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Effects of incorporation of sugarcane fibre on the physicochemical and sensory properties of chicken sausage

Running title: Sugarcane fibre in chicken sausage

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Abstract

Improving functional and eating qualities of processed meat products through incorporation of plant fibre is of interest to both consumers and food industry. This project investigated the physicochemical and sensory properties of chicken sausages with incorporation of up to 3% sugarcane fibre, a byproduct of sugarcane processing. Compared with no sugarcane fibre sample, the cooking yield of chicken sausage with 3% of fibre and 10% of water addition was increased from 94.20% to 97.52%, total phenolic content from 25.43 to 57.09 mg GAE/100g and radical scavenging activity from 28.11% to 60.72%, whereas lipid oxidation of TBARS value was decreased

from 0.535 to 0.428 MDA mg/kg. Moreover, consumer overall liking of chicken sausages was not affected by the incorporation of sugarcane fibre. This research suggested that incorporation of sugarcane fibre could improve eating quality and health benefits of the chicken sausage product, and add value to both the food and sugarcane industry.

Key words: sugarcane fibre; chicken sausage; dietary fibre; antioxidant activity; sensory property

1. Introduction

Compared to red meat, white meat such as poultry meat has become popular due to several advantages such as low fat content and high nutritional value including high levels of digestible proteins and unsaturated lipids (Marangoni et al. 2015). It is predicted that poultry meat production will likely keep growing due to its relatively lower price and less religious influences (Petracci et al. 2013). There is also an increased demand for processed chicken meat products for convenience to consumers and added value to food industry (Michel et al. 2011).

Dietary fibre is mainly derived from edible parts of plants, and is low in calories and cannot be completely digested and absorbed by small intestine. In addition, dietary fibre demonstrates potential health benefits by reducing the risk of chronic diseases such as cardiovascular disease and diabetes (Ozyurt & Otles 2016). Dietary fibre is also considered as a technologically beneficial ingredient in food processing as it improves both physicochemical and sensory properties such as cooking yield, water holding capacity and gel forming capacity (Elleuch et al. 2011). It has been reported that dietary fibre could be incorporated into food products including bakery products, beverages, dairy and meat products (Buriti et al. 2014; Choi et al. 2014; Liutkevičius et al. 2016; Karp et al. 2017) to improve the product quality and add value to the food industry.

Sugarcane (*Saccharum officinarum* L.) is a main source of sugar and is cultivated widely around the world. Australia is a major sugarcane producer and a large amount of sugarcane bagasse is generated after manufacturing sugar, which is mainly left in the field or transformed into energy (Renouf et al. 2013). In 2016, 36.5 million tonnes of sugarcane were crushed in Australia in which about three tenth of sugarcane was produced as wet bagasse (Australian Sugar Milling Council, 2016). Sugarcane bagasse can be processed into edible sugarcane fibre. Although sugarcane fibre has been utilized in the production of paper pulp (Andrade & Colodette 2014), or incorporated into high density polyethylene to prepare reinforced polymer composites (El-Fattah et al. 2015), there are limited high value applications such as food products. It was reported that adding sugarcane fiber by 10 g /100 g of flour mass would not compensate costumer’s satisfaction on the bread product (Sangnark & Noomhorm 2004). More recently, it was observed that the extract of sugarcane bagasse exhibited antimicrobial activities against foodborne pathogens of *Staphylococcus aureus*, *Listeria monocytogenes*, and *Escherichia coli*, mainly because of the phenolic compounds (Zhao et al. 2015). However, no information is available on incorporating of sugarcane fiber in meat product. Therefore, the objective of this work was to investigate the physicochemical and sensory properties of chicken sausages after incorporation of sugarcane fibre. The results of this research may promote the development of healthier chicken products by utilization of an agricultural byproduct of sugarcane fibre, providing potential benefits to the food and sugarcane industries and also providing potential benefits for human health.

