OPTIMISATION OF VITAMIN E-ENRICHED PALM FAT, OAT AND XANTHAN GUM IN A GLUTEN-BASED NUGGET FORMULATION

RAFIDAH ABD HAMID*; FARAH ASHIKIN MOHD BURDA*; NOOR LIDA HABI MAT DIAN*; SALMI YATI SHAMSUDIN*; WAN ROSNANI AWG ISA*; KARIMAH AHMAD*; SIVARUBY KANAGARATNAM* and MISKANDAR MAT SAHRI*

ABSTRACT

The objective of this study was to optimise the incorporation of the vitamin E-enriched palm fat, oat and xanthan gum in gluten-based vegetarian nugget formulation. The effects of these ingredients on the texture, oil, and vitamin E content of the fried nugget formulations were analysed. The formulation was optimised using Response Surface Method (RSM). The vitamin E and oil content in fried nuggets were dependent on the amount of palm fat used in the formulation. Less xanthan gum, and more oat and palm fat resulted in higher oil content in the fried nuggets. Palm fat and xanthan gum significantly influenced the texture of the nuggets. The firmness increased as more oat was added. The optimum combination of these ingredients is 6.4% palm fat, 6.8% xanthan gum and 10% oat. These findings provide a basis in formulating gluten-based nuggets with vitamin E-enriched palm fat. Other plant proteins such as soya-based protein may be selected in future research.

Keywords: palm fat, oat, xanthan gum, gluten, vitamin E, food formulation, nugget.

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INTRODUCTION

A high red meat intake is frequently associated with cancer risk, obesity and metabolic syndrome (Biesalski, 2005). A study in Japan suggested that there was a possible linkage between a Western diet (characterised by a high fat intake and consumption of meat or meat products) and risk of colon cancer (Oba *et al*., 2006). A number of epidemiological studies have associated red and processed meat consumption with the development of two major chronic diseases in the Western world: cardiovascular disease and colon cancer (McAfee *et al*., 2010; Cross *et al*., 2007; Kelemen *et al*., 2005; Kontogianni *et al*., 2008). Researchers from the British Heart Foundation determined that adding an extra portion of processed red meat to a daily diet would increase the risk of death by 20%, of fatal cardiovascular disease by 21%, and of cancer mortality by 16% (Pan *et al*., 2012).

Animal fats have been singled out as one of the causes of these dietary diseases. These fats are found in different parts between and within membranes and tendons. Animal fats are made of saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, and *trans*-fatty acids; they are the major ingredients in processed meat formulations. In order to reduce or eliminate the consumption of animal fats in daily intakes, fat substitution can be done.

Meat products have great potential for delivering important nutrients such as fatty acids, minerals, dietary fibre, antioxidants, and bioactive peptides into the diet (Decker and Park, 2010). Incorporation of functional ingredients in vegetable fat can be done to increase its functional value for consumers

* Malaysian Palm Oil Board, 6 Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia.
E-mail: rafidah@mpob.gov.my

in processed meat products (Toldra and Reig, 2011). Animal fat has been partially replaced with various vegetable oils (palm, cottonseed, corn, soyabean, peanut, *etc.*). Both liquid oils and vegetable fats have been used to produce better alternative and lipid profile formulations in meat-based functional foods (Jime´nez-Colmenero, 2007). A fat blend comprising palm oil and palm stearin has been used to partially substitute chicken fat in frankfurters, and its sensory acceptability was comparable to a commercial sample (Tan *et al.*, 2006). Osman and Nor Aini (1999) reported that a blend of palm olein and tallow shortening was good for baking. Palm oil and its fractions have been used in various solid fat formulations since the oil does not require hydrogenation and is able to produce *trans*-free and low saturated products (Miskandar and Noor Lida, 2011). Fat reduction resulted in poor texture and binding, but this was overcome by the addition of a binder. Starches and fibres restored the texture parole values of low-fat bolognas (Pietrasik and Janz, 2010). These ingredients have been applied in many vegetarian food formulations.

In order to cater for the vegans, meat imitations have been developed. Vegetarian diets and practices are becoming increasingly admired in most developed countries. A study in the United States by Farmer *et al.* (2011) reported that the nutrient intake pattern for a vegetarian diet is consistent with the current dietary guidelines. They found out that vegetarians had higher intake of vitamins E and A, calcium, magnesium, and fibre than non-vegetarians. They suggested that food and nutrition practitioners to assist vegetarians, particularly those who are new to this eating pattern, in planning menus that incorporate good sources of zinc, such as legumes, seeds, and fortified foods. Numerous low-fat and functional meat products have been developed in many countries (Arihara, 2006). However, report on vegetarian diet in Malaysia is almost non-existent and not many convenient and functional vegetarian foods are available on the shelves.

In order to replace the protein component of meat in a meat imitation product, plant protein from various sources such as soya-based protein and vital wheat gluten can be incorporated in processed meat products because of the binding property of these protein sources. These proteins provide viscosity, structure, texture, bite and reduced processing time due to their high water-binding capacity and fibrous structure.

Other than protein, binding agents such as xanthan gum, guar gum, Arabic gum, locust bean gum, and gelatin can be added to improve texture of processed meat products and imitations (Chen *et al.*, 2007; Totosaus and Pérez-Chabela, 2009; Somboonpanyakul *et al.*, 2007; Feng *et al.*, 2013; García and Totosaus, 2008; Lin and Huang, 2003). Binding agents act as thickener, emulsifier, and stabiliser in meat imitations. Xanthan gum is one of the most popular food binding agents. The most significant property of xanthan gum is in its ability to increase the viscosity of a liquid by adding a small quantity of the gum (García-Ochoa *et al.*, 2000). It is even more pseudoplastic than most other hydrocolloids. This pseudoplasticity will enhance the sensory qualities, including the mouth-feel and flavour released in the final products (Sikora *et al.*, 2008).

Dietary fibres such as oat, grains, and legumes can be added in meat imitation to help digestion. Oat is known as a good source of minerals such as manganese, selenium, phosphorus, magnesium, and iron. It is also a good source of vitamin B_1 and soluble dietary fibre (Murray *et al.*, 2006). Oat contains a considerable proportion of starch that is generally a good source of slow-release carbohydrate. Resistant and slowly digestible starches contribute to low glycemic index, a feature beneficial in the management of diabetes and hyperlipidemia (Dong *et al.*, 2011; Liu *et al.*, 2011). Hydrated oatmeal at 15% addition level, in a low-fat sausage, has achieved the greatest overall acceptability during sensory evaluation (Yang *et al.*, 2007). Vegetable oil and rice bran fibres at 10% addition level had lower cooking loss and better emulsion stability in a low-fat meat batter (Choi *et al.*, 2009). The present study was undertaken to determine the optimum amount of vitamin E-enriched palm fat, oat, and xanthan gum in the formulation of a gluten-based vegetarian nugget using Response Surface Method (RSM).

