re-weighed. Expressible moisture (%) = [(initial weight-final weight)/initial weight)] x 100.

2.7 Sensory analysis

The panel consisted of eight members experienced in the analysis of meat products. The sensory profile was developed in two additional sessions. The resultant descriptors were: intensity of pink colour (low – high); number of holes (no holes – many holes); meaty odour, the odour associated with cooked pork; cooked ham odour, the typical odour associated with cooked ham; juiciness, amount of perceived juice released from the product during mastication (initial chews); tenderness, force required during the first bite between molars to deform the sample; springiness, degree and rapidity of recovery from a deforming force (compression by molar teeth); adhesiveness, force required to remove material that adheres to the mouth; cooked ham flavour, the typical flavour associated with cooked ham; and saltiness, taste of sodium chloride. Scores of the samples per plate were indicated in a 10 cm structured lineal scale, transformed into a numerical scale (0-100) for the statistical analysis. The quantitative descriptive test was performed in individual cabins with controlled environmental conditions under red light (ISO-8589, 1988). The test comprised five weekly sessions, and excepting the first session, samples from hams cooked on both the present and the previous week were presented (two repetitions per run) randomly in three / four samples per plate. Cross-sectional slices of each ham, 2 mm thick, were cut into three portions, wrapped in aluminium foil and marked with a random 3-digit code. To avoid the possible effects of the order of presentation and first-order carryover effects, the samples were presented in a balanced order (Macfie, Bratchell, Greenhoff & Vallis, 1989). To cleanse their palate between samples, panelists were given bottled water and unsalted crackers.

2.8 Data analysis

Statistical analysis was performed using Design Expert software. Each model was selected, i.e., linear, quadratic, by evaluating the regression coefficient (R^2) and lack of fit obtained from the analysis of variance (ANOVA). Models were considered significant when *P* values were lower than 0.05. Automatic reduction algorithms were applied to reduce the number of insignificant terms in the models. For the response expressible moisture, run 24 was identified as an outlier and therefore excluded for the statistical analysis. In addition to the response surface models, Pearson correlations were calculated using SPSS (v. 18.0, Chicago, USA) software.

3. RESULTS AND DISCUSSION

An RSM experiment was performed to evaluate the effect of meat comminution level and two sources of starch (RS and PS) as substitutes for conventionally used STPP in reformed cooked hams. Figs. 1-5 show the representation of the predicted values of the response surface models as contour or interaction plots. In the plots, the levels of one or two factors are shown while the others are fixed to the levels specified in the figures. Table 3 presents several formulations selected to optimize cooking loss and overall liking. Finally, a detail of the model characteristics of the responses with significant effect ($P < 0.05$) for reformed hams and the significance and F values of the individual, interaction and quadratic effects is presented in the supplementary material (Tables A1-3).

In general, the two studied starch types (RS and PS) improved cook loss and decreased ham flavour intensity in a similar fashion to each other, but RS had stronger effects on the instrumental measures of texture (expressible moisture and texture profile analysis, TPA), while PS could improve juiciness in formulations when low/no added STPP is included. Interaction between CD and RS effects was found for the colour of the hams measured instrumentally and with a trained sensory panel. Coarsely ground meat resulted in a small increase in cook loss, reduced TPA parameters and produced a more intense ham flavour. Finally, STPP was the sole factor affecting overall liking, which may be mostly explained by a reduced number of holes and improved juiciness of the hams at higher phosphate levels.

3.1 Cook loss, pH and chemical composition

Cook loss data was fitted to a quadratic model (R^2 0.97), and was mainly affected by STPP and the interactions between STPP and each starch (Table A1). As predicted, brined meat pH and the percentage of moisture increased in the cooked hams with the rise of STPP in the brine, while the cook loss was reduced (Table A1), as has been found in previous papers (Lee, Hendricks & Cornforth, 1998; Moiseev et al., 1997; Trout & Schmidt, 1984). Phosphates function to increase the binding and retention of the myofibrillar water due to the increase in muscle pH and ionic strength and the disruption of the myofibril structure when they are added (Bertram, Kristensen & Andersen, 2004; Lowder et al., 2013; Offer & Trinick, 1983; Trout & Schmidt, 1986). Conversely, starches have a different mechanism of action, i.e. they are thought to entrap the extra-myofibrillar water in starchy gel structures (Resconi et al., 2015). The complementary nature of their modes of action might explain why starches were more effective in reducing cook loss when low amounts of STPP were added (Figure 1).

Figure 1 reveals that with the addition of approximately 1.25% of starch, a 50% reduction in the use of STTP could be achieved, while maintaining a similar cook loss as obtained when adding the traditional levels of STPP (0.30% in the brined meat). In the study of Zhang and Barbut (2005), chicken meat batters produced with modified tapioca starch had lower cook loss compared to products made with regular tapioca starch and regular and modified potato starch. In the present study, the two starches studied acted similarly and no synergistic effect was observed. Fat and protein percentage were lowered by the two starches (Table A1) as expected, since they provide carbohydrates, but their functionality in retaining water might also have influenced the results.

