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Investigating the effects of ingredient levels on physical quality properties of cooked hamburger patties using response surface methodology and image processing technology

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ABSTRACT

A three-factor central composite design was adopted to determine the interactive effects of fat (15–30%), water (10–20%) and textured soy protein (3–9%) content on the shrinkage, fat loss and moisture loss of hamburger patties after cooking. Image processing was used to estimate the shrinkage of hamburger patties. Textured soy protein (TSP) content was found to be the most important factor for minimizing fat and moisture loss. Both fat and water content were found to be significantly effective ($P < 0.05$) in the model for shrinkage and moisture loss in linear form. The changes in shrinkage due to fat, water and TSP content were also in linear form. The model for fat loss was in linear and quadratic form, whereas the model for moisture loss was in full quadratic form. The models for shrinkage, fat loss and moisture loss had the *R*-square values of 0.954, 0.969 and 0.964, respectively.

1. Introduction

In Turkey, meat and meat products are usually marketed in small butcher shops as steaks and or in ground form. Most people prefer to consume meat and meat products in the latter form. Therefore, in Turkey, a large number of meat products are prepared from ground meat, such as hamburger patties, meatballs, and kebabs (Ulu, 2004, 2006; Yilmaz & Daglioglu, 2003).

Besides quality factors such as colour, taste and texture, the characteristics such as shrinkage, fat loss and moisture loss of hamburger patty are considered as important quality criteria by the consumers. The industrial companies manufacturing hamburger patties for the fast food sector have to pay considerable attention to the standardization of the sizes of hamburger patties. In the fast food sector, the hamburger patties are generally consumed with hamburger buns, and the appearance of patties in the buns is important for the consumers. If the raw and expected sizes of cooked hamburger patties do not meet the required standards, the products are possibly rejected by fast food companies. Hamburger patty shrinkage has never been directly measured. The researchers usually measured the differences between diameter and thickness of the cooked and raw hamburger patties and used these parameters for estimating the shrinkage (Modi, Mahendrakar, Narasimha Rao, & Sachindra, 2003; Serdaroglu & Degirmencioglu, 2004; Serdaroglu, Yildiz-Turp, & Abrodimov, 2005; Ulu, 2006). Measuring the diameter and thickness appeared to be insufficient for the estimation of shrinkage because of the uncertainties in the selection of measurement points.

According to the model presented by Godsalve, Davis, and Gordon (1977) for muscle meat, during cooking, the muscle proteins denature, thereby leading to a decrease in their water holding capacity and shrinkage of the protein network. The shrinking network exerts a mechanical force on the water between the fibres. In the presence of pressure gradients, the excess interstitial water is expelled to the surface of the meat. The expelled fluid is commonly known as cooking loss.

Although there are differences between muscle meat and hamburger patty with regard to the structure and the content, shrinkage is strongly related to the loss of moisture and fat of the meat product. Numbers of researches have been conducted to study the effects of ingredients (Gujral, Kaur, Singh, & Sodhi, 2002; Hsu & Chung, 2000, 2001; Modi et al., 2003; Serdaroglu, 2006; Yilmaz, 2005) and cooking conditions (Hsu & Chung, 1998; Jakobsen & Bertelsen, 2000) on the overall quality of burgers, patties and meatballs. Some researches have also been performed on the shrinkage characteristic of fresh meat (Kong, Tang, Lin, & Rasco, 2008; Zheng, Sun, & Du, 2006).

Computer vision and image processing techniques (IPT) help in the accurate, fast and objective quality determination of important characteristics of food products (Aguirre, Frias, Barry-Ryan, & Grogan, 2009; Briones & Aguilera, 2005; Brosnan & Sun, 2004;

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Johansen, Laugesen, Janhøj, Ipsen, & Frøst, 2008; Kilic, Boyaci, Koksel, & Kusmenoglu, 2007). As an objective, fast and non-destructive tool, image processing has been increasingly applied to determine the different qualitative properties of fresh meat (Barbera & Tassone, 2006; Jackman, Sun, Du, Allen, & Downey, 2008; Tan, 2004) and a wide range of meat products (Du & Sun, 2006a, 2006b; Mendoza et al., 2009; Valous, Mendoza, Sun, & Allen, 2009). IPT could also be automatically implemented for the measurement of the shrinkage of hamburger patty.

Response surface methodology (RSM), a powerful mathematical and statistical technique for testing multiple process variables and their interactive and quadratic effects, is useful in solving multivariable equations obtained from experiments simultaneously. In the analysis of interactions between the responses (dependent variables) and the factors (independent variables) of experiment, this technique provides an advantage of the reduction in the number of experiments as compared to the full experimental design (Ghodke, Ananthanarayan, & Rodrigues, 2009; Murphy, Gilroy, Kerry, Buckley, & Kerry, 2004; Shih, Kuo, Hsieh, Kao, & Hsieh, 2008; Tiwari, Muthukumarappan, O'Donnell, & Cullen, 2008).