MATERIALS AND METHODS

Experimental Design

In this study, the experimental design adopts 27 points RSM Central Composite Design (CCD) in order to fit the quadratic model of the RSM. A central composite full design consists of one block and five centre points. The design of experimental matrix is shown in *Table 1*.

Sample Preparation

The wheat gluten base was prepared by mixing 300 g vital wheat gluten with 390 ml water. The ingredients were kneaded gently for 10 min to form dough. The dough was rested for 5 min before it was kneaded again. The dough was rested for 5 min before it was cut into flat cutlets, around 2 cm (¾ inch) thickness. The cutlets were then dropped into boiling water and allowed to cook for 20 min. The cutlets were then drained and pressed to remove excessive water. These gluten cutlets were ready to be used or kept frozen at -20°C until required.

Prior to use, the gluten cutlets were ground using a food processor. The ground gluten was

TABLE 1. DESIGN OF EXPERIMENTAL MATRIX

Run order	1000 ppm vitamin E enriched palm fat (%)	Oat (%)	Xanthan gum (%)
1	5	20	1
2	10	30	10
3	7	10	1
4	5	20	5
5	7	20	5
6	7	10	10
7	10	30	1
8	5	30	1
9	10	10	10
10	5	30	5
11	7	30	5
12	5	10	10
13	7	30	1
14	5	30	10
15	5	10	1
16	7	10	5
17	10	20	1
18	10	20	10
19	5	10	5
20	7	20	1
21	7	30	10
22	7	20	10
23	10	30	5
24	10	20	5
25	5	20	10
26	10	10	5
27	10	10	1

then mixed with ground oat and sago flour. Melted palm fats which contained 1000 ppm vitamin E, xanthan gum, and cold water were added to the mixture. Finally, salt, sugar, white pepper powder and chicken flavour were added in and the mixture was mixed for 5 min using a food processor to form a nugget patty. The formulation of the gluten-based nugget is specified in *Table 2* where the percentage of palm fats, oat and xanthan gum varied according to *Table 1* and the amount of ground gluten made up the formulation to 100%. Altogether 27 nuggets formulations were produced as specified in *Table 1*.

Later, the nugget patty was rolled and moulded into a round cylinder with about 0.75 cm thickness using a round cylinder mould. The round nugget patty was coated with a batter which was made of a mixture of 30 g wheat flour and 90 g water, before it was coated with breadcrumbs to form nuggets. The nuggets were then fried in a pan for 2 min until

TABLE 2. FORMULATION OF THE GLUTEN-BASED NUGGET

Ingredients	(%)
Ground gluten	X_4
Palm fat	X_3
Oat	X_2
Xanthan gum	X_1
Cold water	10
Sago flour	10
Salt	0.3
Sugar	0.2
White pepper powder	0.2
Chicken flavour	1.3

Note: X_1, X_2 and X_3 according to *Table 1*.
X_4 = 100 – (total of other ingredients).

the colour turned to golden brown. Palm olein was used as the frying oil. The nuggets were drained and allowed to cool down before proceeding with analyses.

Determination of Oil Content

Fried sample was ground using a food processor before it was weighed and put into a clean thimble. Cotton wool was used to cover the sample in the thimble. The thimble then was placed into a Soxhlet extractor. A round bottom flask that contained a few pieces of anti-bumping granules and 150 ml petroleum ether 60/80 A.R. (Systerm, Shah Alam, Malaysia) was connected to the Soxhlet extractor. The extraction was carried out for 5 hr. When the extraction was completed, the petroleum ether in the flask was extracted out using a rotary evaporator at 38^{o}C (Buchi Labortechnik AG, Flawil, Switzerland) leaving only the oil in the flask. Nitrogen gas was flushed into the flask for at least 30 min to remove traces of petroleum ether. The flask was transferred into a desiccator which contained silica gel for 24 hr before the final weight was taken. The oil content was determined using the following equation:

$$\text{Oil (\%)} = \frac{[\text{Weight of flask + Oil (g)}] - [\text{Weight of empty flask (g)}]}{\text{Weight of sample (g)}} \times 100\%$$

Vitamin E Analysis

The amount of vitamin E in fried sample was determined using HPLC Hewlett-Packard (HP 1100) with YMC column (150 x 6.0 mm internal diameter) and a fluorescence detector (Ex=295 nm and Em=330 nm) at pressure of 23-27 bar. The mobile phase used was 0.05% isopropyl alcohol in hexane solution. Calibration curves were prepared by analysing standard tocotrienol rich fraction containing 93.67% vitamin E. The curves were linear within the concentration range considered ($r \geq 0.998$).

Texture Analysis

The texture of the sample was determined using a Texture Analyser (TA.XT21, Texture Technologies, Corp, UK) with a 5 kg load cell. A compression force versus time program was used to compress and cut the sample. A blade set with Warner Bratlzer was used to cut the sample, with pre-test speed and test speed of 2.0 mm s^{-1}, and post-test speed 10.0 mm s^{-1}. The texture was expressed as firmness (g) and toughness (gs) of the sample.

Statistical Analysis

Data were evaluated using Response Surface Methodology (Minitab Version 14). Significance was established at a level of $p<0.05$. All analyses were conducted in triplicate.

RESULTS AND DISCUSSION

Oil and Vitamin E Content

Regression analysis of the results shows that the amount of palm fat and xanthan gum added into the formulation have a significant effect on the amount of oil content in the final product ($p<0.05$). However, interactions between these ingredients do not significantly affect the oil content of the product.

Results in *Figure 1* generally indicate that an increase in the amount of palm fat added to the formulation resulted in the increase in the vitamin E content of the gluten nugget at 10%, 20%, and 30% oat content. However, this trend did not apply to the oil content of the product. The highest vitamin E content was recovered from the fried gluten nuggets which contained 10% vitamin E-enriched palm fat and 10% oat.