3.2 Visual characteristics

With respect to instrumental colour measurements, only yellowness and chroma produced significant models (with R^2 0.45 and 0.46, respectively). These parameters increased in association with rice starch inclusion in hams made with 100% ground meat with the kidney plate, but opposite results were found for the 80/20 treatment (Figure 2). The pink colour intensity assessed by the sensory panel corresponds with the results found instrumentally, wherein an interaction between comminution degree and RS inclusion was found (Figure 2). In sausages, one study found that starch affected lightness, redness and yellowness in a linear fashion but these parameters were also affected by interactions between other non-meat ingredients (Amini Sarteshnizi et al., 2015); whereas another study found that starch had an effect only on lightness (García-García & Totosaus, 2008). We have previously found a reduction in redness with the inclusion of rice starch in whole muscle hams (Resconi et al., 2015).

Many inter-related factors are thought to influence the colour of reformed hams, including the concentration and chemical state of myoglobin and the physical characteristics of the product (Cofrades et al., 2004). The present results might be explained by the effects of rice starch and comminution degree on the percentage of protein which could dilute/concentrate the myoglobin, but also by their effects in water distribution and other texture parameters. However, it should be noted that a difference in objective measurements of colour is not necessarily translated into a difference in colour acceptability (Resconi et al., 2016). In fact, in the present study, no correlation between overall liking and pink colour intensity was found (Table 3). Furthermore, the mean cured colour ratio obtained was 2.41 ± 0.133, which was unchanged by the factors studied and indicates that an "excellent cured colour" (Sindelar et al., 2007) was reached in the restructured hams.

Other than colour, another visual aspect presumably relevant in hams could be the presence of holes in the product (Hullberg, Johansson & Lundström, 2005). Although Irish consumers stated that they are not very concerned by the presence of holes in cooked ham (Resconi et al., 2016), if the number and size of holes are considerable, it might be perceived as a defect in the product by consumers (deeming it inferior) and make it difficult to slice for retailers. Phosphate was the single factor that affected the number of holes in a linear manner (R^2 = 0.47), indicating their major role in providing effective binding of the meat pieces in a restructured product. This is supported by previous studies (Trout et al., 1984). Although starches have previously been shown to have a positive effect on binding meat particles (Petracci et al., 2013), no such effect was found in the present study by the sensory panel.

3.3 Sensorial and instrumental assessment of the texture

Expressible moisture, measured by instrumental compression, was reduced with the inclusion of RS but no other factors significantly affected ($P < 0.05$) of this parameter, although there was a tendency for PS to decrease the expressible moisture ($P = 0.074$). Previous studies have found that starch binds the loosely bound or free water in meat systems (Motzer et al., 1998; Schilling et al., 2004b), which was supported by a recent NMR analysis in cooked hams (Resconi et al., 2015). On the other hand, juiciness, the sensory parameter that measures the moisture released by compression with the teeth, was positively influenced by PS (but not RS) when low / no STPP was included in the hams (Figure 3). In another study, modified corn starch also improved the juiciness of hams (Prabhu & Sebranek, 1997). The differences we have found between the two starches studied in expressible moisture and juiciness might relate to the smaller size and higher number of granules in rice starch compared to potato starch granules (Li et al., 2002), which might explain the ability of RS to bind the water hydrated in the starch gels more tightly than PS.

Texture profile analysis parameters produced significant linear models that were in general affected by all the factors studied independently (Table A2). Both starches reduced hardness, chewiness, gumminess (as opposed to STPP) and cohesiveness, with the effect of RS being stronger compared to PS. Previous studies (Motzer et al., 1998; Schilling et al., 2003) have also reported a reduction in texture parameters with starch inclusion in restructured hams. Because starch dilutes the meat component of the product, this may provoke a disruption of the meat matrix. Potato starch granules are probably too large to be trapped in the protein but almost all the rice starch granules were embedded in the protein network due to their smaller size (Li et al., 2002) and that might provide some explanation for our results. However, the observed effects of the starches in the texture profile analysis were not perceived in the sensory test.

While in whole muscle hams, phosphates reduced TPA hardness and gumminess (Resconi et al., 2015), these parameters were increased linearly in reformed hams (as well as springiness and chewiness), which reflect their role in the binding of meat pieces (Trout et al., 1986). In the study of Nielsen, Petersen and Møller (1995), an increase in hardness was associated with phosphate inclusion to a level of 0.2%, after which hardness then decreased. Here, we have found a continual linear increase in hardness with added phosphate up to the maximum levels studied (0.3%). In the sensory analysis, STPP increased springiness and tenderness, and decreased adhesiveness (Figure 5). This is supported by previous research (Resconi et al., 2016; Sheard, Nute, Richardson, Perry & Taylor, 1999). The effect of phosphate on sensory springiness agrees with the TPA analysis, but the effect on tenderness is opposite. It may be that the structure of the meat pieces individually are less tough while overall the ham is more tightly bound with the action of phosphates, which could explain also why STPP increased the tenderness particularly in the coarsely ground samples (Figure 5). The effect of phosphates on juiciness, could also contribute to the perception of a less tough ham product.

