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EFFECT OF FAT REPLACEMENT WITH DIFFERENT TYPES OF EGGPLANTS ON THE PHYSICOCHEMICAL AND SENSORIAL PROPERTIES OF CHICKEN SAUSAGES: A CHEMOMETRIC APPROACH

(Kesan Penggantian Lemak dengan Pelbagai Jenis Terung terhadap Sifat Fisikokimia dan Deria Rasa Sosej Ayam: Pendekatan secara Kemometrik)

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Abstract

Animal fat plays an important role in processed meat products as it is responsible for improving some physicochemical and sensorial qualities of the final products. However, consumption of high-fat food products is linked to a higher risk of various cardiometabolic diseases such as type 2 diabetes mellitus and cardiovascular diseases. Eggplant has the potential to be used as a fat replacer, but different types of eggplants could produce various results. Thus, this study aimed to produce reduced-fat chicken sausages re-formulated with five different types of eggplants [Round Asian Eggplant (RAE), Pearl Red Eggplant (PRE), Pea Eggplant (PE), Round Black Eggplant (RBE), and Green Thai Eggplant (GTE)] as the fat replacers. The chicken sausages were evaluated for physicochemical and sensorial properties and compared to sausage containing only chicken fat as the control. The RAE, PRE, and PE sausages had the lowest fat content at 4.34%, 6.30% and 7.64%, respectively, thus can be claimed as reduced fat chicken sausages. There were no significant differences among all formulations in terms of ash, moisture, protein, cooking loss, water holding capacity, springiness, and cohesiveness. The sensory analysis revealed that consumers accepted the RAE and PRE sausages compared to the control and the least preferred was PE. This was supported by the PCA, which positively proposed lower fat content (4.34%) and higher a^* value (3.21) while rejecting higher pH (6.35) and b^* values (15.88) of the reduced-fat-chicken sausages. In conclusion, eggplants can be used as fat replacers to produce reduced-fat chicken sausages with Round Asian Eggplant being the best option.

Keywords: chicken meat products, fat mimetics, fat replacers, healthier meat products, low-fat sausages

Abstrak

Lemak haiwan memainkan peranan penting dalam produk daging yang diproses kerana ia bertanggungjawab untuk menambah baik beberapa kualiti fizikokimia dan deria rasa produk akhir. Walau bagaimanapun, pengambilan produk makanan tinggi lemak dikaitkan dengan risiko yang lebih tinggi untuk pelbagai penyakit kardiometabolik seperti diabetes mellitus jenis 2 dan penyakit kardiovaskular. Terung mempunyai potensi untuk digunakan sebagai pengganti lemak, tetapi jenis terung yang berbeza boleh menghasilkan keputusan yang pelbagai. Oleh itu, kajian ini bertujuan untuk menghasilkan sosej ayam kurang lemak yang dirumus semula menggunakan lima jenis terung yang berbeza [*Round Asian Eggplant* (RAE), *Pearl Red Eggplant* (PRE), *Pea Eggplant* (PE), *Round Black Eggplant* (RBE), dan *Green Thai Eggplant* (GTE)] sebagai pengganti lemak. Sosej ayam telah dinilai untuk sifat fizikokimia dan deria rasa dan dibandingkan dengan sosej yang mengandungi hanya lemak ayam sebagai kawalan. Sosej RAE, PRE, dan PE mempunyai kandungan lemak terendah masing-masing pada 4.34%, 6.30%, dan 7.64%, oleh itu boleh diperakukan sebagai sosej ayam kurang lemak. Tiada perbezaan yang ketara antara semua formulasi dari segi abu, kelembapan, protein, kehilangan berat memasak, kapasiti memegang air, keanjalan dan kepaduan. Analisis deria rasa mendedahkan bahawa pengguna menerima sosej RAE dan PRE berbanding dengan kawalan dan yang paling tidak disukai adalah PE. Ini disokong oleh PCA, yang secara positif mencadangkan kandungan lemak yang lebih rendah (4.34%) dan nilai *a** yang lebih tinggi (3.21) sambil menolak nilai pH (6.35) dan *b** (15.88) yang lebih tinggi untuk sosej ayam dikurangkan lemak. Kesimpulannya, terung boleh digunakan sebagai pengganti lemak untuk menghasilkan sosej ayam kurang lemak dengan *Round Asian Eggplant* menjadi pilihan terbaik.

Kata kunci: produk daging ayam, lemak mimetic, pengganti lemak, produk daging yang lebih sihat, sosej rendah lemak

Introduction

The growing concerns about the potential health risks associated with the consumption of high-saturated fat have caused the meat industries to modify traditional meat products or develop new formulations with lower fat contents and better fatty acid profiles [1,2]. Fat contributes to the flavour, texture, colour, mouthfeel, and appearance, so it is not completely removed from meat product formulations [3], alternatively, the fat is replaced with plant-based ingredients that function similar to fat but reduce the total fat, calories, and cholesterol content [4,5]. According to the Nutrient Comparative Claims, a food product is claimed as reduced fat if it has at least a 25 per cent lower fat content than the original product [6].

Eggplant (*Solanum melongena)* also known as brinjal, berenjena, aubergine or melanzane is an edible fruit that originated in India [7] and is commonly cultivated in Asia, Europe, Africa, and the Near East [8]. The eggplants are grouped based on the fruit shape into three botanical types: dwarf (*S. melongena var. depressum*), egg-shaped (*S. melongena var. esculentum*) and long and slender in shape (*S. melongena var. serpentinum*) [9,10]. They are an excellent source of dietary fibre and vitamins such as vitamin B6, vitamin K, vitamin C, niacin, and folate in addition to minerals including potassium, copper, magnesium, manganese, and molybdenum [11, 12]. Eggplant fruits are suitable plant-based ingredients to be incorporated into meat products due to their characteristics. For example, Akesowan and Jariyawaranugoon [13] reported that the incorporation of 2.73% w/w of eggplant powder shows positive attributes towards shrinkage, cooking yield and firmness of chicken nuggets extended with white button mushroom. Ammar [11] proved that the addition of 5 to 10% w/w eggplant pulp can successfully produce high-fibre chicken nuggets with some positive attributes such as water holding capacity and cooking yield and sensory evaluation. Eggplant powder added to pork sausage formulations produced sausages with a higher moisture and protein content and lower fat content [14]. Zhu et al. [15] also reported that eggplant powder mixed with soybean oil and used as a fat replacer improved the water- and fat-binding, texture, and sensory properties of pork sausages.

However, no study has evaluated the different types of eggplants as fat replacers. In addition, the best variables to describe the meat products added with eggplants could further increase the understanding of eggplants' functionalities. Therefore, this study determined the physicochemical and sensory properties of chicken sausages with five different eggplants: Round Asian Eggplant (RAE), Pearl Red Eggplant (PRE), Pea Eggplant (PE), Round Black Eggplant (RBE) and Green Thai Eggplant (GTE) as the fat replacers. The most discriminant variables of the newly formulated chicken sausages were selected by using a chemometric approach based on multivariate statistics. The outcomes are expected to highlight the potential of eggplants as fat replacers in the production of healthier meat products and could also be a reference for further research.