2. Materials and methods

2.1 Materials

After extraction of juice from sugarcane, sugarcane fibre was obtained by drying the residue and grinding it into powder. The sugarcane fibre used in this study was a gift from KFSU Ltd. (Ayr, QLD, Australia). According to analysis, every 100 g of sugarcane fibre contains 85.0 g insoluble fibre, 2.1 g soluble fibre, 4.6 g total sugar, 2.2 g protein, 2.6 g fat and 2.0 g moisture content, with traces of minerals. The average particle size of the fiber is about 93 μm. Chicken thigh meat (skin on) and sodium chloride (salt) were purchased from Woolworths supermarket (Australia), and sausage seasoning (Beaut chicken meal, mainly composed of maize flour, salt, soy protein isolate, spices and herbs) from Denco Trading Pty Ltd. (Healthwood, QLD, Australia). Sausage casings (collagen) were purchased from Nippi Inc. (Tokyo, Japan). trichloroacetic acid, 2-thiobarbituric acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), methanol, Folin-Dennis reagent, sodium carbonate and gallic acid were purchased from Sigma-Aldrich (Castle Hill, NSW, Australia). All chemicals were analytical grade.

2.2 Preparation of chicken sausage

Two batches of chicken sausages were prepared using 9 different formulations with and without incorporation of sugarcane fibre. Briefly, the nine formulations were 3 levels of fibre (0, 2, 3 g) x 3 levels of water (5, 10, 15 g) with the amount of chicken meat adjusted so the total weight was 98 g prior to addition of 1g of salt and 1g of seasoning for each formulation to make up to 100 g (Table 1).

Each formulation was prepared in 3 kg per batch. With the addition of the fibre and other ingredients (formulations are reported in Table 1), chicken thigh meat was chopped for 3 min to form meat batter in a bowl chopper (model MTK562, CBS Foodtech Pty Ltd., NSW, Australia). The meat batter was then stuffed into the sausage casings (2.6 cm diameter) using a sausage stuffer (model H31PA, CBS Foodtech Pty Ltd., NSW, Australia). All sausage samples were kept in a refrigerator at 2-4 °C for 24 hours before cooking and further analysis, to allow for hydration of the sugarcane fiber.

2.3 Cooking yield, water loss and fat loss

Chicken sausages (about 500 g) were packed in plastic bags, hence sausages had no direct contact with the water to avoid water gain and loss by the heating media, and were then cooked in a temperature equilibrated Julabo water bath (John Morris Scientific Pty Ltd., VIC, Australia) set at 95 °C for approximately 30 min to achieve an internal temperature of 74 °C, monitored by inserting a thermometer into the meat. After cooking, the chicken sausages, still in the plastic bags, were cooled in cold water to room temperature, weighed, packed in a plastic box, and refrigerated at 4 °C until further analysis. The weights of fresh and cooked sausages were recorded to calculate cooking yield and cooking loss based on the formula as follow:

$$Cooking\ yield\ (\%) = \frac{Weight\ of\ cooked\ sausage}{Weight\ of\ raw\ sausage} \times 100\%$$

$$\text{Cooking loss (\%)} = \frac{\text{Weight of fresh sausage - Weight of cooked sausage}}{\text{Weight of fresh sausage}} \times 100\%$$

The weight lost during cooking was determined according to the methods described by Petersson et al. (2014). Total moisture content (M %) of raw and cooked sausage samples were determined by drying 5 g of both fresh and cooked sausage at 100 °C for about 24 h until constant weight. Water loss and fat loss were calculated by following formula. Each determination was conducted in three replicates.

$$Water\ loss\ (\%) = M\%\ in\ raw\ sausage - (M\%\ in\ cooked\ sausage \times cooking\ yield)$$

$$Fat\ loss\ (\%) = Cooking\ loss - Water\ loss$$

2.4 Colour measurement

Colour of fresh and cooked chicken sausage was determined using a Minolta Chromameter (model CR-300, Konica Minolta Sensing Inc., Osaka, Japan). D65 illumination and a 10° observer angle were used. The sausage was sliced across the diameter and the colour measured on the internal surface (Yadav et al. 2016). The measurements were expressed by L* for lightness, a* for redness and b* for yellowness. Six measurements of each sample were recorded.