RSM has been used for the simultaneous analysis of the effects of process parameters in fresh meat processing (Jakobsen & Bertelsen, 2000) and also in some meat products (Desmond, Troy, & Buckley, 1998; Hsu & Chung, 2000, 2001; Hsu & Yu, 1999). According to these researches, RSM can help in predicting the combined effects of ingredients on shrinkage, fat loss and moisture loss of hamburger patties.

The aim of the present work is to determine the combined effect of fat, water and TSP content on shrinkage, fat loss and moisture loss of hamburger patties and to develop mathematical models to find the optimum percentages of these ingredients for these criteria by using RSM and IPT. These models will provide a new approach for proposing optimum levels for water, fat and TSP addition in order to produce standard products preferred by the consumers.

Table 1
Experimental range levels of three independent variables in terms of actual values.

Variables	Symbols	Coded variable levels				
		−α (−1.682)	−1	0	1	+α (1.682)
Fat (%)	X_1	9.9	15.0	22.5	30.0	35.1
Water (%)	X_2	6.6	10.0	15.0	20.0	23.4
TSP (%)	X_3	1.0	3.0	6.0	9.0	11.0

2. Materials and methods

2.1. Experimental design

In this study, effects of fat, water and TSP contents on shrinkage, fat loss and moisture loss of hamburger patties after cooking were investigated using RSM. Experimental range levels of the three independent variables in terms of the actual values are given in Table 1 with coded variable levels. Twenty runs were performed in a completely random order according to the central composite design with three factors, six replicates at the center points and a single run for each of the other combinations. Duplicate experiments were carried out at all design points. The experimental design is given in Table 2.

Beef meat, fat, spices and additives were supplied from local market. Hamburger patty samples were produced in 3 kg batches for every run. Beef meat (moisture 74%, fat 10%) was ground, and fat (fat 90%, moisture 8%), water, TSP (protein 70%, moisture 3%) and spices (cumin 0.4%, red pepper 0.4%, black pepper 0.3%, onion powder 0.2%, allspice 0.2% and salt 1.5%) were separately added in order to adjust the percentages of the ingredients according to experimental design for each 3 kg batch. Each portion was kneaded for 15 min using hands to obtain homogeneous dough. The dough was stored in a cold room (+4 °C) for 1 day. The dough in each batch was shaped into hamburger patties by using manual hamburger patty forming machine. The prepared hamburger patties had the following dimensions: a diameter of 6 cm, a height of 1.5 cm and an approximate weight of 50–60 g. Hamburger patties were cooked in a pre-heated Teflon® coated pan according to a standard protocol of 3 min, 1 min and then 15 s on each side to achieve an internal end-point temperature of 72 °C (measured using a thermocouple). The flow chart for the production of hamburger patty is shown in Fig. 1.

2.2. Image acquisition

The raw and cooked hamburger patties were placed directly on a flatbed scanner (HP Scanjet 3400C) that was placed in a closed

Table 2
Central composite design arrangement and experimental responses.

Run order	Fat (%)	Water (%)	TSP (%)	Meat (%)	Spices (%)	Shrinkage (%)	Moisture loss (%)	Fat loss (%)
1	15	20	9	53	3	34.70	9.20	8.35
2	30	10	3	54	3	52.16	15.35	27.66
3	30	10	9	48	3	42.70	8.10	14.67
4[a]	22.5	15	6	53.5	3	41.68	14.98	30.76
5[a]	22.5	15	6	53.5	3	42.85	15.01	28.75
6	22.5	6.5	6	62	3	40.89	10.01	24.54
7	15	20	3	59	3	44.67	18.66	23.18
8[a]	22.5	15	6	53.5	3	46.20	14.67	30.43
9	15	10	3	69	3	35.87	14.49	22.96
10	15	10	9	63	3	31.42	8.14	10.41
11	35	15	6	41	3	52.53	14.39	28.98
12[a]	22.5	15	6	53.5	3	43.58	13.34	30.63
13	22.5	15	11	48.5	3	38.21	5.45	3.25
14	22.5	15	1	58.5	3	49.24	21.01	28.27
15[a]	22.5	15	6	53.5	3	43.58	14.66	29.10
16	30	20	9	38	3	49.01	10.88	14.43
17[a]	22.5	15	6	53.5	3	43.58	15.44	29.60
18	22.5	23.5	6	45	3	48.51	18.75	27.54
19	10	15	6	66	3	30.73	13.48	17.80
20	30	20	3	44	3	55.23	21.62	31.47

[a] Central points of experimental design.