Materials and Methods

Preparation of chicken sausages

Five different types of eggplant fruits [Round Asian Eggplant (RAE), Pearl Red Eggplant (PRE), Pea Eggplant (PE), Round Black Eggplant (RBE) and Green Thai Eggplant (GTE)] were purchased from the local market in Bandar Sri Damansara, Selangor. The eggplants were separately rinsed with clean water and boiled for five minutes to make them softer and stop the enzymatic browning before being mashed using mortar and pestle into paste form. Frozen chicken breasts were purchased from a meat shop (Sri Ternak, Sri Kembangan, Selangor). The chicken breasts were ground using a mincer machine (Hobart 4822, USA). The control chicken sausage was formulated with 70% chicken meat, 10% fat, 10% corn starch, 1.25% salt, 0.5% sugar, 0.5% black pepper, 0.25% STPP and 7.5 % ice water. For the treatment of fat-replaced chicken sausages, the fat was replaced either by RAE, PRE, PE, RBE, or GTE at 10% of the total weight of the formulation. The minced chicken meat and other ingredients were placed into the bowl cutter (K3 Model-BenchType, Taiwan) and mixed for 10 minutes, then, added with the eggplant paste and continued mixing for another 6 minutes. The mixture was weighed into approximately 30 g portions and stuffed into the sausage casings, boiled for 10 minutes, taken out and cooled down in iced water. The casings were removed and the sausages were vacuum-packed in a polyethylene bag.

Proximate analysis

Proximate compositions of the chicken sausages were determined according to the AOAC methods [16]. Moisture content was determined by using the oven drying method where the chicken sausages were heated to 105 °C overnight and the moisture content was calculated based on the weight loss of the chicken sausages. Ash content was determined by igniting the chicken sausages at 550 °C using the furnace (Method No. 930.05). For crude fat, the Soxhlet extraction method was used where the weight of fat extracted petroleum ether was measured (Method No. 930.09). The crude protein content was determined by using the micro-Kjeldahl method (Method No. 978.04). The carbohydrate was calculated by the difference. The percentage of fat reduction was calculated based on the fat reduced in the newly formulated sausage against the fat of the control sample.

Water holding capacity (WHC)

Each chicken sausage was pre-weighed at 1.5 g and placed in a centrifuge tube with a filter paper (Whatman No. 1) and centrifuged for 15 minutes at 4000 g at 20°C using a centrifuge (KUBOTA 5800, Japan). The dried chicken sausages were then re-weighed, and the reading was recorded. WHC was determined using the following calculation [17]:

$$\text{WHC (\%)} = \frac{\text{(water weight before centrifuge - water weight after centrifuge)}}{\text{the sample weight}} \times 100 \quad (1)$$

Cooking loss

The chicken sausages were pan-fried evenly for 5 minutes using a non-stick pan with the internal temperature reaching 75°C. The cooking loss of the chicken sausages was determined by measuring the initial weight and final weight after cooking the sausages as follows [17]:

$$\text{Cooking loss (\%)} = \frac{\text{(initial weight – final weight) of chicken sausage}}{\text{the initial weight of chicken sausage}} \times 100 \quad (2)$$

pH analysis

The pH values were analyzed before the manufacture of chicken sausages. Five g of meat batter from each chicken sausage sample were homogenized with 40 mL of distilled water. Then the pH values of the chicken sausages were measured using a pH meter (Jenway Model 3505 pH meter, UK) [17].

Colour measurements

The colour of the chicken sausage was measured using a colourimeter (Minolta spectrophotometer CM 3500d, Japan) and the colour reading includes lightness (L^*), redness (a^*) and yellowness (b^*). The equipment was standardized using a white colour standard [17].

Texture analysis

The texture measurement of the chicken sausages was conducted using a computer-assisted TA-XT2i Texture Analyzer (Stable Micro Systems, UK). A compression test was used to determine hardness (g), cohesiveness (mm/mm), chewiness (g/m^3) and springiness (mm/mm). The test was carried out by using a 75 mm compression platen type probe with a 25 kg load cell at a pre-test speed of 2.00 mm/sec, test speed of 2.00 mm/sec and post-test speed of 5.00 mm/sec, a distance of 10.00 mm and auto-trigger type (5.0 g) [17].

Sensory analysis

A Hedonic test was conducted to evaluate the appearance, colour, texture, flavour, aroma and overall acceptability between the chicken sausages incorporated with different types of eggplant and against the control. A nine-point hedonic scale was used to evaluate the chicken sausages ranging from 9 (like extremely) to 1 (dislike extremely) by 30 untrained panellists [18].

Statistical analysis

Data obtained was analyzed using one-way ANOVA to identify significant differences among the means of various chicken sausages treatments using Tukey's test ($p<0.05$). The statistical program used was Minitab software, release 19 (Minitab Inc., Pennsylvania, USA). The results were expressed as means ± SD (standard deviation) of three replicates [18].

Dataset pre-processing

The distributions of (1) physicochemical properties, i.e., proximate, WHC, cooking loss, pH, colour measurement and texture values and (2) sensory properties were evaluated by developing the box and whisker plot (BWP) at a significant level (α) of 0.05 using XLSTAT-Pro (2017) statistical software (Addinsoft, Paris, France). The outlier presence of which values exceeded three times the box's height marked with a dot or '×' was evaluated to confirm the dataset variability. The BWP skewness was also examined to confirm the transformation of physicochemical and sensory properties as a whole dataset. The dataset distribution is deemed positively skewed or right-skewed when its mean value is larger than the median value, and vice versa; hence, the dataset is then subjected to transformation before correlation and principal component analyses (PCA) [19].

Correlation analysis

The correlation between the physicochemical and sensory properties was carried out using Pearson correlation to measure the strength (weak, moderate, or strong) and direction (positive and negative) of the linear relationship between two variables. In this study, the strong, weak, and moderate correlation were determined by correlation matrix (CM) value; $|0.000| < R < |0.300|$ for weak, $|0.300| < R < |0.700|$ for moderate and $|0.700| < R < |1.000|$ for strong CMs [20].

Principal component analysis

The PCA of Pearson correlation was carried out at α of 0.05 to (1) identify the variables with different factor loadings and (2) suggest the significant variables that might contribute to the formulations of chicken sausages. The dataset was transformed into smaller sets of new independent variables denoted as principal components (PCs). The cumulative variability of the PCs was examined to determine the percentage of the dataset explained in the formulations. At the same time, physicochemical properties and sensory properties variables were ranked based on their factor loadings: Strong for $FL \geq |0.750|$, moderate for $|0.500| < FL < |0.749|$ and weak for $FL \leq |0.499|$. Based on these FLs, the contribution of each physicochemical and sensory property and their intercorrelation in the formulations were examined and further explained [20].

Results and Discussion

Proximate composition

Table 1 shows the proximate analysis of the fat-replaced chicken sausages compared to the control. There were no significant differences (p<0.05) between the sausages regarding the ash, moisture, protein and carbohydrate contents. Although the eggplants provide minerals such as calcium, magnesium, phosphorus, potassium, iron, copper and zinc [21], their addition to chicken sausages did not significantly increase the ash content, with fat-replaced chicken sausages containing between 1.27% w/w to 2.08% w/w ash compared to the control of 1.43% w/w. The moisture content was probably not affected due to the similar water-binding ability of the eggplants to chicken fat. The high-water retention properties of the eggplant fibres also contribute to the moisture content of the meat products [11], which is positive as fat controls moisture release from the inner layers of the meat products [21]. Cengiz and Gokoglu [23] also showed an insignificant (p>0.05) effect on moisture content for frankfurter-type sausages incorporated with citrus fibre and soy protein concentrate as fat replacers.