2.5 Total phenolic content

Total phenolic content (TPC) of sausage samples (casing removed), sugarcane fibre as well as the sausage seasoning were measured using the Folin-Dennis reagent method (Song et al. 2013; Akcan et al. 2017). The sausage sample (4 g), 0.5 g sugarcane fibre and 0.5g seasoning were thoroughly mixed with 20 ml methanol respectively and allowed to stand for 1 h at room temperature. The samples were centrifuged at 4000 *g* for 10 min, and 0.5 ml supernatant was mixed with 2.5 ml Folin-Dennis reagent and left to stand for 5 min. The mixture was then added to 2 ml 7.5% sodium carbonate solution, and then heated at 50 °C for 10 min. After cooling, the sample absorbance was measured on a UV/Vis 3200 double beam spectrophotometer (Labomed, Inc., Los Angeles, USA) at 760 nm. The TPC was expressed as mg gallic acid equivalent (GAE) /100 g sample based on a standard curve of gallic acid.

2.6 Antioxidant activity analysis

Antioxidant activity of the sausage samples was analyzed by radical scavenging activity using 2,2-diphenyl-1-picrylhydrazyl (DPPH), according to the method by Malav et al. (2015). Four grams of chicken sausage samples was mixed with 20 ml of methanol in a 50 ml test tube. The tube was shaken on a Ratek vortex mixer (Ratek Instruments Pty Ltd., VIC, Australia) for 3 min and kept at room temperature for 1 h for extraction and then filtered through a Whatman No. 1 filter paper. One ml of filtrate was mixed with 4 ml of 0.1 mM DPPH in methanol and then kept in the dark for 30 min. Methanol was used as the blank and a mixture of methanol and DPPH was used as control. The sample absorbance was recorded at 517 nm on the UV/Vis 3200 spectrophotometer and the RSA was calculated as:

$$RSA\ (\%) = \frac{Absorbance\ of\ control - Absorbance\ of\ sample}{Absorbance\ of\ control} \times 100\%$$

2.7 Thiobarbituric acid reactive substances (TBARS) value

The chicken sausage lipid oxidation was measured as thiobarbituric acid-reacting substances (TBARS) value, according to the methods described by Alina et al. (2012) and Xiong et al. (2015). Briefly, 5 g of sausage sample (casing removed) was mixed thoroughly with 25 ml aqueous solution containing 5 ml of trichloroacetic acid (TCA, ≥99.0%), then mixed with 20 ml Milli-Q water. The mixture was placed in a 100 ml beaker for 1 h at room temperature, and then filtered through a Whatman No.1 filter paper. The filtrate was diluted to 50 ml with Milli-Q water. A mixture of 5 ml 0.02 M aqueous solution of 2-thiobarbituric acid (TBA) and 5 ml diluted filtrate was heated in a water bath at 95 °C for 20 min to formation of a pink colour. The sample absorbance was recorded at 532 nm on the UV/Vis 3200 spectrophotometer. The TBARS value was expressed as mg malondialdehyde (MDA) equivalent/kg sample.

2.8 Texture profile analysis

Texture profile of the sausages was measured based on a double bite test on a Lloyd material single column testing machine (Ametek Test Inc., Largo, FL, USA). Samples were taken from the middle of a sausage and cut to 20 mm of height with casing removed. The samples were then refrigerated at 4 °C overnight, and tested after allowing them to reach room temperature. Each sample was compressed twice to 50% of its original height with a test speed of 2 mm/s, using a cylindrical probe with a diameter of 20 mm. The time interval between the two cycles was 5s (Park et al. 2012; Petersson et al. 2014; Yadav et al. 2016). The mean of ten measurements on ten separate sausages was calculated for each treatment. The values of hardness (N), cohesiveness, and springiness (mm) were calculated based on the force vs time graphs of the measurements (Bourne 1978).