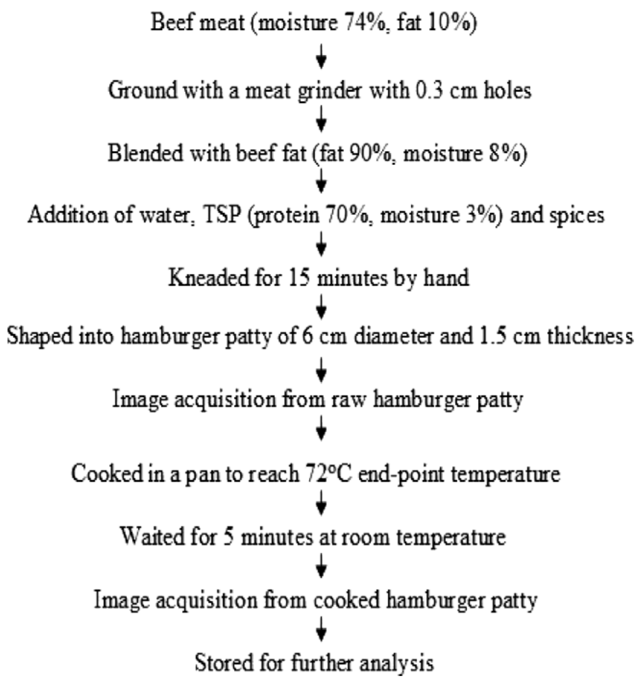

Fig. 1. Flow chart of hamburger patty production.

box to avoid light from outside, scanned with a spatial resolution of 200 points per inch, and the images were stored as JPEG (Joint Photographic Experts Group) file format with a size of 1900 × 1900 pixels. White background was used to enhance the contrast between the background and the object of interest. As indicated by Stien et al. (2006), the scanner was calibrated using the white surface that exists in the scanner lid, and same calibration was used throughout the experiment. The scanner platen was wiped clean between each scanning by using paper tissue and a fat-solvent liquid.

2.3. Image processing

2.3.1. Instrumentation

The image processing system consisted of a PC with Intel® Core™ 2 CPU, T7200 2.00 GHz processor, 2 GB Ram and Nvidia GeForce GO 7400 graphic card for image capture and processing. Image processing and further operations were performed in Windows Vista™ Professional environment with original algorithms implemented using Matlab® 7.5.0 (The Mathworks, Natick, MA) for the development of image analysis programmes.

2.3.2. Image segmentation

Segmentation was performed in five main steps, which were as follows:

- Detection of the hamburger patty on the background was performed by using Matlab function "edge" and an operator "sobel". These were used to calculate the threshold value, and then, the function "edge" was used again to obtain a binary mask that contained the segmented hamburger patty.
- Dilation was done by using linear structuring element created using the Matlab function "strel" to clean the gaps on the lines that surrounding the object of interest. Dilation was completed by the "imdilate" function using the horizontal structuring element.
- Filling the interior gaps was also essential and the "imfill" function with structuring element holes was helpful in obtaining a gap-filled binary image.
- Removing the connected objects from the borders was still essential to obtain a clear binary image, and this was done by using the "imclearborder" function with a set value of 5 (this set value worked successfully and was the same for all hamburger patty images).
- Smoothening was the final step to obtain a natural image, and this was done two times by using the "imerode" function with a structuring element diamond created by the "strel" function.

2.3.3. Measurement of the shrinkage

The shrinkage was measured using a segmented binary image. The matrix size of this image was 1900 × 1900, and it had two parts black (background) and white (hamburger patty). A simple algorithm was used to calculate the area of hamburger patty (white pixels whose value is 1). Raw and cooked hamburger patty images were processed at the same time using Matlab, and the algorithm proportioned these two areas to obtain the shrinkage percentage of hamburger patty after cooking.

The shrinkage percentages were calculated by using the following equation (Eq. (1)), and the results are given in Table 2.

$$\text{Shrinkage } (\%) = \frac{(\text{Area of raw sample} - \text{Area of cooked sample})}{\text{Area of raw sample}} \times 100 \quad (1)$$

Shrinkage was also calculated for some hamburger patty samples that had a clean round shape after cooking by using the classical method, and these results were compared with the results obtained by image processing. In this method, the shrinkage was determined by measuring the diameter of raw and cooked hamburger patties before and after cooking, respectively, as described by Modi et al. (2003).

2.4. Chemical analysis

Moisture, protein and fat contents were determined according to the methods described by the AOAC (1990). Moisture loss and fat loss are also calculated according to following equations (Eqs. (2) and (3)), and the results are given in Table 2.

$$\text{Moisture loss } (\%) = \frac{(M_1 - M_2)}{M_1} \times 100 \quad (2)$$

M_1: Moisture content of the raw hamburger patty (%),
M_2: Moisture content of the cooked hamburger patty (%).

$$\text{Fat loss } (\%) = \frac{(F_1 - F_2)}{F_1} \times 100 \quad (3)$$

F_1: Fat content of the raw hamburger patty (%),
F_2: Fat content of the cooked hamburger patty (%).

2.5. Mathematical and statistical analysis

A full second-order polynomial model equation (Eq. (4)) was fitted to the experimental data, and the coefficients of the model equation were determined. The result in an empirical model in relation to the response is

$$R = \beta_0 + \beta_1{}^*F + \beta_2{}^*W + \beta_3{}^*\text{TSP} + \beta_{11}{}^*F^2 + \beta_{22}{}^*W^2 + \beta_{33}{}^*\text{TSP}^2 + \beta_{12}{}^*F^*W + \beta_{13}{}^*F^*\text{TSP} + \beta_{23}{}^*W^*\text{TSP} \quad (4)$$

where β_0, β_i, β_{ii} and β_{ij} are regression coefficients for the intercept, linear, quadratic and interaction coefficients, respectively, and F, W and TSP are the coded independent variables which indicate the fat content (%), the water content (%) and the textured soy protein content (%) of the hamburger patty, respectively. The validation of the models was done by ANOVA (Analysis of Variance), and the significance of all the factors was checked. The final interpretation of the models was assessed by drawing response surface plots. Statistical analyses were performed using a trial version of package program Minitab® 15.1.30.0 (Minitab Inc., 2009).