Table 1. The proximate composition of the fat-replaced chicken sausages with eggplants compared to the control with fat

Sample[1]	Ash (% w/w)	Moisture (% w/w)	Protein (% w/w)	Carbohydrate (% w/w)	Fat (% w/w)	Fat Reduced Against Original Formulation (% w/w)
Control	1.43 ± 0.07^{a}	67.62 ± 2.13^{a}	11.76 ± 0.89^{a}	3.21 ± 3.46^{a}	15.98 ± 1.42^{a}	Not related
RAE	1.75 ± 0.06^{a}	72.92 ± 2.03^{a}	12.25 ± 0.77^{a}	8.74 ± 2.00^{a}	4.34 ± 2.10^{c}	71.95 ± 15.94^{a}
PRE	1.27 ± 0.71^{a}	68.22 ± 7.96^{a}	10.89 ± 1.94^{a}	13.32 ± 7.62^{a}	6.30 ± 2.23^{c}	60.17 ± 14.77^{ab}
PE	1.68 ± 0.46^{a}	70.52 ± 2.47^{a}	11.38 ± 1.05^{a}	8.79 ± 3.46^{a}	7.64 ± 0.54^{bc}	51.78 ± 6.93^{ab}
RBE	1.69 ± 0.18^{a}	70.65 ± 1.15^{a}	11.86 ± 0.45^{a}	7.50 ± 0.37^{a}	8.30 ± 0.48^{bc}	47.61 ± 7.68^{ab}
GTE	2.08 ± 0.95^{a}	71.28 ± 2.36^{a}	10.89 ± 0.94^{a}	4.28 ± 3.75^{a}	11.47 ± 2.28^{ab}	28.25 ± 12.89^{b}

[1]RAE: Round Asian Eggplant, PRE: Pearl Red Eggplant, PE: Pea Eggplant, RBE: Round Black Eggplant, and GTE: Green Thai Eggplant.
[a-c]Mean ± SD with different letters is significantly different (P<0.05) within the same column.

According to San José et al. [24], although protein content varies in different types of eggplants, it is generally low with not less than 1 g per 100 g. There were no significant differences in the protein content of the sausages as expected. Similarly, there was no significant effect (P>0.05) on the carbohydrate content of the sausages, however, the carbohydrate content of the fat-replaced chicken sausages (4.28–13.32% w/w) was higher compared to the control (3.21% w/w), most probably due to the carbohydrate content of the eggplants. Similarly, Bunmee et al., [25] also observed an increase in carbohydrate content in beef patties incorporated with purple eggplant flour. The addition of carbohydrate-based components may contribute to a higher amount of carbohydrates in meat products [26]. Nevertheless, all fat-replaced chicken sausages produced had protein (7.03–14.14%) and carbohydrate (6.69–21.59%) contents similar to various commercially available chicken sausages [27].

All fat-replaced chicken sausages had a significantly reduced fat content, except for sausages incorporated with GTE (11.47% w/w), compared to the control (15.98% w/w), with chicken sausages incorporated with RAE (4.34% w/w) and PRE (6.30% w/w) having the lowest fat content. This agreed with the previous studies by Kahar et al. [28] and Ramle et al. [18], which reported that the replacement of animal fat with plant resources can lower the fat content of meat products. These results confirmed that the use of eggplants as a fat replacer reduces the fat content of meat products except for the addition of GTE. The RAE sausages had the highest (p<0.05) fat reduction compared to the control (71.95% w/w), while the GTE sample was the lowest (28.25%

w/w) (Table 1). All chicken sausages incorporated with different types of eggplants had more than 25% fat reduction, so according to the Food Regulations 1985 [6], they can be claimed as fat-reduced sausages.

Water holding capacity (WHC), cooking loss, and pH

WHC indicates the ability of the chicken sausages to bind water under no influence from outside forces and determines the juiciness in conjunction with the flavour, texture, and colour of meat products [29]. Table 2 shows no significant differences (p>0.05) in the WHC for all the chicken sausages. The fat in the control formulation could entrap water molecules thus retaining the WHC value, and eggplants can hold the water due to their hydrophilic nature and porous texture of the fibres [30]. In addition, eggplant particles may fill the space around the protein gel matrix and bind water within which also increases the WHC [31]. The WHC data was predicted to be directly proportional to the moisture content, with a higher WHC indicating stronger development of the protein network that entraps the water within the meat products due to the enhanced intermolecular cross-linking between myofibrillar proteins and eggplant [32].

Table 2. The water holding capacity (WHC), cooking loss and pH of the fat-replaced chicken sausages with eggplants compared to the control with fat

Sample[1]	WHC (% w/w)	Cooking Loss (% w/w)	pH
Control	99.97 ± 0.03^{a}	10.75 ± 1.86^{a}	6.36 ± 0.03^{a}
RAE	99.58 ± 0.41^{a}	8.24 ± 1.73^{a}	6.26 ± 0.12^{ab}
PRE	99.90 ± 0.03^{a}	7.21 ± 1.67^{a}	6.20 ± 0.06^{b}
PE	99.41 ± 0.90^{a}	7.12 ± 1.52^{a}	6.35 ± 0.02^{ab}
RBE	99.93 ± 0.05^{a}	10.00 ± 3.33^{a}	6.31 ± 0.02^{ab}
GTE	99.66 ± 0.49^{a}	12.83 ± 2.61^{a}	6.33 ± 0.02^{ab}

[1]RAE: Round Asian Eggplant, PRE: Pearl Red Eggplant, PE: Pea Eggplant, RBE: Round Black Eggplant, and GTE: Green Thai Eggplant.
[a-b]Mean ± SD with different letters is significantly different (P<0.05) within the same column.

Cooking loss is one of the important parameters to evaluate the quality of meat products and is defined as the percentage of weight loss due to heat treatment and cooking loss depends on the capacity of the gel matrix to immobilise fat and water in finely comminuted meat products [33]. There were no significant differences between the fat-replaced sausages compared to the control chicken sausages (Table 2). The cooking loss of the control sausages was attributed to moisture evaporation and fat leakage due to melting during cooking [34], whereas the cooking loss of the eggplants-incorporated sausages could be due to moisture loss. However, since no notable difference was observed between control and eggplant-incorporated sausages, it can be concluded that not much fat was released from the control sausages, while the eggplants used in this study had water retaining ability during cooking similar to the fat. Nevertheless, the GTE and RBE sausages both had high cooking losses near to the control's value, most probably due to the high-fat content as reported in Table 1. Cooking loss can be an indicator of the WHC of meat products that are mostly influenced by factors such as moisture, fat, protein content and processing methods (heating, cutting, grinding) [35, 36] and is supported by the cooking loss and WHC results, where both showed no significant difference among the chicken sausages. Through hydrogen bonding, the WHC of the myofibrillar protein improves promoting emulsion stability which contributes to the reduced cooking loss of low-fat sausages [31].

No significant difference in pH was observed between the control and all chicken sausages, except for the sausages incorporated with PRE. This indicated that eggplants did not affect the acidity of the sausages and eventually would not influence the taste. Various studies have shown that the replacement of fat with plant-based ingredients did not have a notable effect on the pH of meat products. For example, Das et al., [37] reported that the pH of the meat product was not significantly affected by the addition of soy protein. The addition of other proteins like gelatin in low-fat sausages also did not affect the pH value of the low-fat sausages [38].