2.9 Sensory evaluation

Sensory evaluation was used to predict the acceptability of the sugarcane fibre chicken sausage in terms of appearance, flavour, texture as well as overall liking. Chicken sausages were cooked in the water bath until an internal temperature of 74 °C was reached, then cooled to room temperature. Sausage samples were then sliced into pieces of about 1 cm thick and packed in insulated boxes to keep warm (Alina et al. 2012). Sausage samples were coded with randomly selected numbers, and served in random order. Thirty Food Science major postgraduate students from the University of Melbourne were recruited to evaluate the chicken sausages based on 9-point hedonic scale (1 = extremely dislike, 9 = extremely like). All students have food sensory evaluation experiences. Warm water and biscuits were provided to the panelists to refresh palates between different samples to reduce sample influence (Zhuang et al. 2016).

2.10 Statistical analysis

Unless otherwise stated, 3 individual sausages were tested for each formulation treatment and 2 batches of sausages were analyzed (n = 6). All data were presented as mean ± standard deviation and analyzed by one-way analysis of variance (ANOVA) using SAS software (version 9.4, NSW, Australia). Tukey test with 95% of confidence was used to compare the differences between different samples.

3. Results and Discussion

3.1 Cooking yield, cooking water loss and fat loss

As shown in Table 2, samples with 10% of water addition resulted in the highest cooking yield, lowest water loss and fat loss; followed by 5% water content samples; and the highest water addition samples (15% water) had the lowest cooking yield and the highest water loss and fat loss. Generally, when the samples had the same water content, addition of sugarcane fibre significantly increased the cooking yield, and reduced the water loss and fat loss ($p<0.05$) (Table 2). However, there was no difference between the samples of Water10-Fibre2 and Water10-Fibre3 in terms of the above parameters, indicating addition of 2% or 3 % of sugarcane fiber didn't change the sausage cooking yield when the water addition to the sausage was 10%.

The increased cooking yield of chicken sausage with addition of sugarcane fibre could be due to the porosity and large surface area of sugarcane fibres binding more water and fat molecules, thus less is lost during the cooking process. Moreover, plant fibres including sugarcane fibre, are hydrophilic polyhydroxy compounds, which might also have contributed to its high water binding capacity. The water binding capacity of this commercial sugarcane fibre was about 5.82 g of water/g and oil binding capacity was 4.68 g of peanut oil/g (data from the company), which could be the main reason of increased cooking yield of the sugarcane fibre incorporated sausage samples. Zhuang et al. (2016) reported that pork batter containing sugarcane fibre had reduced water loss and fat separation in the product. Kim et al. (2016) also observed that the moisture content was significantly increased and cooking loss decreased in frankfurters by the addition of pumpkin fibre. However, the highest water addition level (15%) in our study resulted in larger amounts of water loss after cooking (Table 2), indicating 3% of sugarcane fibre addition might not be sufficient to hold this amount of water in the chicken sausage.

3.2 Colour analysis

The colour values of fresh and cooked chicken sausages are significantly influenced by the sugarcane fibre addition, as presented in Table 3. In both fresh and cooked sausages, the incorporation of sugarcane fibre increased the L* values and b* values while the a* values were decreased ($p<0.05$ for all). This is mainly because the sugarcane fibres themselves had a relatively higher L* value and b* value, but lower a* value (data not show). However, there was no difference ($p>0.05$) between the samples with the sugarcane level of 2% and 3%, suggesting these two levels of fibre addition had similar effects on the sausage colour property. Other researchers also reported that the incorporation of plant fibre altered the colour of food products. For example, chicken nuggets with high mugwort fibre content had higher b* values but lower a* values (Hwang et al. 2011), whereas chicken sausages with addition of *makgeolli* lees fibre showed lower L* and a* values but higher b* values (Park et al., 2012).