3. Results

An automatic method for estimating the surface area of raw and cooked hamburger patties was developed in the first stage of the study. In Fig. 2, the images of raw and cooked hamburger patties are shown along with the binary image obtained from image processing. The critical issue in this step is to obtain the binary image without changing the actual area of the real sample. It is clearly seen in the figure that binary image had the same area as that of the original image. This area was also controlled using the classical method, and only 2% of variation was observed between the results of both the methods.

Experimental range levels of fat, water and TSP content (%) were used as coded values between $-\alpha$ (-1.682) and $+\alpha$ (1.682) in the model equations for shrinkage, moisture loss and fat loss as tabulated in Table 1 and the factor with higher coefficient has higher significance on the response.

3.1. Shrinkage

The shape of most food products as well as the direction for determining the length changes during processing. This reduces the reliability of these length measurements (Zheng, Sun, & Zheng, 2006). In the present work, the area was measured using IPT by simply counting the number of pixels on the segmented digital image of raw and cooked hamburger patties. The shrinkage percentage was estimated from the pixel areas of raw and cooked hamburger patties. Fat, water and TSP content affected the shrinkage percentage of the hamburger patties. It is seen in Table 2 that the shrinkage percentage varied between 30.73% and 55.23% in the investigated range of independent parameters. Serdaroglu and Degirmencioglu (2004) reported that the fat level affected hamburger patty shrinkage and reducing the fat level from 20% to 5% significantly decreased shrinkage. A model equation was formulated to predict the shrinkage percentage on the basis of fat, water and TSP content. Fitting of the data to various models (linear, two factorial and quadratic) and their subsequent ANOVA showed that shrinkage could be predicted by using a linear model as the function of independent parameters (Eq. (5)).

$$\text{Shrinkage}\ (\%) = 43.366 + 6.523^{*}F + 2.511^{*}W - 3.563^{*}\text{TSP} \qquad (5)$$

This model showed statistically insignificant lack of fit ($P > 0.05$); therefore, there was no lack of fit between the model equation and experimental results. The coefficient of determination value of the model equation (R^2) is 0.954, and this implies that the model equation has good prediction capability. The effects of independent parameters on shrinkage percentage are shown in Fig. 3a–c.

As expected, fat and water content had positive effect and TSP had negative effect on the shrinkage percentage with coefficients of 6.523, 2.511 and -3.563, respectively. This model equation helps in calculating the shrinkage percentage when the fat, water and TSP content is known. Moreover, it could be possible to do a formulation to obtain a proper shrinkage percentage.

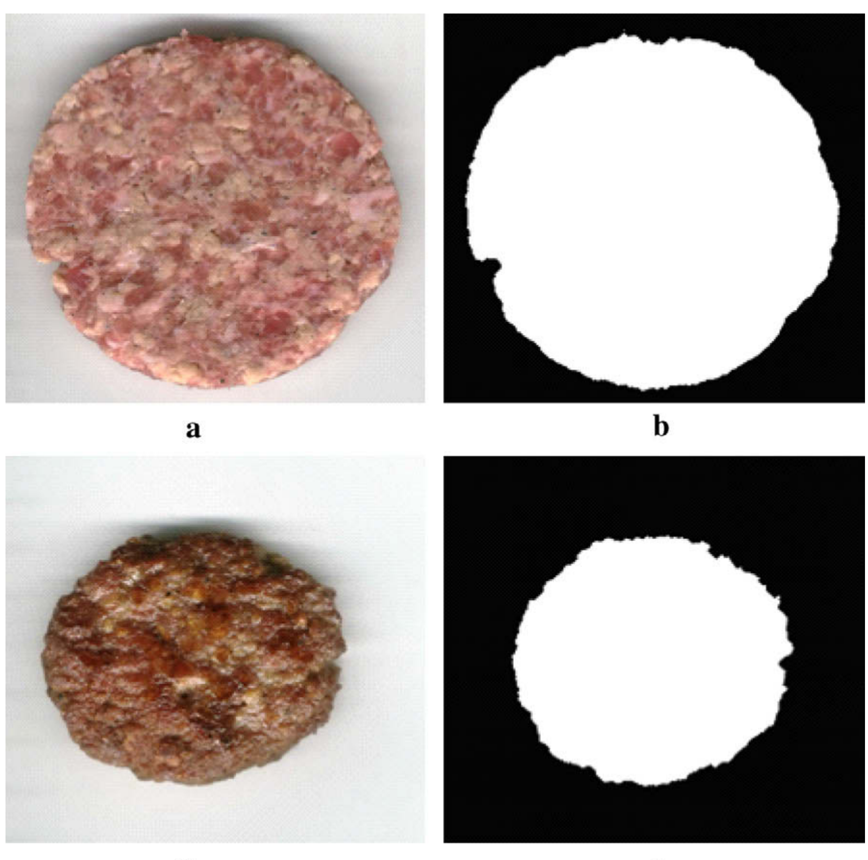

Fig. 2. (a) Original image of the raw hamburger patty, (b) segmented image of the raw hamburger patty, (c) original image of the cooked hamburger patty and (d) segmented image of the cooked hamburger patty.