3.4 Flavour and overall liking

Ham flavour intensity was affected linearly by all the factors tested (R^2 = 0.52), but overall liking was improved only by STPP (Table 4). Meaty and ham odour intensities and saltiness did not provide significant models (P > 0.05), in spite of the increase in salt percentage caused by STPP (Table A1) and the previously reported effects of phosphates on saltiness (Matlock, Terrell, Savell, Rhee & Dutson, 1984). Both starches decreased the ham flavour intensity, which could potentially be explained by the dilution of the meat components, although this was not observed in a recent whole muscle ham study (Resconi et al., 2016).

The typical flavour intensity and the general liking increased with the inclusion of phosphates, as other authors have shown (Moiseev et al., 1997). The Pearson correlations (Table 2) showed that overall liking was particularly related to the number of holes and to sensory juiciness, but also to tenderness, springiness and adhesiveness, and because of the improvement of all these aspects by the use of phosphate, this ingredient was the sole factor affecting overall liking (linear model, R^2 0.47).

3.5 Comminution degree

Cook loss was slightly higher for the coarsely ground meat using the kidney plate (100/0) compared with the more finely comminuted 80/20 treatment, but the effect of comminution degree on cook loss was much less than the effects of the functional ingredients tested (Table 2). Cofrades et al. (2004) also found a lower exudate loss upon heating in finely, compared to coarsely ground beef (grinder plate hole: 0.6 and 1.4 cm, respectively); whereas no effect of pre-mincing in cook yield was found in other studies (Boles et al., 1998; Estévez, Ventanas, Heinonen & Puolanne, 2011). As discussed previously, comminution degree affected the colour of hams differently depending on the level of RS (Figure 2). Similarly, interactions between non-meat ingredients and particle size were found previously for lightness in restructured beef (Cofrades et al., 2004). In another study with deli ham rolls, smaller particles gave lower L* and b* values (Schilling, Alvarado & Marriott, 2004a). In the present study, a tendency for the effect of comminution degree to influence instrumental texture was found (P = 0.056), with the meat ground 100% by the kidney plate being less hard, potentially due to a lower bind strength for the larger meat pieces, as suggested previously (Cofrades et al., 2004). The 100/0 samples were also less chewy, gummy and springy (Table A2). However, differences were not perceived sensorially.

The hams with 100% kidney plate ground meat were associated with a more intense flavour. In reformed beef, the acceptability of flavour of coarsely ground meat was improved compared to finely ground in one study (Cofrades et al., 2004), although no such effects were found in Boles and Shand (1998).

In summary, the 80/20 treatment slightly improved the technological quality but dulled the flavour of the reformed hams. Although TPA measures indicate a better binding of the meat pieces in the 80/20, the sensory perceived texture was not affected; whereas the colour of the ham produced by each comminution level depends on the quantity of RS included (but does not affect product acceptability). In practical terms, the quality differences found in our study could be considered minor and both particles sizes could help to reach an acceptable quality and therefore, other factors such as easy handling and the quality of the raw meat used (quantity of connective tissue/fat) would weigh more in decision making.

3.6 Optimization

Through the use of the optimization tool of the RSM, using the criteria 'minimizing cook loss, maximizing overall liking', 82 different formulations were proposed, which are summarized in Table 3. The two comminution levels studied could be used similarly. The optimal adjunct combinations (higher desirability) for the selected criteria were achieved when 0.3% of STPP and > 0.6% of any starch (or a combination of both) were included. With this solution (solution a), the predicted cook loss improved with respect to a reformed ham without starch (< 2.0% *versus* 2.6%). However, very subtle (almost no) predicted deterioration of the two responses (cook loss and overall liking) could be achieved by reducing STPP to 0.18% and including any starch at 2% (solution b). When using only salt and phosphate as binders, Schwartz and Mandigo (1976) concluded that at least 0.13% of sodium tripolyphosphate is needed when producing restructured pork. The third solution explored (solution c) implies practically avoiding the use STPP (adding just 0.03%) and including 2% of starch, resulting an estimated cook loss of approximately 5% (acceptable) but a lower sensory acceptability (Table 3).

CONCLUSION

Based in our results we recommend a reduction in the use of STPP in reformed hams through the inclusion of starch at optimised levels to achieve a similar technological quality to products with standard phosphate inclusion levels (0.3%). It is likely that formulations achieving this level of reduction will be positively received by consumers. A total exclusion of STPP is not recommended by the models, largely because this work suggests phosphate plays an important role in the sensory quality of reformed ham products. The different type of starch (potato or rice starch) and the different comminution degree studied differed somewhat in their effects on several of the objective characteristics, such as the colour or the texture of the hams. However, both starches and comminution levels studied could be used similarly to achieve good yield and sensory acceptability of the product. Predicted optimal formulations for cook loss and sensory acceptability included 0.3% of STPP and > 0.6% of either starch (or a combination of both), by using either of the comminution levels studied.

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REFERENCES

Amini Sarteshnizi, R., Hosseini, H., Bondarianzadeh, D., Colmenero, F. J., & khaksar, R. (2015). Optimization of prebiotic sausage formulation: Effect of using Î²-glucan and resistant starch by D-optimal mixture design approach. *LWT - Food Science and Technology*, *62*(1, Part 2), 704-710.