Colour and texture properties

Colour is an extrinsic factor that influences customer satisfaction and preferences for meat products [39]. Colour variation can result from the protein-fat interactions, structural proteins and the homogeneity of the cut surface [40]. The colour of the chicken sausages was significantly affected by the addition of different types of eggplant as the fat replacer (Table 3). The lightness (L^*) decreased significantly compared to the control, in line with the results reported by Park et al. [41]. The colour change may be caused by the hydration of the additional dietary fibre (hydrocolloids) as the added fibres were mostly white or egg-coloured [42]. According to Dingstad et al. [43], at least 60 per cent of consumers are willing to purchase sausages when the L^* value was between 62.3 and 68.5. The chicken sausages did not achieve the desired lightness and even become darker after heating, but the L^* values were in the range of commercial chicken sausages (44.42–65.54) [27] with RAE and PRE being most similar to the control. The other darker chicken sausages were influenced by the colour of the eggplant.

In terms of the redness (a^*) and yellowness (b^*), only PE showed a significantly lower value compared to the control, indicating that most eggplants used did not reduce the red colour and alter the yellowness of the chicken sausages. The redness (a^*) of meat products results from the presence of several heme proteins, haemoglobin and myoglobin in the meat and the red colour is the main attribute of meat products [44]. The degree of redness is the general metric used to indicate the freshness of meat and meat products, and meat sausages with higher a^* values usually are more attractive to consumers and have the best market approval rate [45]. Meanwhile, the yellow colour intensity could increase if the fat in sausages was replaced with yellow-coloured plants [46]. Thus, this showed that the colour characteristics of all the eggplants gave yellowness (b^*) values close to the control chicken sausage except for PE. To conclude, most of the eggplants used as the fat replacer did not alter the colour of the chicken sausages, especially RAE and PRE with lightness, redness and yellowness values similar to the control.

Table 3. The colour (L^*, a^*, b^*) and texture properties of the fat-replaced chicken sausages with eggplants compared to the control with fat

Sample[1]	**Colour Measurements**			**Texture Properties**			
	Lightness (L^*)	**Redness (a^*)**	**Yellowness (b^*)**	**Hardness (g)**	**Springiness (mm/mm)**	**Cohesiveness (mm/mm)**	**Chewiness (g/m^3)**
Control	55.14 ± 0.87^a	2.63 ± 0.16^{ab}	14.30 ± 0.67^b	10418 ± 1539^b	0.92 ± 0.02^a	0.40 ± 0.02^a	3835 ± 799^b
RAE	53.11 ± 0.37^{ab}	2.45 ± 0.11^b	13.20 ± 0.61^b	14998 ± 1286^{ab}	0.91 ± 0.02^a	0.39 ± 0.04^a	5269 ± 301^{ab}
PRE	53.05 ± 0.66^{ab}	2.69 ± 0.01^{ab}	13.55 ± 0.37^b	15654 ± 2706^a	0.90 ± 0.02^a	0.44 ± 0.02^a	6260 ± 1243^a
PE	50.40 ± 0.36^c	1.03 ± 0.30^c	15.88 ± 0.65^a	14767 ± 1669^{ab}	0.91 ± 0.02^a	0.43 ± 0.03^a	5778 ± 316^{ab}
RBE	51.97 ± 1.33^{bc}	2.89 ± 0.30^{ab}	14.68 ± 0.71^{ab}	12281 ± 1783^{ab}	0.91 ± 0.02^a	0.41 ± 0.02^a	4592 ± 658^{ab}
GTE	49.43 ± 1.50^c	3.21 ± 0.29^a	14.35 ± 0.29^{ab}	11108 ± 1605^{ab}	0.93 ± 0.01^a	0.41 ± 0.00^a	4274 ± 602^{ab}

[1]RAE: Round Asian Eggplant, PRE: Pearl Red Eggplant, PE: Pea Eggplant, RBE: Round Black Eggplant, and GTE: Green Thai Eggplant.
[a-c]Mean ± SD with different letters is significantly different (P<0.05) within the same column.

The texture of meat products often influences consumer preference. Table 3 shows the texture properties of the fat-replaced chicken sausages with eggplants against the control. Among the five different types of eggplants used, PRE-fat-replaced chicken sausage had significantly ($p<0.05$) high hardness (15654 g) and chewiness (6260 g/m^3) values compared to control, with no significant differences observed in both the hardness and chewiness of the other chicken sausages compared to the control. A similar result was found by Choe and Kim [47] that the addition of wheat fibre mixture increased the hardness of chicken sausages. Other studies also reported that the replacement of fat with various types of fibres increased the hardness of other types of meat products [48, 49]. The meat proteins used in fat encapsulation were reduced when fat replacers were used to replace animal fat, thus more meat proteins should be utilised through the gel structure of the meat matrix to achieve an acceptable texture [50]. These changes in textural properties may be due to dietary fibre, which can bind water and absorb fat [5]. In addition, reducing the fat could lead to increased hardness and chewiness [49].

There were no significant differences in the springiness and cohesiveness of all the chicken sausages which indicates that the replacement of animal fat with different types of eggplants gave the same springiness and cohesiveness to the final products. Similar results were obtained by Choi et al. [51], for reduced fat chicken sausage containing brewer's spent grain dietary fibre with no significant difference in the value of cohesiveness among all the samples. To summarise, the eggplants did not change the textural properties of the fat-replaced chicken sausages compared to the control except for the PRE.

Sensory properties

Table 4 summarises the sensory analysis of the chicken sausage with different types of eggplant used as the fat replacer. The sensory attributes were appearance, colour, texture, flavour, aroma and overall acceptability and all play important roles in consumer preferences to determine the palatability of food products [39]. The panellists rated the PE chicken sausages the lowest compared to the other fat-treated chicken sausages and control, with the other fat-replaced chicken sausages scoring similarly to the control. These results agree with that obtained by Ammar [11], which indicates that the addition of eggplant pulp powder did not affect the sensory scores of chicken meat nuggets compared to the control. These results also suggested that there was no decrementing effect on the sensory properties of chicken sausages after the addition of different types of eggplants except for PE. This is a very important characteristic since additional ingredients could negatively affect the sensory properties of meat products owing to their strong taste and flavour [46], thus changing the attractiveness of food and affecting consumer choice [51].

Table 4. Sensory properties of the fat-replaced chicken sausages with eggplants compared to the control with fat

Sample[1]	Appearance	Colour	Texture	Flavour	Aroma	Overall Acceptability
Control	6.47 ± 1.33^{a}	6.20 ± 1.32^{ab}	6.60 ± 1.28^{a}	7.03 ± 1.16^{a}	6.70 ± 1.09^{a}	7.07 ± 1.20^{a}
RAE	6.37 ± 1.16^{a}	6.50 ± 1.31^{a}	6.23 ± 1.01^{ab}	6.80 ± 1.24^{a}	6.07 ± 1.44^{ab}	6.93 ± 0.94^{a}
PRE	6.43 ± 1.22^{a}	6.20 ± 1.27^{ab}	6.37 ± 1.33^{ab}	6.57 ± 1.17^{a}	6.50 ± 1.38^{a}	6.73 ± 1.11^{a}
PE	5.17 ± 1.62^{b}	5.40 ± 1.42^{b}	5.60 ± 1.20^{b}	4.97 ± 1.65^{b}	5.20 ± 1.56^{b}	5.03 ± 1.52^{b}
RBE	6.53 ± 1.04^{a}	6.33 ± 1.24^{ab}	6.33 ± 1.42^{ab}	6.57 ± 1.35^{a}	6.13 ± 1.47^{ab}	6.70 ± 1.06^{a}
GTE	6.10 ± 1.35^{ab}	6.13 ± 1.22^{ab}	6.43 ± 1.14^{ab}	6.67 ± 1.24^{a}	6.23 ± 1.52^{ab}	6.70 ± 1.39^{a}

[1]RAE: Round Asian Eggplant, PRE: Pearl Red Eggplant, PE: Pea Eggplant, RBE: Round Black Eggplant, and GTE: Green Thai Eggplant.
$^{a-b}$Mean ± SD with different letters is significantly different ($P<0.05$) within the same column.