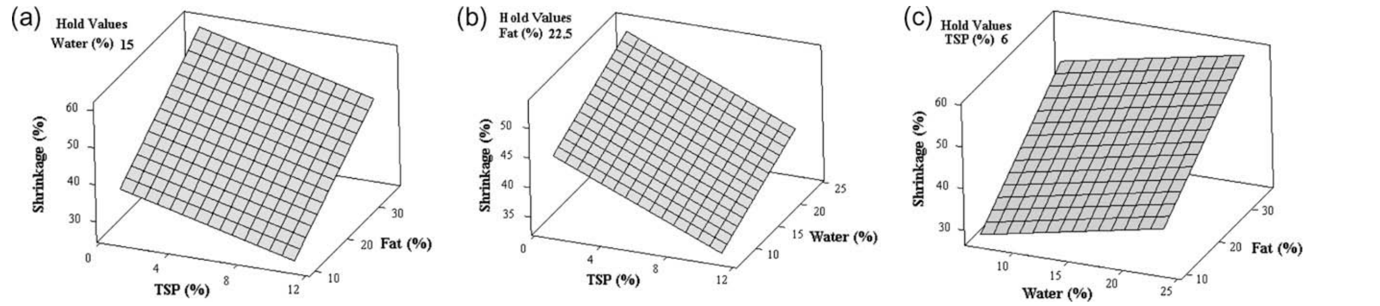

Fig. 3. Surface plot of shrinkage (%) versus (a) fat (%) and TSP (%), (b) water (%) and TSP (%) and (c) fat (%) and water (%) with uncoded data.

3.2. Fat loss

It was observed that the fat loss varied between 3.25% and 31.47% in the investigated ranges of independent parameters. Generally, fat content of the final product is expected to remain constant. An equation that can be used to estimate fat loss as a function of the main formulation parameters will be helpful for the people working in this field. To compensate this requirement, a mathematical equation was predicted as the function of fat, water and TSP content. Linear, quadratic and full quadratic models with interaction terms were investigated, and the results are tabulated in Table 3. While the TSP and fat content was significantly effective in linear and quadratic forms ($P < 0.05$), water content was effective only in the quadratic form. Further, none of the interaction terms were significant ($P > 0.05$). The model equation was re-predicted on the basis of the significant terms, and it is given as Eq. (6).

$$\text{Fat loss } (\%) = 29.948 + 3.084^{*}F - 7.285^{*}\text{TSP} - 2.737^{*}(F)^2 - 1.799^{*}(W)^2 - 5.435^{*}(\text{TSP})^2 \quad (6)$$

The model equation and the experimental results are in good agreement with insignificant lack of fit ($P > 0.05$). The model equation had a high prediction capability with good coefficient of determination value (R^2, 0.969). The effects of independent parameters on fat loss percentage are shown in Fig. 4a–c. TSP content is the most effective factor in the model with a coefficient of −7.285, and its increase lead to a significant decrease in fat loss. There were unexpected observations for the square effects of fat and water content in the model. According to the results, there is a slight decrease in fat loss with excessive addition of fat and water, and it can be recognized from the curvature shown in Fig. 4c. This phenomenon can be explained on the basis of the unusual behavior of excessive fat accumulated just below or on the surface of the hamburger patty while cooking in the pan. Similar results were found by Serdaroglu and Degirmencioglu (2004) as fat retention increased with decreased fat level in hamburger patty formulation. In the same paper, the researchers also cited from the study of Tornberg, Olsson, and Persson (1989) that the mean free distance between fat droplets decreases with an increase in the fat content, and this leads to the coalescence of fat droplets and their subsequent leakage from the product.

3.3. Moisture loss

Moisture loss was varied between 5.45% and 21.62% in the investigated range of independent parameters. Moisture loss directly affects the appearance and texture of the cooked hamburger patty. In several studies on hamburger patty, juiciness was considered to be an important sensory attribute and it affected the overall quality scores of the product (Serdaroglu, 2006; Yilmaz, 2005). Similar to other dependent parameters, a model equation was formulated to predict the moisture loss as function of the independent parameters. The predicted model equation (Eq. (7)) is given as follows:

$$\text{Moisture loss } (\%) = 14.699 + 0.512^{*}F + 2.122^{*}W - 4.392^{*}\text{TSP} - 0.619^{*}(\text{TSP})^2 - 0.826^{*}W^{*}\text{TSP} \quad (7)$$

Lack of fit value of the model equation was higher than the tabulated value, which implied that there was no lack of fit between the model equation and the experimental results. R^2 value was

Table 3
Significance of the factors and the *R*-square values of fitted models for shrinkage (Shr.), fat loss (F.L.) and moisture loss (M.L.).