Berry, B. W., Smith, J. J., & Secrist, J. L. (1987). Effects of Flake Size on Textural and Cooking Properties of Restructured Beef and Pork Steaks. *Journal of Food Science*, *52*(3), 558-563.

Bertram, H. C., Kristensen, M., & Andersen, H. J. (2004). Functionality of myofibrillar proteins as affected by pH, ionic strength and heat treatment - a low-field NMR study. *Meat Science*, *68*(2), 249-256.

Boles, J. A., & Shand, P. J. (1998). Effect of comminution method and raw binder system in restructured beef. *Meat Science*, *49*(3), 297-307.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology*, *33*, 62-66.

Cofrades, S., Serrano, A., Ayo, J., Solas, M. T., Carballo, J., & Colmenero, J. (2004). Restructured beef with different proportions of walnut as affected by meat particle size *European Food Research and Technology*, *218*(3), 230-236.

Estévez, M., Ventanas, S., Heinonen, M., & Puolanne, E. (2011). Protein Carbonylation and Water-Holding Capacity of Pork Subjected to Frozen Storage: Effect of Muscle Type, Premincing, and Packaging. *Journal of Agricultural and Food Chemistry*, *59*(10), 5435-5443.

Feiner, G. (2006). 10 - Re-formed products: non-injection methods for adding brine. In: G. Feiner, *Meat products handbook. Practical science and technology* (pp. 220-233). Cambridge, England: Woodhead Publishing Limited.

Fernández, P., Cofrades, S., Solas, M. T., Carballo, J., & Colmenero, F. J. (1998). High Pressure-Cooking of Chicken Meat Batters with Starch, Egg White, and Iota Carrageenan. *Journal of Food Science*, *63*(2), 267-271.

García-García, E., & Totosaus, A. (2008). Low-fat sodium-reduced sausages: effect of the interaction between locust bean gum, potato starch and j-carrageenan by a mixture design approach. *Meat Science*, *78*, 406-413.

Hughes, E., Mullen, A. M., & Troy, D. J. (1998). Effects of fat level, tapioca starch and whey protein on frankfurters formulated with 5% and 12% fat *Meat Science*, *48*(l/2), 169-180.

Hullberg, A., Johansson, L., & Lundström, K. (2005). Effect of tumbling and RN genotype on sensory perception of cured-smoked pork loin. *Meat Science*, *69*(4), 721-732.

Keenan, D. F., Resconi, V. C., Kerry, J. P., & Hamill, R. M. (2014). Modelling the influence of inulin as a fat substitute in comminuted meat products on their physico-chemical characteristics and eating quality using a mixture design approach. *Meat Science*, *96*(3), 1384-1394.

Kirk, R. S., & Sawyer, R. (1991). Chapter 2: General chemical methods. *Pearson's composition and analysis of foods* (pp. 14-15): Longman Scientific and Technical.

Lee, B. J., Hendricks, D. G., & Cornforth, D. P. (1998). Effect of sodium phytate, sodium pyrophosphate and sodium tripolyphosphate on physico-chemical characteristics of restructured beef. *Meat Science*, *50*(3), 273-283.

Li, J.-Y., & Yeh, A.-I. (2002). Functions of starch in formation of starch/meat composite during heating. *Journal of Texture Studies*, *33*(4), 341-366.

Lowder, A. C., Goad, C. L., Lou, X., Morgan, J. B., Koh, C. L., Deakins, A. P., & DeWitt, C. A. M. (2013). Response surface modeling to predict fluid loss from beef strip loins and steaks injected with salt and phosphate with or without a dehydrated beef protein water binding adjunt. *Meat Science*, *94*(1), 9-18.

Macfie, H. J., Bratchell, N., Greenhoff, K., & Vallis, L. V. (1989). Designs to balance the effect of order presentation and first-order and carryover effects in hall tests. *Journal of Sensory Studies*, *4*, 129-148.

Matlock, R. G., Terrell, R. N., Savell, J. W., Rhee, K. S., & Dutson, T. R. (1984). Factors Affecting Properties of Precooked-Frozen Pork Sausage Patties Made with Various NaCl/Phosphate Combinations. *Journal of Food Science*, *49*(5), 1372-1375.

Moiseev, I. V., & Cornforth, D. P. (1997). Sodium hydroxide and sodium tripolyphosphate effects on bind strength and sensory characteristics of restructured beef rolls. *Meat Science*, *45*(1), 53-60.

Motzer, E. A., Carpenter, J. A., Reynolds, A. E., & Lyon, C. E. (1998). Quality of restructured hams manufactured with PSE pork as affected by water binders. *Journal of Food Science*, *63*(6), 1007-1011.

Nielsen, G. S., Petersen, B. R., & Møller, A. J. (1995). Impact of salt, phosphate and temperature on the effect of a transglutaminase (F XIIIa) on the texture of restructured meat. *Meat Science*, *41*(3), 293-299.

Nielsen, H. T., Høegh, L., & Møller, A. J. (1996). Effect of kappa carrageenan/locust bean gum mixture on bind and cooking loss in high mannuronate alginate restructured beef. *Journal of Muscle Foods*, *7*(4), 413-424.

Offer, G., & Trinick, J. (1983). On the mechanism of water holding in meat: The swelling and shrinking of myofibrils. *Meat Science*, *8*(4), 245-281.