Correlation of physicochemical and sensory properties

Figure 1 (a) and 1 (b) depict the BWP of the physicochemical and sensory properties of the chicken sausages. Among the variables, carbohydrate, moisture, ash, WHC, cooking loss, pH, a^*, chewiness, cohesiveness, overall acceptability, aroma, flavour, texture, and appearance had outliers marked with a dot or (×), which indicated high variability within the dataset. The plus (+) sign in Figure 1 (a) and Figure 1 (b) indicates the mean value for each variable, where only ash, cooking loss, chewiness, cohesiveness, aroma and colour had a similar mean value compared to the median, indicating low or no skewness of the dataset distribution. Other variables showed right and left skewnesses in their dataset distribution, hence, they were transformed before correlation analysis.

The Pearson correlation test was used to determine correlations between two variables, i.e., the physicochemical and sensory properties (Table 5). The correlation matrix (CM) investigated the strength (weak, moderate, or strong) and direction (positive and negative) of the linear relationship between these two variables. Positive and negative correlations between two variables at |0.700| < R < |1.000| indicated strong CM, |0.300| < R < |0.700| for moderate CM and 3|0.000| < R < |0.300| for weak CM. From Table 5, hardness and chewiness had eight strong and moderate CMs followed by *a**, *b**, cooking loss, carbohydrate with seven, and pH, fat, and fat reduction with six strong and moderate CMs. All sensory evaluation variables had five overall strong and moderate CMs. Among these variables, several two matched variables had positive and strong CMs., e.g., hardness and chewiness (R = 0.92), flavour and overall acceptability (R = 0.85), appearance and colour (R = 0.77), cooking loss and springiness (R = 0.73), and carbohydrate and fat reduction (R = 0.70), which denoted that these variables had a proportional relationship to each other.

The positive correlation between hardness and chewiness is similar to a study by Varga-Visi et al. [53], which indicated that there was a strong CM between hardness and chewiness of low-fat turkey sausages. In addition, this result was also supported by De Angelis et al. [54] and is probably due to the addition of the fat replacer which contains fibre which increases the hardness and chewiness of the product [55]. The positive correlation between appearance and colour might be explained by the panellists rating the appearance based on the colour of the chicken sausages, which is supported by the sensory properties results tabulated in Table 4, which shows that PE scored the lowest value for both appearance and colour. A positive correlation between flavour and overall acceptability aligned with the results obtained by Andersen et al. [56], which explained that flavour is the main factor to determine product acceptability. The polymers present in the fat replacer might limit water mobility and inhibit water release during cooking, thus, affecting the texture profile analysis which includes the springiness of the meat product [57]. Furthermore, Garcia-Santos et al. [58] also showed that carbohydrate content significantly affects the fat reduction of sausage.

Fat and fat reduction (R = -0.99), pH and carbohydrate (R = -0.72) and fat and carbohydrate (R = -0.72) were negatively and strongly correlated indicating that these variables had an inverse proportional relationship. Jin et al. [59] showed that there are no significant changes in the pH in Pearson's correlation test on emulsion-type pork sausages. Generally, the pH of the meat product is affected by both the raw meat and the additives [60]. The incorporation of starch significantly decreases the fat percentage of emulsion-type sausage, and these ingredients may be able to replace the voids created by the reduced fat and give more high-molecular carbohydrates to the emulsion-type sausage [61]. Although these variables rendered strong and moderate CMs, the CM value only explained the correlation between two variables [20], so PCA was performed [62].

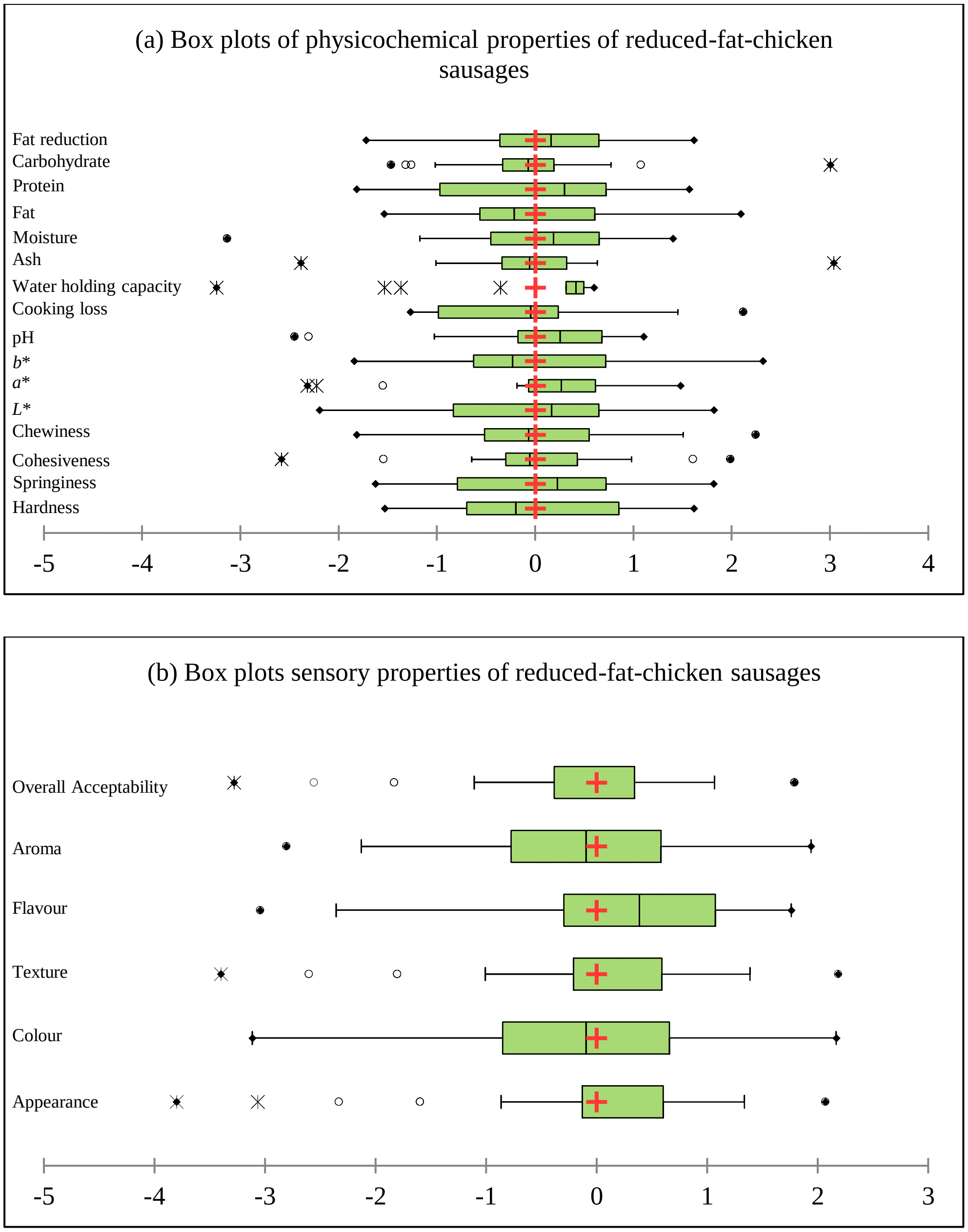


Figure 1. Box plots of (a) physicochemical properties and (b) sensory properties of reduced-fat-chicken sausages