Response	Fitted Model											
	Linear			Linear + squares			Linear + interactions			Full quadratic		
	Shr.	F.L.	M.L.	Shr.	F.L.	M.L.	Shr.	F.L.	M.L.	Shr.	F.L.	M.L.
Constant	*	*	*	*	*	*	*	*	*	*	*	*
Fat (*F*)	*	NS	NS	*	*	NS	*	NS	NS	*	*	*
Water (*W*)	*	NS	*	*	NS	*	*	NS	*	*	NS	*
TSP	*	*	*	*	*	*	*	*	*	*	*	*
$F^{*}F$				NS	*	NS				NS	*	NS
$W^{*}W$				NS	*	NS				NS	*	NS
TSP*TSP				NS	*	*				NS	*	*
$F^{*}W$							NS	NS	NS	NS	NS	NS
F^{*}TSP							NS	NS	NS	NS	NS	NS
W^{*}TSP							NS	NS	*	NS	NS	*
R-square	0.95	0.54	0.93	0.96	0.97	0.94	0.95	0.44	0.94	0.95	0.97	0.96

NS: not significant ($P > 0.05$).
Shrinkage (Shr.), Fat loss (F.L.), Moisture loss (M.L.).
* Significant ($P < 0.05$).

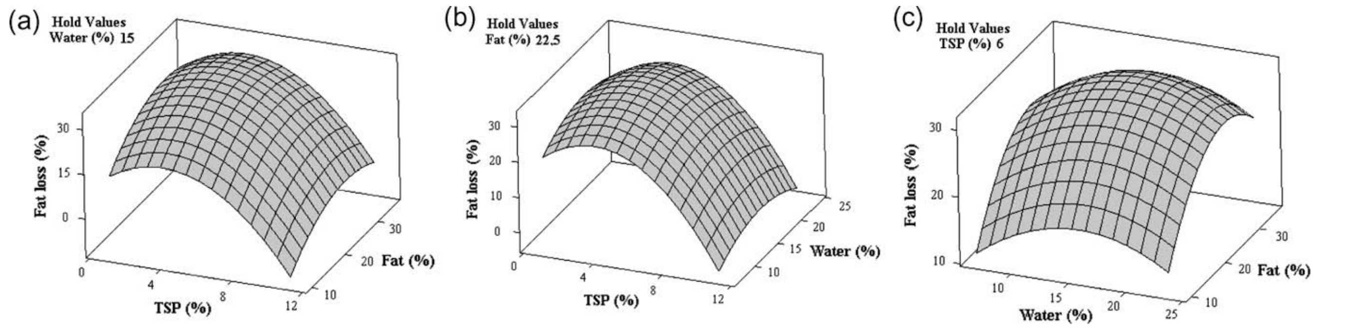

Fig. 4. Surface plot of fat loss (%) versus (a) fat (%) and TSP (%), (b) water (%) and TSP (%) and (c) fat (%) and water (%) with uncoded data.

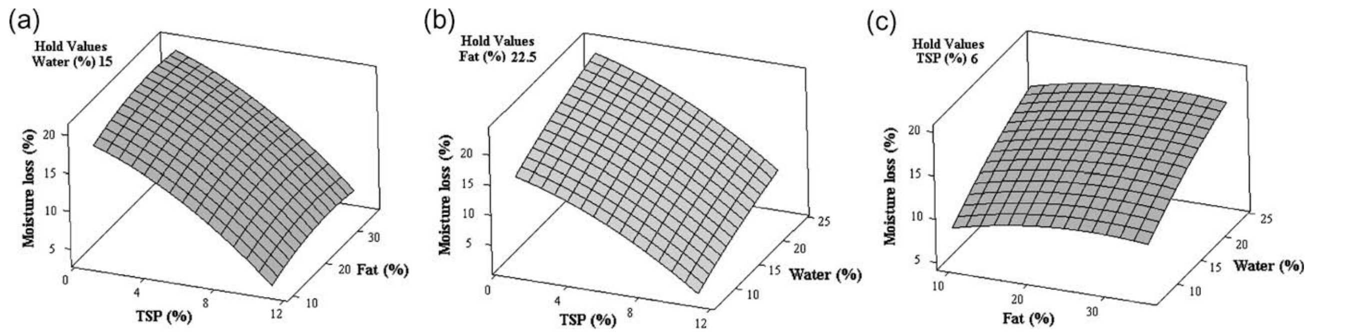

Fig. 5. Surface plot of moisture loss (%) versus (a) fat (%) and TSP (%), (b) water (%) and TSP (%) and (c) water (%) and fat (%) with uncoded data.

Table 4
Results of response surface models and significances of the factors.