The fitted line plot as shown in *Figure 2* confirms that the vitamin E content recovered from the fried gluten nuggets was highly related to the amount of its oil content. The higher the oil content, the higher the vitamin E retained in the fried gluten nugget. About 8%-12% oil was gained during frying. While the vitamin E content of the fried gluten nuggets was in the range of 38 to 101 ppm.

Oil and vitamin E were gained during frying due to oil absorption. Durán *et al.* (2007) reported that the majority of the oil uptake occurs at the end of the frying process and during cooling when the oil wetting the food surface penetrates into the food microstructure. According to Dueik *et al.* (2012), the final oil content in vacuum and atmospheric fried products is greatly related to the food microstructure. Porosity of the food and its oil content are linearly related in vacuum and atmospheric fried products. They also suggested that a centrifugation step at the end of the frying process may heavily reduce the oil content in atmospheric and vacuum-fried products. Earlier study by Moreno *et al.* (2010) also indicated that microstructure and surface roughness are among the key factors in oil absorption.

Gazmuri and Bouchon (2008) have discovered that gluten had a predominant role in the structure, making the dough more elastic and less permeable to oil absorption. High gluten content resulted in lower oil uptake in products with low moisture content. They have examined both, native wheat starch and vital wheat gluten. They strongly believed that product microstructure influenced oil intake. The usage of vital wheat gluten in this study could have limited the oil absorption to a certain limit that the fried gluten nuggets only absorbed 8%-12% oil.

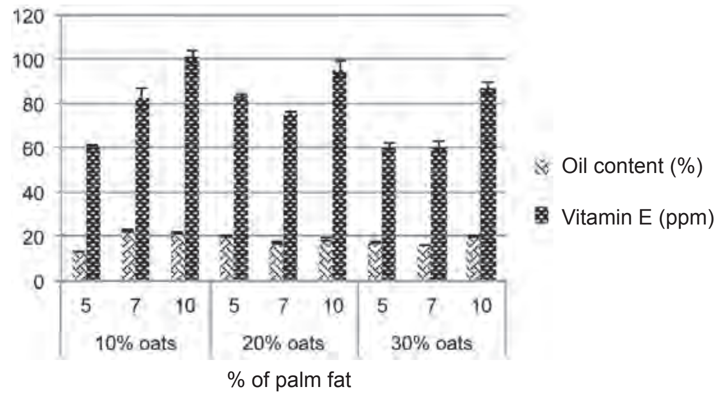

Figure 1. Histogram of oil content of the gluten nuggets and its vitamin E content at 10%, 20% and 30% oat levels when 5%, 7% and 10% vitamin E-enriched palm fat were added into the formulation (while xanthan gum was fixed at 1%).

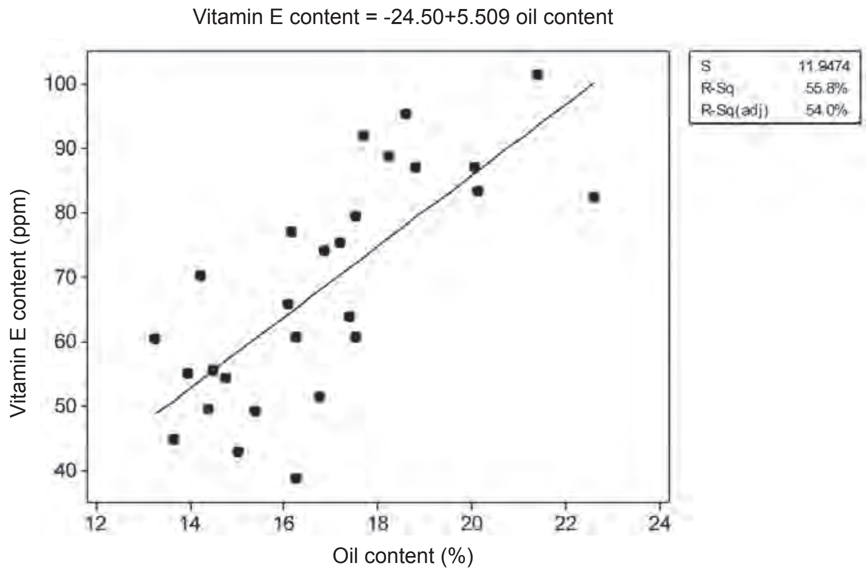

Figure 2. Fitted line plot of vitamin E vs. *oil content of gluten nuggets.*

Figure 3 indicates the trend when 10%, 20%, and 30% oat are added into formulations containing 1%, 5%, and 10% xanthan gum. It was found that at 1% xanthan gum level, an increase in the amount of oat added into the formulation resulted in a decrease in oil and vitamin E content of the gluten nuggets. In this study, lower oil content was observed in samples containing 5% and 10% xanthan gum. Sahin *et al.* (2005) have used xanthan gum in coating batters for chicken nugget. They found that xanthan gum was able to significantly reduce the oil absorption of fried chicken nuggets (Sahin *et al*., 2005). The incorporation of xanthan gum in the nugget may also help in limiting the oil absorption, as well as acting as a binding agent.

The vitamin E content of the gluten nuggets at 5% xanthan gum level showed a gradual reduction when oat content was increased from 10% to 20%. However, this pattern did not continue to decrease when the oat content was increased to 30%. A reverse trend was observed at 10% xanthan gum level where the oil content was slightly increased as the amount of oat was increased from 10% to 30%.

The effect of the interaction between vitamin E-enriched palm fat, oat, and xanthan gum in the formulations on the oil content of the gluten nuggets is best explained by the contour plots in *Figure 4.*

Figure 4a shows that the oil content in the sample was high when more palm fat and less xanthan gum were used in the formulation. It was due to the low apparent viscosity of xanthan gum which could not provide an efficient barrier for oil uptake, as reported by Sahin *et al.* (2005). The moisture evaporated at the product surface, owing to the partial vapour pressure difference between the product and oil during frying. At the same time, oil filled the voids left by the water vapour. At a very low dosage, xanthan gum was not able to control moisture loss. This resulted in high oil uptake in the fried nugget samples.

Similarly, *Figure 4b* shows that the oil content of the gluten nuggets was high as more palm fat and less oat were used in the formulations. Less palm fat (5%-6%) at a very high oat level (>25%) caused the nuggets to be less oily. But, there was an area where too little palm fat (<5.5%) and oat (<15%) would also produce product with the lowest oil content. The decrease in the oil uptake of oat could be correlated to its enhanced moisture retention. Oat has a good water-holding capacity which is attributed to the water binding ability of β-glucan (Piñero *et al*., 2008). Since high water-holding capacity and viscosity development have a great effect on the reduction of oil uptake, the addition of oat improved oil barrier properties of products. The high water-holding capacity of oat caused products to have high viscosity and less moisture loss during frying. Less moisture loss during frying leads to the low oil uptake of the products (Lee and Inglett, 2007).