Table 3 also shows that the cooked sausage L* values were increased while a* and b* values were decreased relative to raw sausage. The cooking process causes myoglobin denaturation, thus increasing soluble myoglobin content and decreasing redness a* value (Sen et al. 2014). The redness values of cooked chicken sausages fortified with brewer's spent grain fibre were also lower compared to uncooked samples (Choi et al. 2014). In addition, sausages with higher water content (e.g. 15% water) had relatively higher L* values, but lower a* and b* value (Table 3), which could be due to reduced density of the sausage matrix under higher water content formula.

3.3 Total phenolic content (TPC)

At the same water content, increasing sugarcane fibre level in the chicken sausages increased the TPC ($p<0.05$), and the highest TPC was observed when the fibre was added at the highest level of 3% (Table 4). Based on our analysis, the raw sugarcane fibre contains 45.17 ± 1.14 mg GAE/ 100g of TPC, and 47.88 ± 0.87 mg GAE/ 100g of TPC after cooking, thus explaining the TPC increase with increasing levels of fibre addition. For sausages with the same fibre content, sausages with addition of the lowest water content (5%) had the highest TPC while those added with the highest water content (15%) had the lowest TPC (Table 4), because of the diluting effect of water. For example, when the fibre addition was same at 3%, the TPC in fresh chicken sausage was 60.73 ± 0.82 mg GAE/ 100g in the 5% water addition sample, which was reduced to 54.71± 0.72 mg GAE/ 100g when 15% of water was added in the sausage.

The presence of TPC in sausage samples without fibre addition (samples Water5-Fibre0, Water10-Fibre0 and Water15-Fibre0 in Table 4) could be due to the phenolic structure of some aromatic amino acids in the chicken meat (Akcan et al. 2017). The 1% of chicken seasoning (containing 19.94±0.53 GAE/ 100g in native sample and 20.72±0.25 mg GAE/ 100g after cooking) might also partly contribute to these results. In addition, the TPC values in cooked chicken sausages were higher than those of fresh chicken sausages, probably because the mild cooking conditions (cook to internal temperature of 74 °C) may have caused partial release of the phenolic compounds in the sugarcane fibre (Turkmen et al. 2005).

3.4 Antioxidant capacity

The free radical scavenging activities (RSA%) of fresh and cooked chicken sausages are presented in Table 4, which indicates that at the same water content, the RSA% was increased ($p<0.05$) with the increased fibre level, and the highest RSA% was noticed when the fibre concentration was at 3%. This is most likely because of the antioxidant capacity of sugarcane fibre, as the DPPH analysis data showed that the sugarcane fibre had an RSA% of 63.11±2.26 for the raw sample and 51.10±3.07 after cooking. The antioxidant capacity of sugarcane fibre in the diet could mainly arise from its phenolic compounds as discussed in section 3.3, and also from the lignin in sugarcane fibre (Kaur & Uppal 2015). Song et al. (2013) also indicated that there was a positive relationship between TPC and antioxidant capacity. The increased antioxidant activity of meat products by addition of plant materials has been recognized in other research, such as addition of cabbage powder into mutton patties (Malav et al. 2015) and guava powder into sheep meat nuggets (Verma et al 2013), mainly due to the phenolic compounds and antioxidant activity of these plant powders.

It was noticed that RSA% of sausages without incorporation of fibre also exhibited antioxidant activity, and the cooked chicken sausages had respectively higher antioxidant activity than those of fresh chicken sausages (Table 4). Meat and meat products may contain some endogenous antioxidants such as proteins and amino acids (Serpen et al 2012). During the cooking process, the secondary and tertiary structure of proteins may be altered and their physicochemical properties could be modified (Sante-Lhoutellier et al. 2007). The denaturation of proteins may increase the exposure of amino acids with antioxidant capacity which is generally present in the centre of the original protein structure, thus increasing their antioxidant activity (Elias et al. 2007). The release of phenolic compounds in plant fibre by heating might also have enhanced the antioxidant activity after cooking (Turkmen et al. 2005).