Response	R^2	Regression coefficients									
		Constant	F	W	TSP	F*F	W*W	TSP*TSP	F*W	F*TSP	W*TSP
Shrinkage[a]	0.954	43.366	6.523*	2.511*	−3.563*	–	–	–	–	–	–
Fat loss[b]	0.969	29.948	3.084*	0.497[NS]	−7.285*	−2.737*	−1.799*	−5.435*	–	–	–
Moisture loss[c]	0.964	14.699	0.512*	2.122*	−4.392*	−0.368[NS]	0.211[NS]	−0.619*	0.476 [NS]	−0.272 [NS]	−0.826*

NS: not significant and neglected in the model.
[a] Linear model is eligible.
[b] Linear and squares model is eligible.
[c] Full quadratic model is eligible.
* Significant ($P < 0.05$).

calculated as 0.964, and it indicated that the model equation had good prediction capability. The effect of fat, water and TSP content on moisture loss is shown in Fig. 5.

Moisture loss characteristics of hamburger patty due to fat, water and TSP content were in full quadratic form (Table 4 and Fig. 5). TSP content affects the moisture loss with the coefficient of −4.392 and increase of TSP addition results firmer texture in hamburger patty according to high water absorbtion capacity of TSP. Increase in water content, as expected, caused a significant increase in moisture loss with a coefficient of 2.122.

4. Conclusion

Fat, water and TSP proportions influence the shrinkage, fat loss and moisture loss of hamburger patties. The developed models can be used for prediction of the amounts of these constituents to obtain the optimum recipe for hamburger patty production. The models can also be used to identify the most important factors for shrinkage, fat loss and moisture loss of hamburger patties. The models showed that the most significant factor for fat loss and moisture loss was TSP content with the regression coefficients of −7.285 and −4.392, respectively. However fat content was much more effective than TSP in determining the shrinkage characteristic of hamburger patties with a regression coefficient of 6.523. The model for fat loss also showed that the excessive amount of fat could cause a slight decrease in fat loss; however, according to the fat loss characteristics, an increase in TSP content significantly decreased the fat loss in comparison to an increase in fat content.

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References

Aguirre, L., Frias, J. M., Barry-Ryan, C., & Grogan, H. (2009). Modelling browning and brown spotting of mushrooms (*Agaricus bisporus*) stored in controlled environmental conditions using image analysis. *Journal of Food Engineering, 91*, 280–286.

AOAC (1990). *Official methods for the analysis* (15th ed.). Arlington, Washington, DC: Association of Official Analytical Chemists.

Barbera, S., & Tassone, S. (2006). Meat cooking shrinkage: Measurement of a new meat quality parameter. *Meat Science, 73*, 467–474.

Briones, V., & Aguilera, J. M. (2005). Image analysis of changes in surface color of chocolate. *Food Research International, 38*, 87–94.

Brosnan, T., & Sun, D.-W. (2004). Improving quality inspection of food products by computer vision – A review. *Journal of Food Engineering, 61*, 3–16.

Desmond, E. M., Troy, D. J., & Buckley, D. J. (1998). The effects of tapioca starch, oat fibre and whey protein on the physical and sensory properties of low-fat beef burgers. *Lebensmittel-Wissenschaft und -Technologie, 31*, 653–657.

Du, C.-J., & Sun, D.-W. (2006a). Automatic measurement of pores and porosity in pork ham and their correlations with processing time, water content and texture. *Meat Science, 72*, 294–302.

Du, C.-J., & Sun, D.-W. (2006b). Estimating the surface area and volume of ellipsoidal ham using computer vision. *Journal of Food Engineering, 73*, 260–268.

Ghodke, S. K., Ananthanarayan, L., & Rodrigues, L. (2009). Use of response surface methodology to investigate the effects of milling conditions on damaged starch, dough stickiness and chapatti quality. *Food Chemistry, 112*(4), 1010–1015.

Godsalve, E. W., Davis, E. A., & Gordon, J. (1977). Water loss rates and temperature profiles of dry cooked bovine muscle. *Journal of Food Science, 42*(4), 1038–1045.

Gujral, H. S., Kaur, A., Singh, N., & Sodhi, N. S. (2002). Effect of liquid whole egg, fat and textured soy protein on the textural and cooking properties of raw and baked patties from goat meat. *Journal of Food Engineering, 53*, 377–385.

Hsu, S. Y., & Chung, H.-Y. (1998). Effects of processing factors on qualities of emulsified meatball. *Journal of Food Engineering, 36*, 337–347.

Hsu, S. Y., & Chung, H.-Y. (2000). Interactions of konjac, agar, curdlan gum, j-carrageenan and reheating treatment in emulsified meatballs. *Journal of Food Engineering, 44*, 199–204.

Hsu, S. Y., & Chung, H.-Y. (2001). Effects of j-carrageenan, salt, phosphates and fat on qualities of low fat emulsified meatballs. *Journal of Food Engineering, 47*, 115–121.

Hsu, S. Y., & Yu, S. H. (1999). Effects of phosphate, water, fat and salt on qualities of low-fat emulsified meatball. *Journal of Food Engineering, 39*, 123–130.