Figure 4c signifies the oil content in the gluten nuggets based on the amount of xanthan gum and oat used in the sample. The oil content was high when more oat and less xanthan gum were used in the formulation. The trend is similar to *Figure 4a* which addresses the effect of palm fat and xanthan gum. Oat plays an important role in increasing water absorption and product moisture. The same goes to the oil absorption. In general, dietary fibre increases water and oil absorption and mixing tolerance. This is due to the hydroxyl groups of the fibre structure, which allow more oil interaction through hydrogen bonding. In addition, oat starch has higher water absorption than other cereals (Salehifar and Shahedi, 2007).

Firmness and Toughness of Product

Firmness indicates the resistance of a material to externally applied pressure. In this study, firmness is used to express the hardness of samples. Toughness is a property where a material is capable of absorbing energy until it reaches deformation; intermediate between softness and brittleness. In this study, toughness signifies the difficulty to cut or bite the nugget.

Regression analysis of the results shows that the amount of oat and xanthan gum added to the formulation have significant effects on the firmness and toughness of the final product ($p<0.05$). However, interactions between these ingredients do not significantly affect the texture of the product.

Figure 5 indicates the trend in firmness and toughness when 10%, 20%, and 30% oat were added into formulations containing 1%, 5%, and 10% xanthan gum. It was found that at 1% xanthan gum level, an increase in the amount of oat added into the formulation resulted in an increase in firmness and toughness of the gluten nuggets. The firmness and toughness of gluten nuggets at 5% xanthan gum showed a gradual increment when the percentage of oat content was increased from 10% to 20%. However, it did not continue to increase when the percentage of oat content was increased to 30%. On the contrary, at 10% xanthan gum level, the toughness of the gluten nuggets was slightly decreased as the amount of oat was increased from 10% to 30%. However, there were no changes in the firmness of gluten nuggets at different oat levels.

The histogram in *Figure 6* shows the firmness and toughness of gluten nuggets when 1%, 5%, and 10% xanthan gum were added into the formulations containing 10%, 20%, and 30% oat. At 10% oat level, a gradual reduction of toughness and firmness

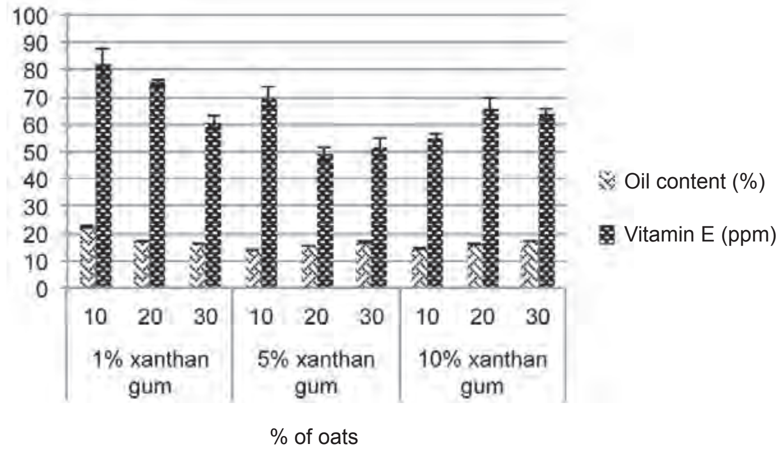

Figure 3. Histogram of oil content of the gluten nuggets and its vitamin E content at 1%, 5% and 10% xanthan gum levels when 10%, 20% and 30% oat were added into the formulation (while vitamin E-enriched palm fat was fixed at 7%).