Table 5. Correlation matrix of physicochemical and sensory properties

Variables	Correlation matrix[1,2]									
	Hardness	**Springiness**	**Cohesiveness**	**Chewiness**	***L****	***a****	***b****	**pH**	**Cooking loss**	**WHC**
Hardness	1.00	-0.13	0.07	**0.92**	-0.11	**-0.42**	**-0.30**	**-0.42**	**-0.55**	-0.08
Springiness	-0.13	1.00	-0.01	0.00	-0.26	**0.30**	-0.09	0.10	**0.73**	0.15
Cohesiveness	0.07	-0.01	1.00	**0.43**	-0.16	-0.19	**0.30**	-0.20	-0.12	-0.28
Chewiness	**0.92**	0.00	**0.43**	1.00	-0.17	**-0.41**	-0.16	**-0.46**	**-0.46**	-0.14
*L**	-0.11	-0.26	-0.16	-0.17	1.00	0.05	**-0.43**	-0.15	-0.18	0.29
*a**	**-0.42**	**0.30**	-0.19	**-0.41**	0.05	1.00	**-0.44**	-0.16	**0.51**	0.22
*b**	**-0.30**	-0.09	**0.30**	-0.16	**-0.43**	**-0.44**	1.00	**0.38**	-0.01	**-0.32**
pH	**-0.42**	0.10	-0.20	**-0.46**	-0.15	-0.16	**0.38**	1.00	0.21	-0.26
Cooking loss	**-0.55**	**0.73**	-0.12	**-0.46**	-0.18	**0.51**	-0.01	0.21	1.00	0.24
WHC	-0.08	0.15	-0.28	-0.14	0.29	0.22	**-0.32**	-0.26	0.24	1.00
Ash	-0.15	0.14	-0.29	-0.25	**-0.47**	0.11	0.08	0.20	0.11	0.19
Moisture	-0.11	-0.07	0.18	-0.06	-0.12	-0.02	0.07	0.23	0.08	**-0.42**
Fat	**-0.67**	0.24	-0.18	**-0.65**	0.23	0.21	0.17	**0.59**	**0.39**	0.12
Protein	0.13	-0.14	**-0.41**	-0.08	0.17	-0.09	-0.25	0.05	-0.13	0.02
Carbohydrate	**0.65**	-0.14	0.14	**0.65**	-0.10	-0.16	-0.15	**-0.72**	**-0.38**	0.19
Fat reduction	**0.66**	-0.19	0.23	**0.65**	-0.23	-0.21	-0.19	**-0.60**	**-0.38**	-0.11
Appearance	-0.12	-0.06	-0.07	-0.14	0.21	0.27	-0.21	-0.11	0.05	0.16
Colour	-0.05	-0.08	-0.12	-0.09	0.11	0.21	-0.15	-0.09	0.03	0.06
Texture	-0.17	-0.08	-0.02	-0.17	0.19	0.19	-0.14	-0.02	0.05	0.08
Flavour	-0.19	-0.02	-0.17	-0.24	0.29	**0.37**	**-0.30**	-0.10	0.14	0.19
Aroma	-0.09	0.06	-0.07	-0.09	0.19	0.23	-0.23	-0.07	0.09	0.25
Overall Acceptability	-0.18	-0.03	-0.21	-0.24	0.29	**0.40**	-0.33	-0.12	0.14	0.24
Number of strong and moderate CMs	8	2	3	8	2	7	7	6	7	2

[1]|0.000| < R < |0.300| = weak correlation, |0.300| < R < |0.700| = moderate correlation and |0.700| < R < |1.000| = strong correlation matrix.

[2]Correlation matrix with the bold value indicated strong and moderate correlations between two variables

Table 5. (Continued)

Variables	Correlation matrix[1,2]											
	Ash	**Moisture**	**Fat**	**Protein**	**Carbohydrate**	**Fat reduction**	**Appearance**	**Colour**	**Texture**	**Flavour**	**Aroma**	**Overall Acceptability**
Hardness	-0.15	-0.11	**-0.67**	0.13	**0.65**	**0.66**	-0.12	-0.05	-0.17	-0.19	-0.09	-0.18
Springiness	0.14	-0.07	0.24	-0.14	-0.14	-0.19	-0.06	-0.08	-0.08	-0.02	0.06	-0.03
Cohesiveness	-0.29	0.18	-0.18	**-0.41**	0.14	0.23	-0.07	-0.12	-0.02	-0.17	-0.07	-0.21
Chewiness	-0.25	-0.06	**-0.65**	-0.08	**0.65**	**0.65**	-0.14	-0.09	-0.17	-0.24	-0.09	-0.24
*L**	**-0.47**	-0.12	0.23	0.17	-0.10	-0.23	0.21	0.11	0.19	0.29	0.19	0.29
*a**	0.11	-0.02	0.21	-0.09	-0.16	-0.21	0.27	0.21	0.19	**0.37**	0.23	**0.40**
*b**	0.08	0.07	0.17	-0.25	-0.15	-0.19	-0.21	-0.15	-0.14	**-0.30**	-0.23	**-0.33**
pH	0.20	0.23	**0.59**	0.05	**-0.72**	**-0.60**	-0.11	-0.09	-0.02	-0.10	-0.07	-0.12
Cooking loss	0.11	0.08	**0.39**	-0.13	**-0.38**	**-0.38**	0.05	0.03	0.05	0.14	0.09	0.14
WHC	0.19	**-0.42**	0.12	0.02	0.19	-0.11	0.16	0.06	0.08	0.19	0.25	0.24
Ash	1.00	-0.14	-0.07	0.03	0.05	0.05	-0.04	-0.01	-0.02	0.02	0.11	0.03
Moisture	-0.14	1.00	-0.16	**-0.33**	**-0.53**	0.15	0.06	0.09	0.08	0.06	-0.13	0.04
Fat	-0.07	-0.16	1.00	-0.06	**-0.72**	**-0.99**	0.08	0.00	0.17	0.16	0.12	0.13
Protein	0.03	-0.33	-0.06	1.00	0.07	0.09	0.02	0.02	-0.07	-0.04	-0.03	0.00
Carbohydrate	0.05	**-0.53**	**-0.72**	0.07	1.00	**0.70**	-0.12	-0.08	-0.19	-0.18	-0.01	-0.15
Fat reduction	0.05	0.15	**-0.99**	0.09	**0.70**	1.00	-0.09	-0.04	-0.19	-0.20	-0.14	-0.16
Appearance	-0.04	0.06	0.08	0.02	-0.12	-0.09	1.00	**0.77**	**0.42**	**0.52**	**0.38**	**0.63**
Colour	-0.01	0.09	0.00	0.02	-0.08	-0.04	**0.77**	1.00	**0.40**	**0.50**	**0.32**	**0.59**
Texture	-0.02	0.08	0.17	-0.07	-0.19	-0.19	**0.42**	**0.40**	1.00	**0.62**	**0.56**	**0.62**
Flavour	0.02	0.06	0.16	-0.04	-0.18	-0.20	**0.52**	**0.50**	**0.62**	1.00	**0.58**	**0.85**
Aroma	0.11	-0.13	0.12	-0.03	-0.01	-0.14	**0.38**	**0.32**	**0.56**	**0.58**	1.00	**0.65**
Overall Acceptability	0.03	0.04	0.13	0.00	-0.15	-0.16	**0.63**	**0.59**	**0.62**	**0.85**	**0.65**	1.00
Number of strong and moderate CMs	1	2	6	2	7	6	5	5	5	5	5	5