Petracci, M., Bianchi, M., Mudalal, S., & Cavani, C. (2013). Functional ingredients for poultry meat products. *Trends in Food Science & Technology*, *33*(1), 27-39.

Pietrasik, Z., & Janz, J. A. M. (2010). Utilization of pea flour, starch-rich and fiber-rich fractions in low fat bologna. *Food Research International*, *43*, 602-608.

Prabhu, G. A., & Sebranek, J. G. (1997). Quality Characteristics of Ham Formulated with Modified Corn Starch and Kappa-Carrageenan. *Journal of Food Science*, *62*(1), 198-202.

Resconi, V. C., Keenan, D. F., Barahona, M., Guerrero, L., Kerry, J. P., & Hamill, R. M. (2016). Rice starch and fructo-oligosaccharides as substitutes for phosphate and dextrose in whole muscle cooked hams: Sensory analysis and consumer preferences. *LWT - Food Science and Technology*, *66*, 284-292.

Resconi, V. C., Keenan, D. F., Gough, S., Doran, L., Allen, P., Kerry, J. P., & Hamill, R. M. (2015). Response surface methodology analysis of rice starch and fructo-oligosaccharides as substitutes for phosphate and dextrose in whole muscle cooked hams. *LWT - Food Science and Technology*, *64*(2), 946-958.

Ruusunen, M., Niemistö, M., & Puolanne, E. (2002). Sodium reduction in cooked meat products by using commercial potassium phosphate mixtures. *Agricultural and Food Science in Finland*, *11*, 199-207.

Schilling, M. W., Alvarado, C. Z., & Marriott, N. G. (2004a). Particle size and nonmeat adjunct effects on the protein functionality of boneless cured pork formulated with PSE and RFE raw material. *Journal of Muscle Foods*, *15*(1), 57-68.

Schilling, M. W., Marriott, N. G., Acton, J. C., Anderson-Cook, C., Alvarado, C. Z., & Wang, H. (2004b). Utilization of response surface modeling to evaluate the effects of non-meat adjuncts and combinations of PSE and RFN pork on water holding capacity and cooked color in the production of boneless cured pork. *Meat Science*, *66*(2), 371-381.

Schilling, M. W., Marriott, N. G., Acton, J. C., Anderson-Cook, C., Duncan, S. E., & Alvarado, C. Z. (2003). Utilization of response surface modeling to evaluate the effects of nonmeat adjuncts and combinations of PSE and RFN pork on the texture of boneless cured pork. *Journal of Muscle Foods*, *14*(2), 143-161.

Schwartz, W. C., & Mandigo, R. W. (1976). Effect of salt, sodium tripolyphosphate and storage on restructure pork. *Journal of Food Science*, *41*(6), 1266-1269.

Sheard, P. R., Nute, G. R., Richardson, R. I., Perry, A., & Taylor, A. A. (1999). Injection of water and polyphosphate into pork to improve juiciness and tenderness after cooking. *Meat Science*, *51*(4), 371–376.

Sindelar, J. J., Cordray, J. C., Sebranek, J. G., Love, J. A., & Ahn, D. U. (2007). Effects of varying levels of vegetable juice powder and incubation time on color, residual nitrate and nitrite, pigment, pH, and trained sensory attributes of ready-to-eat uncured ham. *Journal of Food Science, 72*(6), S388-S395.

Skrede, G. (1989). Comparison of various types of starch when used in meat sausages. *Meat Science*, *25*(1), 21-36.

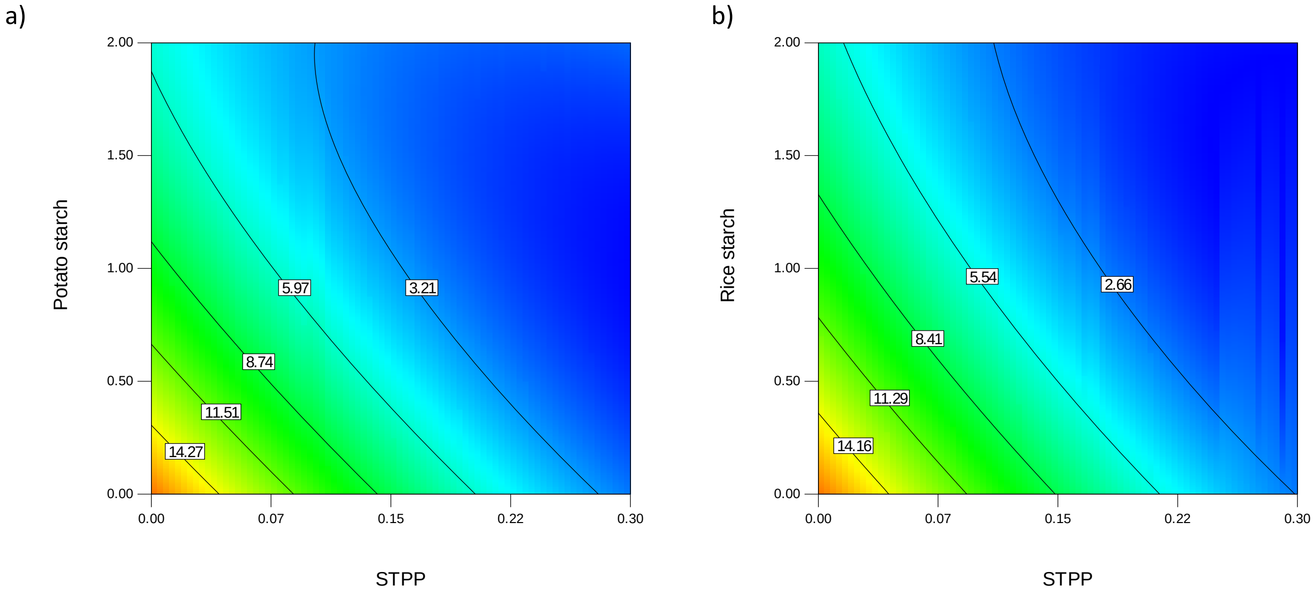
Teye, M., & Teye, G. A. (2011). The Use of Sweet Potato (Ipomoea Batatas) Starch as Binder in Beef and Pork Frankfurter-Type Sausages. *Journal of Animal Science Advances, 1*(1), 21-27.