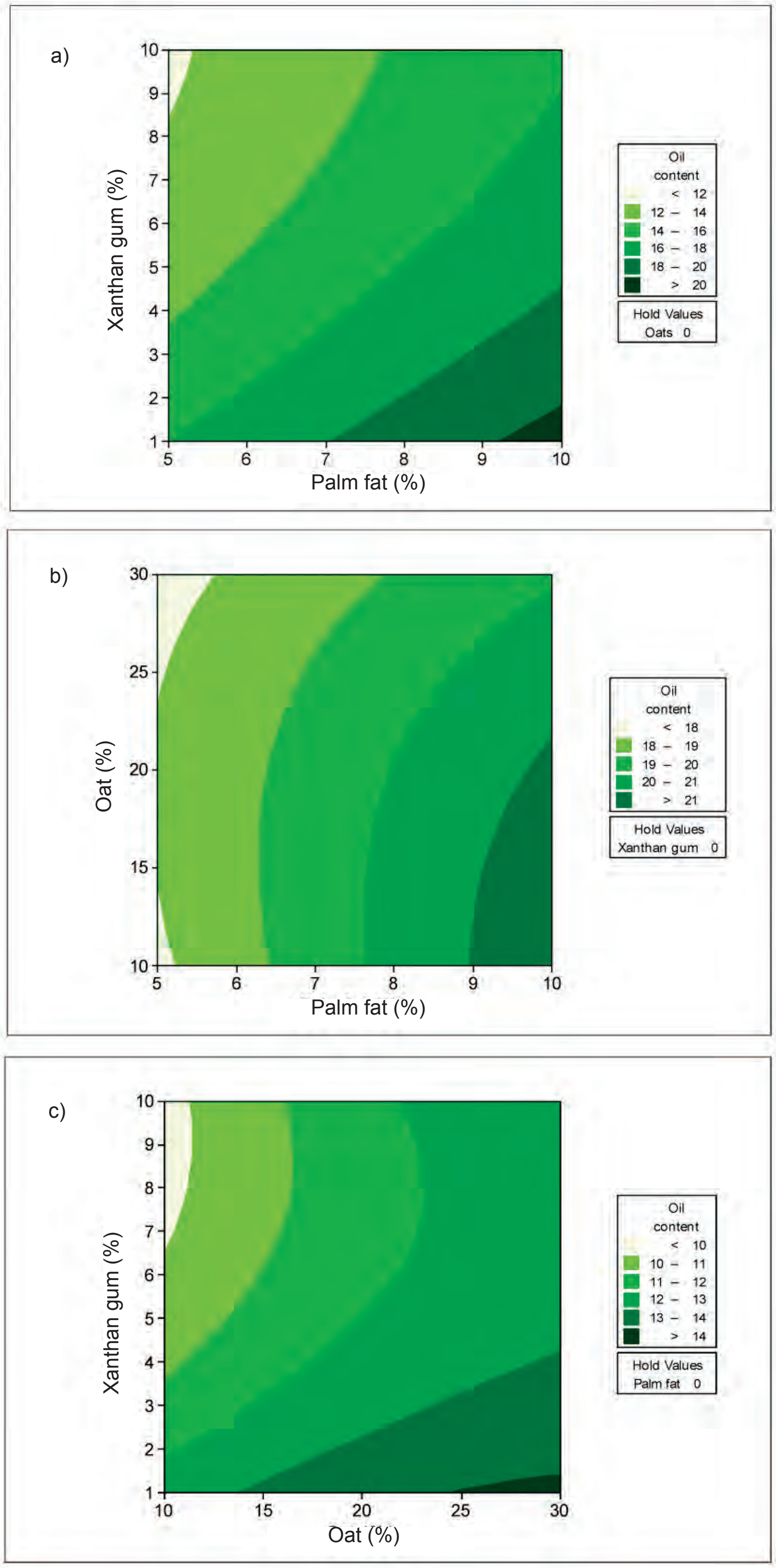

Figure 4. Contour plot of the effect of: a) palm fat and xanthan gum, b) palm fat and oat, and c) xanthan gum and oat, on the oil content of gluten nugget.

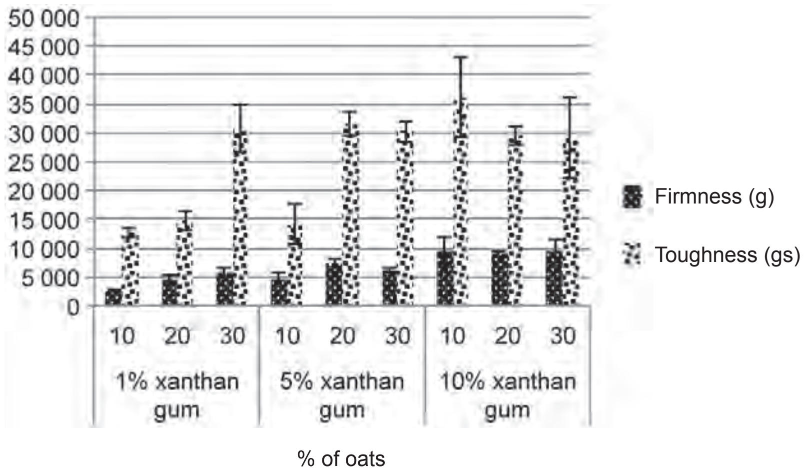

Figure 5. Histogram of firmness and toughness of the gluten nuggets at 1%, 5%, and 10% xanthan gum levels when 10%, 20%, and 30% oat were added into the formulation (while palm fat was fixed at 7%).

was observed when the level of xanthan gum was increased from 1% to 5%. However, the firmness and toughness shot up at 10% xanthan gum level. The trend was very significant at 20% oat level. The firmness and toughness of the gluten nuggets at 30% oat showed gradual increment when the percentage of xanthan gum content was increased from 1% to 5%, and it continued to increase when the percentage of oat content was increased to 10%.

The firmness and toughness values of fried gluten nuggets in this study were in the range of 2666 to 14086 g and 6200 to 9085 g, respectively.

The firmness of the gluten nuggets as influenced by the amount of oat and palm fat used is shown in *Figure 7a.* The firmness of the sample was high when 15%-25% oat and 5%-6% palm fat were used. A highly firm sample would be produced when more than 20% oat and 9%-10% palm fat were used.

Figure 7b indicates that the firmness of the gluten nuggets is very much influenced by the amount of xanthan gum added in the formulation. When more xanthan gum was added (9%-10%) to a low palm fat level (<6%) samples, highly firm samples were formed. This is in agreement with Cengiz and Gokoglu (2007) who reported that the fat level has a significant effect on the product texture and juiciness. Reducing the fat in the formulation of the processed meat product had caused the product to become firmer, rubbery, less juicy, and darker in colour, less acceptable in skin formation and mouth-feel. In this study, the addition of xanthan gum as stabiliser had increased the product firmness and improved its viscosity and consistency.

The firmness of fried gluten nuggets as a result of xanthan gum and oat used in the formulation is illustrated in *Figure 7c.* When 9%-10% xanthan gum

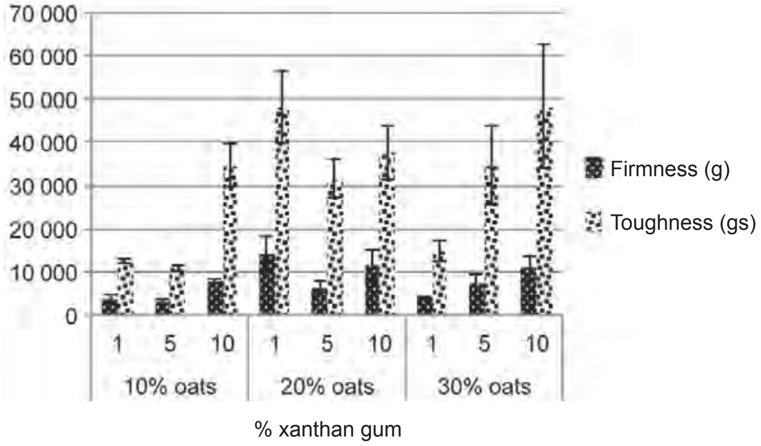

Figure 6. Histogram of firmness and toughness of the gluten nuggets at 10%, 20% and 30% oat levels when 1%, 5% and 10% xanthan gum were added into the formulation (while vitamin E-enriched palm fat was fixed at 5%).