[1]|0.000| < R < |0.300| = weak correlation, |0.300| < R < |0.700| = moderate correlation and |0.700| < R < |1.000| = strong correlation matrix.
[2]Correlation matrix with the bold value indicated strong and moderate correlations between two variables.

Association of the physicochemical and sensory properties of the chicken sausages

The PCA was performed to identify (1) variables with different factor loadings and (2) significant variables that might contribute to the formulation of the chicken sausages. Table 6 shows the factor loading (FL) of each variable in their respective principal component (PC). The number of PCs generated was based on the number of variables, and as the number of PC increased, the eigenvalue (EV) and dataset variability (DV) decreased, while cumulative explained variability (CEV) increased. This was evident as PC1 had the highest EV and DV and the lowest CEV. The increment of PC numbers indicated that more variables explained the dataset in this study, hence, all physicochemical and sensory properties variables were explained until PC5. However, among these variables, those with strong (FL ≥ |0.750|) and moderate (|0.500| < FL < |0.749|) FL were the significant variables that explained the formulation of chicken sausages.

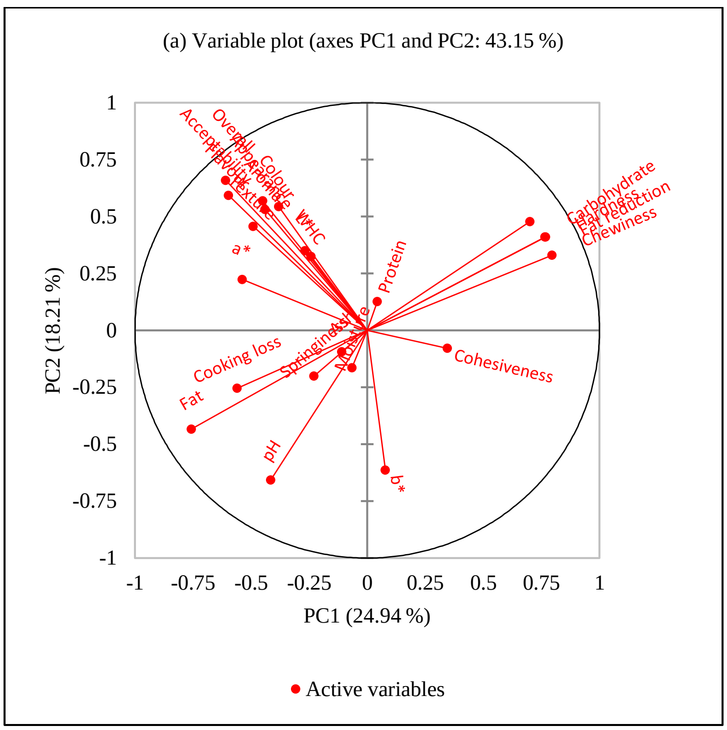
Table 6. Factor loading of variables in principal components (PCs) for the formulation of the reduced fat-chicken sausages

Variables	Factor Loading (FL)[1,2]				
	PC1	PC2	PC3	PC4	PC5
Hardness	**0.7659**	0.4100	-0.0111	0.0418	0.0342
Springiness	-0.2288	-0.2004	-0.4283	**-0.6014**	-0.2234
Cohesiveness	0.3453	-0.0790	0.4642	-0.3639	-0.4019
Chewiness	**0.7965**	0.3302	0.1056	-0.1631	-0.1777
*L**	-0.2674	0.3498	0.0079	**0.6245**	-0.5028
*a**	**-0.5383**	0.2240	-0.3175	-0.3652	-0.1716
*b**	0.0785	**-0.6133**	0.3528	-0.0712	0.2379
pH	-0.4154	**-0.6572**	0.1934	0.1667	0.2940
Cooking loss	**-0.5600**	-0.2546	-0.3509	**-0.5317**	-0.1818
Water holding capacity	-0.2412	0.3242	**-0.6157**	0.0492	-0.1284
Ash	-0.1087	-0.0932	-0.3650	-0.2796	**0.7500**
Moisture	-0.0657	-0.1640	**0.6587**	-0.3090	-0.0036
Fat	**-0.7573**	-0.4336	-0.0546	0.2486	-0.2132
Protein	0.0436	0.1265	-0.3232	**0.5457**	0.3173
Carbohydrate	**0.7015**	0.4784	-0.3424	-0.0697	0.0361
Fat reduction	**0.7681**	0.4101	0.0336	-0.2552	0.1723
Appearance	-0.4500	**0.5686**	0.2610	-0.0530	0.1166
Colour	-0.3812	**0.5443**	0.3047	-0.0824	0.2269
Texture	**-0.4904**	0.4567	0.3201	-0.0446	0.0660
Flavour	**-0.5969**	**0.5931**	0.1788	-0.0659	0.0590
Aroma	-0.4398	**0.5307**	0.0305	-0.0989	0.0807
Overall acceptability	**-0.6089**	**0.6591**	0.1536	-0.0724	0.1031
Eigenvalue (EV)	5.4867	4.0066	2.2880	1.9979	1.5487
Dataset variability (DV), %	24.9396	18.2118	10.4001	9.0813	7.0396
Cumulative explained variability (CEV), %	24.9396	43.1514	53.5515	62.6328	69.6724

[1]*FL ≥ |0.750| = strong factor loading and |0.500| < FL < |0.749| = moderate factor loading*
[2]*Factor loading with bold value indicated strong and moderate factor loading in the principal component*

Chewiness (FL = 0.7965), hardness (FL = 0.7659), fat reduction (FL = 0.7681), fat (FL = -0.7573), carbohydrate (FL = 0.7015), overall acceptability (FL = -0.6089), flavour (FL = -0.5969), cooking loss (FL = -0.5600) and a* (FL = -0.5383) had strong and moderate FL in PC1 (Table 6). Texture with an FL value of -0.4904 was considered moderate FL since the FL value was nearer to |0.500|. Variables with the same positive or negative signs were positively correlated. For instance, chewiness, hardness, fat reduction, and carbohydrate were positively correlated, while fat, overall acceptability, flavour, cooking loss, *a** and texture had a similar correlation. Meanwhile, the chewiness, hardness, fat reduction, and carbohydrate had negative correlations to the latter, as shown in Figure 2(a), where chewiness, hardness, fat reduction, and carbohydrate are located nearer to each other, and the fat, overall acceptability, flavour, cooking loss, *a** and texture resided in the opposite direction. Accordingly, it is proposed that chewiness, hardness, and carbohydrate content negatively affect the overall acceptability, flavour and texture of the RAE formulated sausages since these variables fell in the RAE group in Figure 2(b). Also, the fat content and *a** value related to the redness of the sausages rendered a positive effect on the overall acceptability and flavour of the GTE formulated sausages in Figure 2(b).