Trout, G. R., & Schmidt, G. R. (1984). Effect of Phosphate Type and Concentration, Salt Level and Method of Preparation on Binding in Restructured Beef Rolls. *Journal of Food Science*, *49*(3), 687-694.

Trout, G. R., & Schmidt, G. R. (1986). Effect of phosphates on the functional properties of restructured beef rolls: the role of pH, ionic strength, and phosphate type. *Journal of Food Science*, *51*(6), 1416-1423.

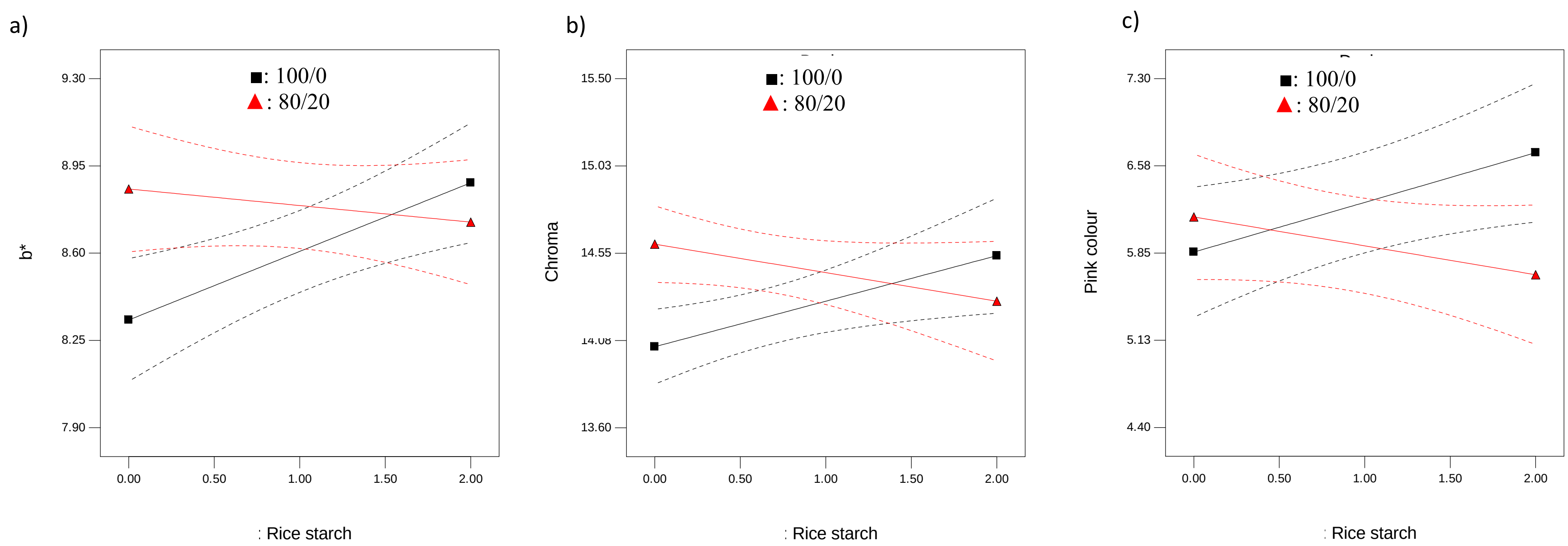
Zhang, L., & Barbut, S. (2005). Effects of regular and modified starches on cooked pale, soft, and exudative; normal; and dry, firm, and dark breast meat batters. *Poultry Science*, *84*(5), 789-796.