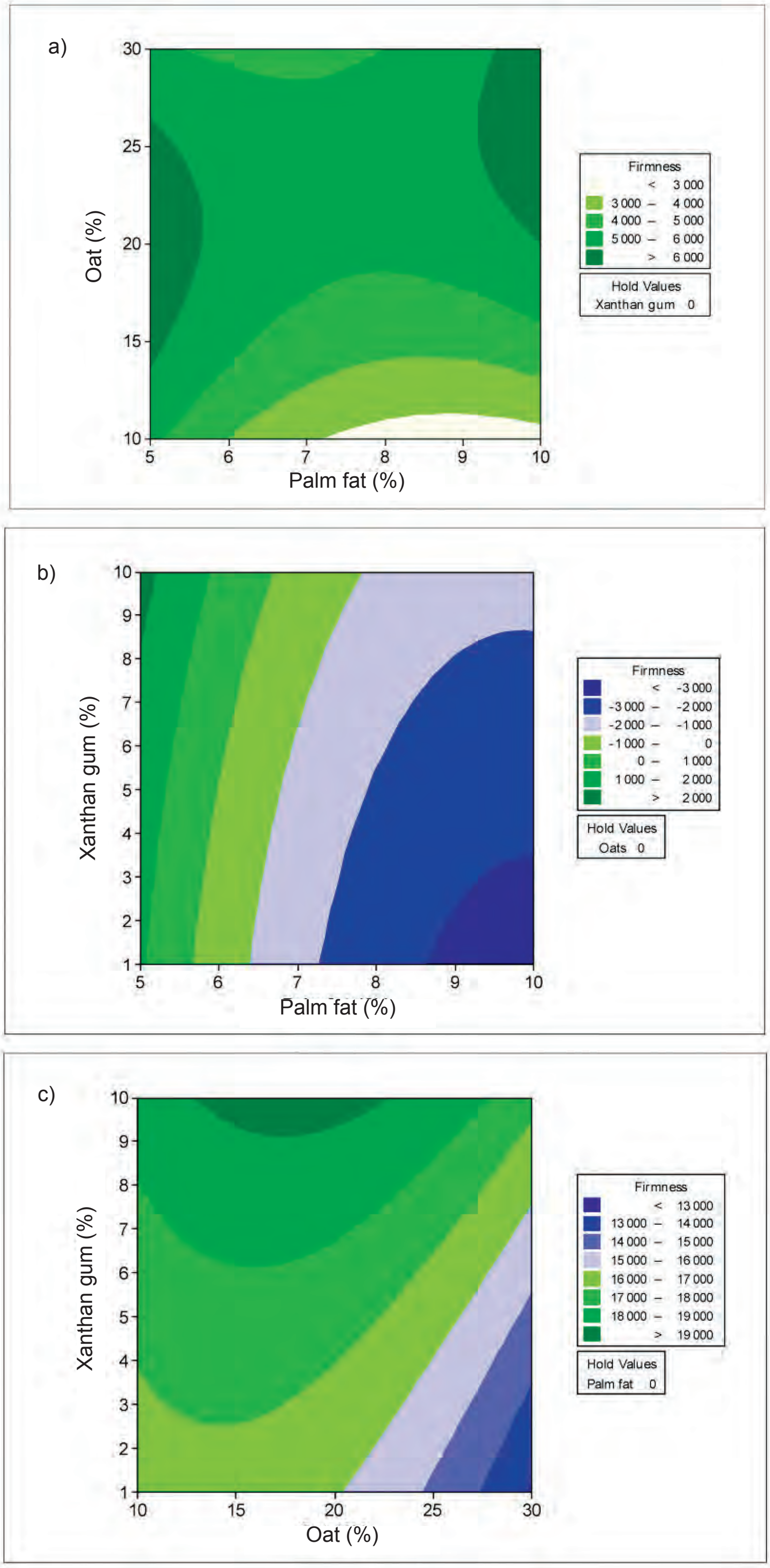

Figure 7. Contour plot of the effect of: a) palm fat and oat, b) palm fat and xanthan gum, and c) xanthan gum and oat, on the firmness of gluten nugget.

was added in formulations containing 15%-20% oat, highly firm nuggets were produced. More than 20% oat at lower xanthan gum levels (<5%) had resulted in less firm or softer nuggets.

The toughness property of fried gluten nugget as affected by palm fat and oat level is shown in *Figure 8a.* Nuggets that have less toughness property could be produced with 10%-15% oat and more than 7% palm fat formulations. Higher oat levels of more than 15%, with 5%-7% palm fat could result in reasonably tougher nuggets.

The toughness property of gluten nuggets is found to have positive correlation with the amount of xanthan gum used as shown in *Figure 8b.* On the other hand, it has negative correlation with the level of palm fat. This finding is also supported by the contour plot in *Figure 8c* which shows that highly tough nuggets could be produced when more than 8% xanthan gum was added to oat at 10%-30% level. It is noted that only a small amount of xanthan gum is required to produce a desired nugget with optimum firmness and toughness. It is able to increase the viscosity of liquid at a very small quantity of gums.