In PC2, the overall acceptability (FL = 0.6591), pH (FL = -0.6572), b* (FL = -0.6133), flavour (0.5931), appearance (FL = 0.5686), colour (FL= 0.5443), and aroma (FL= 0.5307) had strong and moderate FL. Likewise, these variables were positively correlated with (1) overall acceptability, flavour, appearance, colour and aroma, and (2) pH and *b**, while (1) and (2) were negatively correlated to each other. These correlations indicated that pH and *b** value of the sausages negatively affected the overall acceptability, flavour, appearance, colour and aroma (Figure 2a), especially in PE sausages and controls (Figure 2b). Moreover, the RAE and RBE formulations had the best overall acceptability, flavour, appearance, and colour since these variables were located in the RAE and RBE groups. No correlation was present for all variables in PC1 and PC2 since they were located at 90° in Figure 2(a). However, the overall acceptability had moderate FL in both PC1 and PC2.



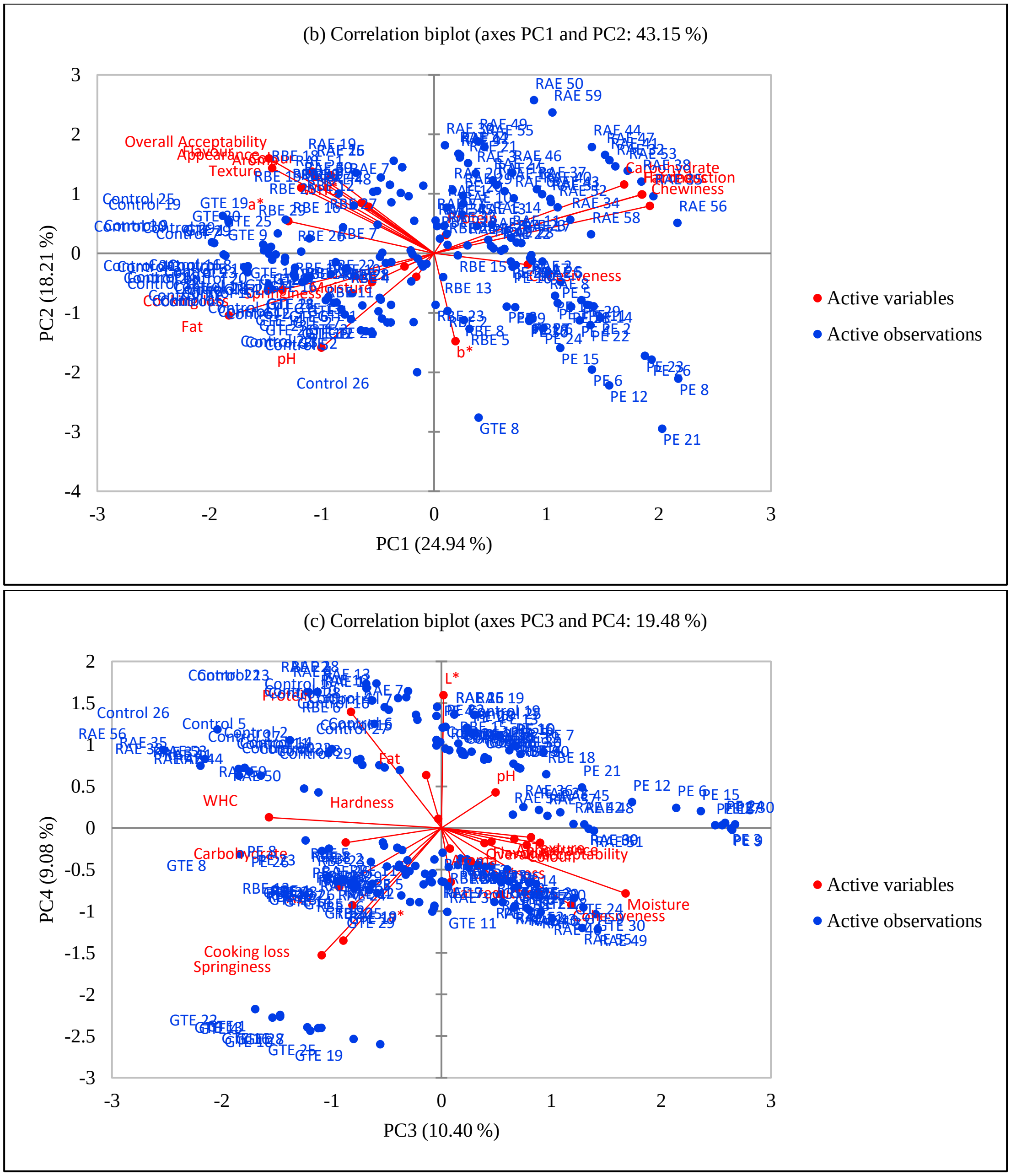


Figure 2. (a) Variable plot (PC1 and PC2), (b) correlation biplot of (PC1 and PC2) and (c) correlation biplot of (PC3 and PC4) of variables and formulations of reduced-fat-chicken sausage

WHC (FL = -0.6157) and moisture (FL=0.6587) in PC3 were negatively correlated while springiness (FL = -0.6014) and cooking loss (FL = -0.5317) in PC4 were positively correlated. Similarly, *L** (FL = 0.6245) and protein (FL = 0.5457) in PC4 were positively correlated. The WHC and moisture were dominant in RAE and GTE, respectively, while both springiness and cooking loss were dominant in GTE (Figure 2(c)). Figure 2(c) also depicted that both the *L** value and protein were dominant in the control, RAE and PE. The cohesiveness did not achieve moderate or strong FL, while ash was only found in PC5, indicating they were very unlikely to affect the formulation. Nevertheless, although some variables in PC3, PC4 and PC5 had strong and moderate FL, they played less important roles in dictating their influences on the sensory evaluation since they were present in higher PC numbers with low DV. Based on the PCA, overall, the panellists rated the chicken sausages based on the most discriminant variables, which were the fat content (4.34% ± 2.10), *a** value (3.21 ± 0.29), pH (6.35 ± 0.02), *b** value (15.88 ± 0.65). The RAE sample was positively selected due to its low-fat content and high *a** value, while the PE sample was less preferred due to its high pH and *b** values.

Conclusion

In conclusion, the incorporation of eggplants as fat replacers in chicken sausages' production can be considered a successful strategy. Despite many positive results of the majority of the eggplants, three types of eggplants; the Round Asian Eggplant (RAE), Pearl Red Eggplant (PRE) and Pea Eggplants (PE) had lower fat values compared to the control, and therefore, can be claimed as reduced-fat meat products. Further analysis using the principal component analysis, the panellists were influenced to positively rate the sample with the lowest fat content and high *a** value, which represents the RAE sample while rejecting the PE sample due to high pH and *b** values. Therefore, based on the overall result, Round Asian Eggplant (RAE) can be considered the best eggplant type with the highest potential to be used as a fat replacer in the production of reduced-fat chicken sausages.

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