Figure 1. Contour plots presenting the response surfaces for cook loss in reformed hams, in relation to starch and phosphate level, expressed in percentages



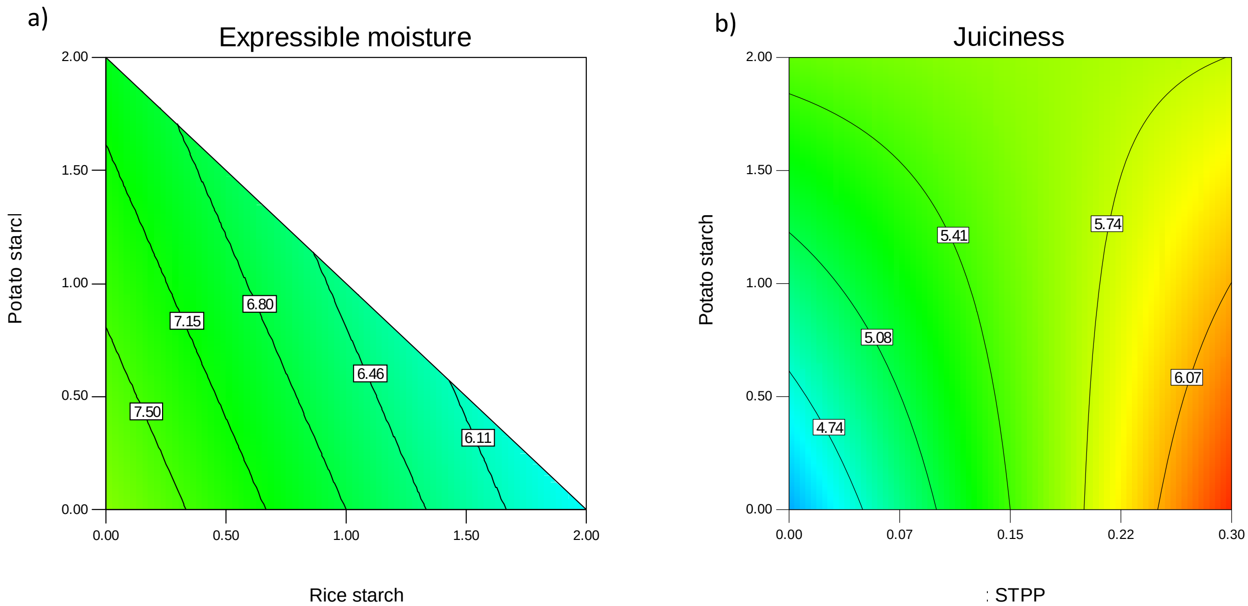
The levels of the ingredients are expressed in % by weight of the brined meat. The remaining factors were fixed at the following settings: a) Rice starch: 0, Comminution degree: average; b) Potato starch: 0, Comminution degree: average. STPP: sodium tripolyphosphates.

Figure 2. Interaction plots (comminution degree x rice starch) according to the response surface models for colour in reformed hams: yellowness (b*), chroma and pink colour intensity



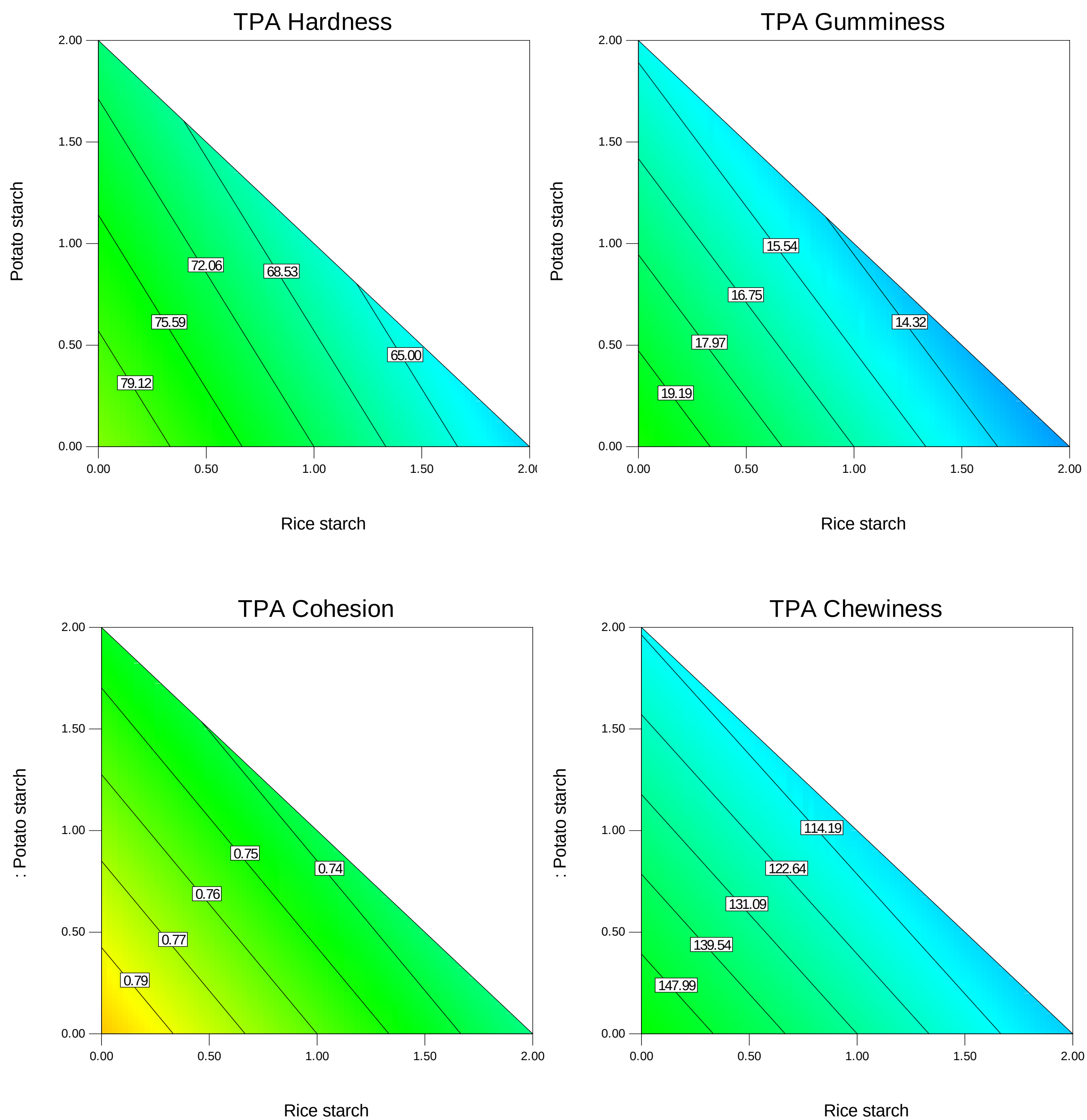
The levels of RS are expressed in % by weight of the brined meat. The remaining factors were fixed at the following settings: STPP: 0.3, Potato starch: 0. MS: meat size. RS: rice starch. STPP: sodium tripolyphosphates.