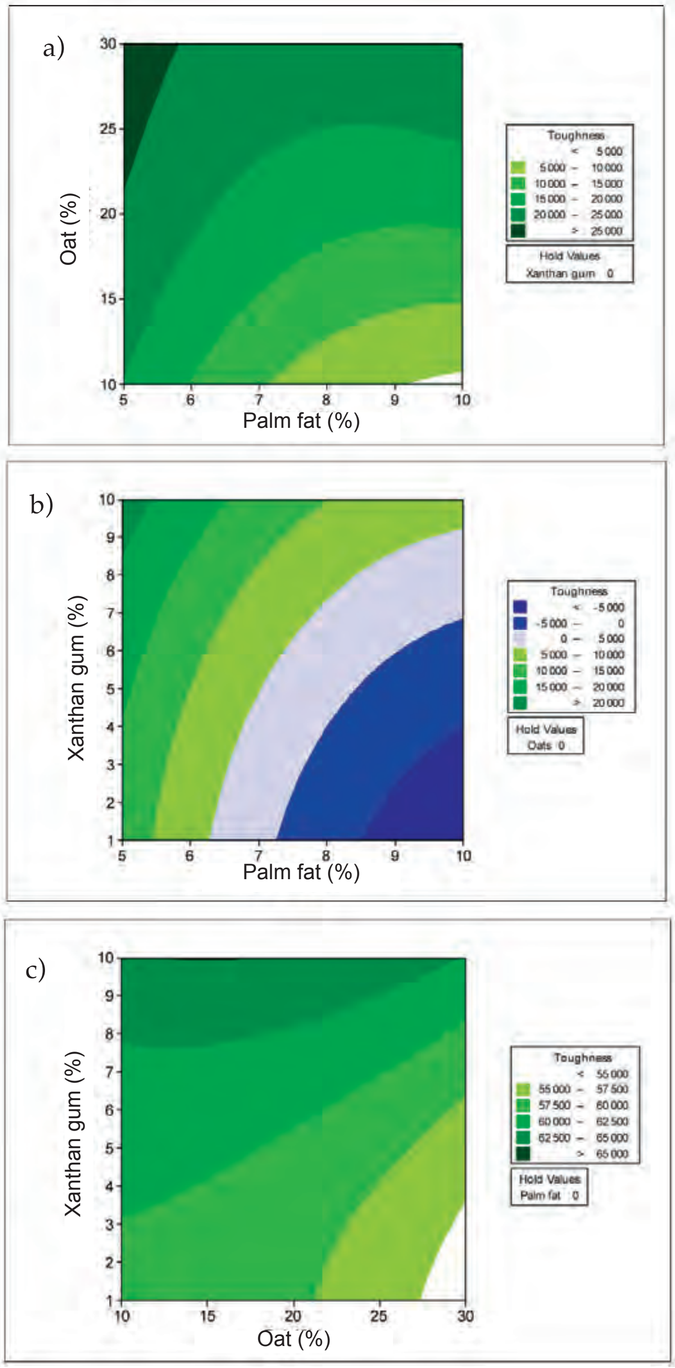

Figure 8. Contour plot of the effect of: a) palm fat and oat, b) palm fat and xanthan gum, and c) xanthan gum and oat, on the toughness of gluten nugget.

According to Sahin *et al.* (2005), it helps ingredients to blend more effectively and stay blended.

The optimum percentage of ingredients for gluten-based nuggets derived from the RSM software was 6.4% vitamin E-enriched palm fat, 6.8% xanthan gum and 10% oat.

CONCLUSION

The amount of vitamin E-enriched palm fat and xanthan gum added to the formulation significantly affected the firmness of the gluten nuggets; as less palm fat and xanthan gum were used, firmer nuggets were produced. The firmness increased as more oat was added. The optimum combination of these ingredients was 6.4% vitamin E-enriched palm fat, 6.8% xanthan gum, and 10% oat. These findings can be used in formulating gluten-based vegetarian nuggets with vitamin E-enriched palm fat.

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REFERENCES

ARIHARA, K (2006). Strategies for designing novel functional meat products. *Meat Science, 74(1)*: 219-229. DOI:10.1016/j.meatsci.2006.04.028.

BIESALSKI, H-K (2005). Meat as a component of a healthy diet – are there any risks or benefits if meat is avoided in the diet? *Meat Science, 70(3)*: 509-524. DOI:10.1016/j.meatsci.2004.07.017.

CENGIZ, E and GOKOGLU, N (2007). Effects of fat reduction and fat replacer addition on some quality characteristics of frankfurter-type sausages. *International Journal of Food Science and Technology, 42(3)*: 366-372. DOI: 10.1111/j.1365-2621.2006.01357.x.

CHEN, H H; XU, S Y and WANG, Z (2007). Interaction between flaxseed gum and meat protein. *J. Food Engineering, 80(4)*: 1051-1059. DOI:10.1016/j.jfoodeng.2006.08.017.

CHOI, Y S; CHOI, J H; HAN, D J; KIM, H Y; LEE, M A; KIM, H W; JEONG, J Y and KIM, C J (2009). Characteristics of low-fat meat emulsion systems with pork fat replaced by vegetable oils and rice bran fiber. *Meat Science, 82(2)*: 266-271. DOI:10.1016/j.meatsci.2009.01.019.

CROSS, A J; LEITZMANN, M F; GAIL, M H; HOLLENBECK, A R; SCHATZKIN, A and SINHA, R (2007). A prospective study of red and processed meat intake in relation to cancer risk. *PLos Medicine, 4(12)*: 1973. DOI: 10.1371/journal.pmed.0040325.

DECKER, E A and PARK, Y (2010). Healthier meat products as functional foods. *Meat Science, 86(1)*: 49-55. DOI:10.1016/j.meatsci.2010.04.021.

DONG, J; CAI, F; SHEN, R and LIU, Y (2011). Hypoglycaemic effects and inhibitory effect on intestinal disaccharidases of oat beta-glucan in streptozotocin-induced diabetic mice. *Food Chemistry, 129(3)*: 1066-1071. DOI: 10.3402/fnr.v57i0.22754.

DUEIK, V; MORENO, M C and BOUCHON, P (2012). Microstructural approach to understand oil absorption during vacuum and atmospheric frying. *J. Food Engineering, 111(3)*: 528-536. DOI:10.1016/j.jfoodeng.2012.02.027.

DURÁN, M; PEDRESCHI, F; MOYANO, P and TRONCOSO, E (2007). Oil partition in pre-treated potato slices during frying and cooling. *J. Food Engineering, 81(1)*: 257-265. DOI:10.1016/j.jfoodeng.2006.11.004.

FARMER, B; LARSON, B T; FULGONI, V L; RAINVILLE, A J and LIEPA, G U (2011). A vegetarian dietary pattern as a nutrient-dense approach to weight management: an analysis of the National Health and Nutrition Examination Survey 1999-2004. *J. American Dietetic Association, 111(6)*: 819-827. DOI: 10.1016/j.jada.2011.03.012.

FENG, T; YE, R; ZHUANG, H; RONG, Z; FANG, Z; WANG, Y; GU, Z and JIN, Z (2013). Physicochemical properties and sensory evaluation of Mesona Blumes gum/rice starch mixed gels as fat-substitutes in Chinese cantonese-style sausage. *Food Research International, 50 (1)*: 85-93. DOI:10.1016/j.foodres.2012.10.005.

GARCÍA, E G and TOTOSAUS, A (2008). Low-fat sodium-reduced sausages: effect of the interaction between locust bean gum, potato starch and κ-carrageenan by a mixture design approach. *Meat Science, 78(4)*: 406-413. DOI: 10.1016/j.meatsci.2007.07.003.

GARCÍA-OCHOA, F; SANTOS, V E; CASAS, J A and GÓMEZ, E (2000). Xanthan gum: production, recovery, and properties. *Biotechnology Advances, 18(7)*: 549-579. DOI:10.1016/S0734-9750(00)00050-1.

GAZMURI, A M and BOUCHON, P (2008). Analysis of wheat gluten and starch matrices during deep-fat frying. *Food Chemistry, 115(3)*: 999-1005. DOI:10.1016/j.foodchem.2009.01.020.

JIME´NEZ-COLMENERO, F (2007). Healthier lipid formulation approaches in meat based functional foods. Technological options for replacement of meat fats by non-meat fats. *Trends in Food Science & Technology, 18(11)*: 567-578. DOI:10.1016/j.tifs.2007.05.006.