Jackman, P., Sun, D.-W., Du, C.-J., Allen, P., & Downey, G. (2008). Prediction of beef eating quality from colour, marbling and wavelet texture features. *Meat Science, 80*, 1273–1281.

Jakobsen, M., & Bertelsen, G. (2000). Colour stability and lipid oxidation of fresh beef. Development of a response surface model for predicting the effects of temperature, storage time, and modified atmosphere composition. *Meat Science, 54*, 49–57.

Johansen, S. M. B., Laugesen, J. L., Janhøj, T., Ipsen, R. H., & Frøst, M. B. (2008). Prediction of sensory properties of low-fat yoghurt and cream cheese from surface images. *Food Quality and Preference, 19*, 232–246.

Kilic, K., Boyaci, I. H., Koksel, H., & Kusmenoglu, I. (2007). A classification system for beans using computer vision system and artificial neural networks. *Journal of Food Engineering, 78*, 897–904.

Kong, F., Tang, J., Lin, M., & Rasco, B. (2008). Thermal effects on chicken and salmon muscles: Tenderness, cook loss, area shrinkage, collagen solubility and microstructure. *LWT – Food Science and Technology, 41*(7), 1210–1222.

Mendoza, F., Valous, N. A., Allen, P., Kenny, T. A., Ward, P., & Sun, D.-W. (2009). Analysis and classification of commercial ham slice images using directional fractal dimension features. *Meat Science, 81*, 313–320.

Minitab Statistical Software (2009). *Trial version 15.1.30.0*. Pennsylvania: Minitab Inc. Available from http://www.minitab.com.

Modi, V. K., Mahendrakar, N. S., Narasimha Rao, D., & Sachindra, N. M. (2003). Quality of buffalo meat burger containing legume flours as binders. *Meat Science, 66*, 143–149.

Murphy, S. C., Gilroy, D., Kerry, J. F., Buckley, D. J., & Kerry, J. P. (2004). Evaluation of surimi, fat and water content in a low/no added pork sausage formulation using response surface methodology. *Meat Science, 66*(3), 689–701.

Serdaroglu, M., & Degirmencioglu, O. (2004). Effects of fat level (5%, 10%, 20%) and corn flour (0%, 2%, 4%) on some properties of Turkish type meatballs (koefte). *Meat Science, 68*, 291–296.

Serdaroglu, M., Yildiz-Turp, G., & Abrodimov, K. (2005). Quality of low-fat meatballs containing Legume flours as extenders. *Meat Science, 70*, 99–105.

Serdaroglu, M. (2006). Improving low fat meatball characteristics by adding whey powder. *Meat Science, 72*, 155–163.

Shih, I.-L., Kuo, C.-Y., Hsieh, F.-C., Kao, S.-S., & Hsieh, C. (2008). Use of surface response methodology to optimize culture conditions for iturin A production by *Bacillus subtilis* in solid-state fermentation. *Journal of the Chinese Institute of Chemical Engineers, 39*(6), 635–643.

Stien, L. H., Manne, F., Ruohonene, K., Kause, A., Rungruangsak-Torrisen, K., & Kiessling, A. (2006). Automated image analysis as a tool to quantify the colour and composition of rainbow trout (*Oncorhynchus mykiss* W.) cutlets. *Aquaculture, 261*, 695–705.

Tan, J. (2004). Meat quality evaluation by computer vision. *Journal of Food Engineering, 61*, 27–35.

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., & Cullen, P. J. (2008). Colour degradation and quality parameters of sonicated orange juice using response surface methodology. *LWT – Food Science and Technology, 41*(10), 1876–1883.

Tornberg, E., Olsson, A., & Persson, K. (1989). A comparison in fat holding between hamburgers and emulsion sausages. In *Proceedings of the 35th international congress on meat science and technology* (pp. 753–757). Denmark: Kopenhagen.

Ulu, H. (2004). Effect of wheat flour, whey protein concentrate and soya protein isolate on oxidative processes and textural properties of cooked meatballs. *Food Chemistry, 87*, 523–529.

Ulu, H. (2006). Effects of carrageenan and guar gum on the cooking and textural properties of low fat meatballs. *Food Chemistry, 95*, 600–605.

Valous, N. A., Mendoza, F., Sun, D.-W., & Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams. *Meat Science, 81*(1), 132–141.

Yilmaz, I., & Daglioglu, O. (2003). The effect of replacing fat with oat bran on fatty acid composition and physicochemical properties of meatballs. *Meat Science, 65*, 819–823.

Yilmaz, I. (2005). Physicochemical and sensory characteristics of low fat meatballs with added wheat bran. *Journal of Food Engineering, 69*, 369–373.

Zheng, C., Sun, D.-W., & Du, C.-J. (2006). Estimating shrinkage of large cooked beef joints during air-blast cooling by computer vision. *Journal of Food Engineering, 72*, 56–62.

Zheng, C., Sun, D.-W., & Zheng, L. (2006). Recent developments and applications of image features for food quality evaluation and inspection – A review. *Trends in Food Science and Technology, 17*, 642–655.