Figure 3. Contour plots presenting the response surfaces for expressible moisture and juiciness in reformed hams



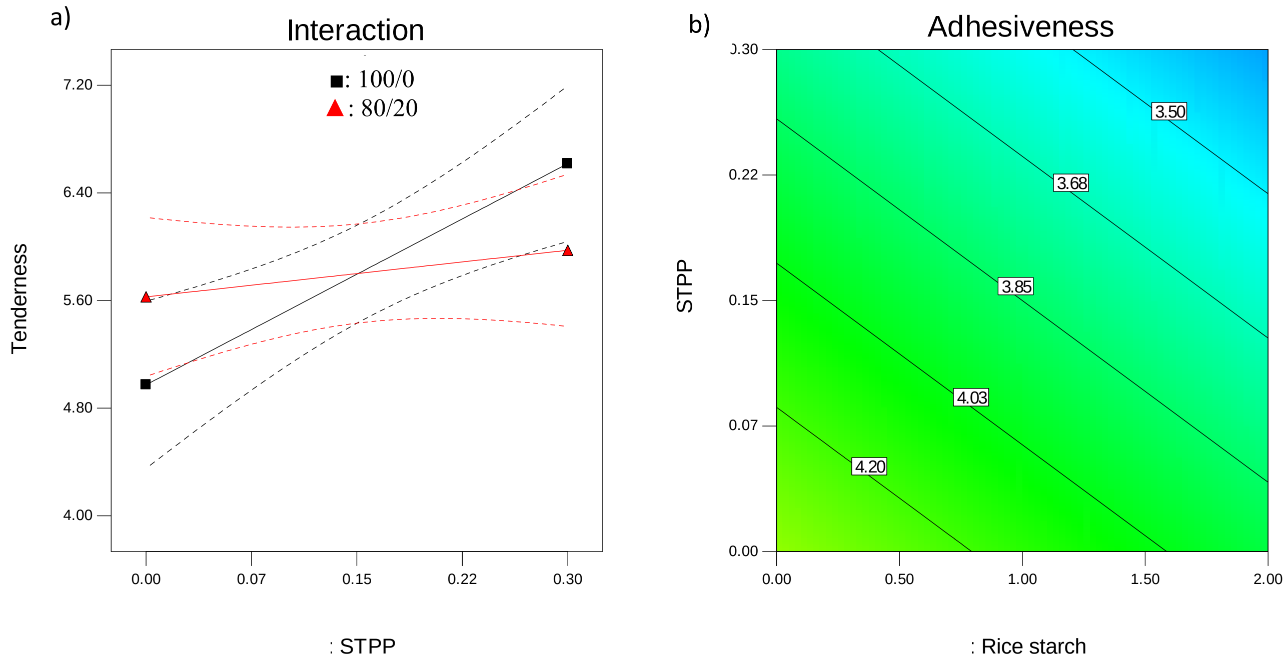
The levels of the ingredients are expressed in % by weight of the brined meat. The remaining factors were fixed at the following settings: a) STPP: 0, Meat Size: average; b) Rice starch: 0, Comminution degree: average. STPP: sodium tripolyphosphates.

Figure 4. Contour plots presenting the response surfaces for texture profile analysis parameters in reformed hams



The levels of the ingredients are expressed in % by weight of the brined meat. The remaining factors were fixed at the following settings: STPP: 0, Comminution degree: average, STPP: sodium tripolyphosphates.

Figure 5. Representation of the response surface models for two sensory attributes in reformed hams



The levels of the ingredients are expressed in % by weight of the brined meat. The remaining factors were fixed at the following settings: a) Potato starch: 0, Comminution degree: average; b) Rice starch: 0, Potato starch: 0, STPP: sodium tripolyphosphates.