KELEMEN, L E; KUSHI, L H; JACOBS, D R JR and CERHAN, J R (2005). Associations of dietary protein with disease and mortality in a prospective study of postmenopausal women. *American Journal of Epidemiology, 161(3)*: 239-249. PMID:15671256 (PubMed - indexed for MEDLINE).

KONTOGIANNI, M D; PANAGIOTAKOS, D B; PITSAVOS, C; CHRYSOHOOU, C and STEFANADIS, C (2008). Relationship between meat intake and the development of acute coronary syndromes: the CARDIO2000 case–control study. *European Journal of Clinical Nutrition, 62(2)*: 171-177. PMID:17356558 (PubMed - indexed for MEDLINE).

LEE, S and INGLETT, G E (2007). Effect of an oat β-glucan-rich hydrocolloid (C-trim30) on the rheology and oil uptake of frying batters. *J. Food Science: Food Engineering and Physical Properties, 72(4)*: 222-226. PMID:17995775 (PubMed - indexed for MEDLINE]).

LIN, K W and HUANG, H Y (2003). Konjac/gellan gum mixed gels improve the quality of reduced-fat frankfurters. *Meat Science, 65(2)*: 749-755. DOI: 10.1016/S0309-1740(02)00277-2.

LIU, S; YANG, N; HOU, Z H; YAO, Y; LU, L; ZHOU, X and REN, G (2011). Antioxidant effects of oat avenanthramides on human serum. *Agricultural Sciences in China, 10(8)*: 1301-1305. DOI:10.1016/S1671-2927(11)60122-3.

MCAFEE, A J; MCSORLEY, E M; CUSKELLY, G J; MOSS, B W; WALLACE, J M W; BONHAM, M P and FEARON, A M (2010). Red meat consumption: An overview of the risks and benefits. *Meat Science, 84(1)*: 1-13. DOI:10.1016/S1671-2927(11)60122-3.

MISKANDAR, M S and NOOR LIDA, H M D (2011). Formulation of *trans*-free and low saturated margarine. *J. Oil Palm Res. Vol. 23*: 958-967.

MORENO, M C; BROWN, C A and BOUCHON, P (2010). Effect of food surface roughness on oil uptake by deep-fat fried products. *J. Food Engineering, 101(2)*: 179-186. DOI:10.1016/j.jfoodeng.2010.06.024.

MURRAY, M T; PIZZORNO, J and PIZZORNO, L (2006). *The Condensed Encyclopedia of Healing Foods.* Simon and Schuster, Atria Books, 1230 Avenue of the Americas, New York, NY 10020.

OBA, S; SHIMIZU, N; NAGATA, C; SHIMIZU, H; KAMETANI, M; TAKEYAMA, N; OHNUMA, T and MATSUSHITA, S (2006). The relationship between the consumption of meat, fat, and coffee and the risk of colon cancer: a prospective study in Japan. *Cancer Letters, 244(2)*: 260-267. DOI:10.1016/j.canlet.2005.12.037.

OSMAN, A and NOR AINI, I (1999). Physical and chemical properties of shortenings from palm oil: tallow and palm olein: tallow blends with and without interesterification. *J. Oil Palm Res. Vol. 11 (1)*: l-10.

PAN, A; SUN, Q; BERNSTEIN, A M; SCHULZE, M B; MANSON, J E; STAMPFER, M J; WILLETT, W C and HU, F B (2012). Red meat consumption and mortality. Results from 2 prospective cohort studies. *Arch Intern Med., 172(7)*: 555-563. DOI: 10.1001/archinternmed.2011.2287.

PIETRASIK, Z and JANZ, J A M (2010). Utilization of pea flour, starch-rich and fiber-rich fractions in low fat bologna. *Food Research International, 43(2)*: 602-608. DOI:10.1016/j.foodres.2009.07.017.

PIÑERO, M P; PARRA, K; HUERTA-LEIDENZ, N; ARENAS DE MORENO, L; FERRER, M; ARAUJO, S and BARBOZA, Y (2008). Effect of oat's soluble fibre (β-glucan) as a fat replacer on physical, chemical, microbiological and sensory properties of low-fat beef patties. *Meat Science, 80(3)*: 675-680. DOI: 10.1016/j.meatsci.2008.03.006.

SAHIN, S; SUMNU, G and ALTUNAKAR, B (2005). Effects of batters containing different gum types on the quality of deep-fat fried chicken nuggets. *J. Science of Food and Agriculture, 85(14)*: 2375-2379. DOI: 10.1002/jsfa.2258.

SALEHIFAR, M and SHAHEDI, M (2007). Effects of oat flour on dough rheology, texture and organoleptic properties of taftoon bread. *J. Agriculture Science and Technology, 9*: 227-234. (http://jast.modares.ac.ir/article_4455_942.html).

SIKORA, M; KOWALSKI, S and TOMASIK, P (2008). Binary hydrocolloids from starches and xanthan gum. *Food Hydrocolloids, 22(5)*: 943-952. DOI:10.1016/j.foodhyd.2007.05.007.

SOMBOONPANYAKUL, P; BARBUT, S; JANTAWAT, P and CHINPRAHAST, N (2007). Textural and sensory quality of poultry meat batter containing malva nut gum, salt and phosphate. *LWT - Food Science and Technology, 40(3)*: 498-505. DOI:10.1016/j.lwt.2005.12.008.

TAN, S S; AMINAH, A; ZHANG, X G and ABDUL, S B (2006). Optimizing palm oil and palm stearin utilization for sensory and textural properties of chicken frankfurters. *Meat Science, 72(3)*: 387-397. DOI: 10.1016/j.meatsci.2005.07.012.

TOLDRA, F and REIG, M (2011). Innovations for healthier processed meats. *Trends in Food Science & Technology, 22(9)*: 517-522. DOI:10.1016/j.tifs.2011.08.007.

TOTOSAUS, A and PÉREZ-CHABELA, M L (2009). Textural properties and microstructure of low-fat and sodium-reduced meat batters formulated with gellan gum and dicationic salts. *LWT - Food Science and Technology, 42(2)*: 563-569. DOI:10.1016/j.lwt.2008.07.016.

YANG, H S; CHOI, S G; JEON, J T; PARK, G B and JOO, S T (2007). Textural and sensory properties of low fat pork sausages with added hydrated oatmeal and tofu as texture-modifying agents. *Meat Science, 75(2)*: 283-289. DOI: 10.1016/j.meatsci.2006.07.013.