3.5 TBARS value

TBARS value is commonly used to indicate the extent of lipid oxidation in food products, and a higher TBARS value suggests a higher level of oxidation. At the same water content, the TBARS values in both the fresh and cooked chicken sausages were reduced ($p<0.05$) with the increase of sugarcane fibre (Table 4). The lowest TBARS values were observed when the fibre concentration was the highest, at 3%, regardless of the added water level, indicating lower lipid oxidation in these samples and potential antioxidant capacity of the sugarcane fibre as discussed above. It was reported that the TBARS values were also decreased in sausage (*mortadella*) with citrus fibre incorporated (Viuda-Martos et al. 2010), mutton patties with addition of cabbage powder (Malav et al. 2015), and goat meat nuggets with incorporation of broccoli powder extracts (Rituparna et al. 2012), mainly because of the increased phenolic compounds and antioxidant activities in the meat products. For the sausages with the same fibre content, samples containing 5% of added water had the highest TBARS value while those containing 15% of added water had the lowest. This is likely due to the dilution effect of water and reduced density of sausage matrix.

Significant increases in TBARS values were observed for all sausage samples after cooking (Table 4), indicating increased lipid oxidation. It is likely that the cooking process promotes lipid oxidation due to lipolysis during heating, inactivation of antioxidant compounds, and release of iron from haem pigments that accelerate lipid oxidation by catalytic reactions (Sen et al. 2014; Kilic et al. 2015). Free radicals may also be generated during cooking by the interactions between pro-oxidants and low molecular weight metals which could propagate oxidative reactions (Akcan et al. 2017). As discussed in section 3.3 and 3.4, the cooking process increased the TPC and antioxidant activity of sausage samples, but this was not sufficient to inhibit the lipid oxidation as determined by TBARS value. However, incorporation of sugarcane fibre reduced the increase in level of TBARS values caused by the cooking process (Table 4). This also suggested the antioxidant capacity of sugarcane fibre in the sausage samples.

3.6 Texture analysis

Double bite compression test was applied to imitate the mastication process in the mouth, using two compression cycles. At the same water content, the chicken sausage samples were harder with the increased fibre content, and at the same fibre content, sausages were softer when more water was added (Table 5). The addition of sugarcane fibre increased the hardness of chicken sausage, probably due to the formation of a stronger three-dimensional network within the meat matrix (Park et al. 2012). However at the same water content, the sausage cohesiveness was similar between fibre levels ($p>0.05$) (Table 5), suggesting addition of up to 3% of sugarcane fibre does not change the cohesiveness of the chicken sausages.

The springiness was similar for sausage samples with 5% and 15% of water content; the values were decreased with the increasing fibre concentration, possibly because of the increased hardness of the samples. However, at 10% water addition, the sample springiness was relatively higher, especially when the fibre content was 3% ($p<0.05$, Water10-Fibre3). This could be because the appropriate ratio of water, fibre and chicken meat in the sausage matrix had formed a fine gel network and resulted in higher springiness.

The incorporation of plant fibre into meat products may alter the product texture properties, depending on the fibre and meat types. For example, the hardness of chicken sausages was enhanced by the addition of corn bran and dried apple pomace together, but was not affected by the addition of dried tomato pomace alone (Yadav et al., 2016). Chicken sausage hardness was increased, but cohesiveness was decreased, by the addition of *makgeolli* lees fibre (Park et al. 2012), while the incorporation of pumpkin fibre into frankfurters increased both the hardness and springiness (Kim et al. 2016). The present research indicated that the incorporation of up to 3% sugarcane fibre into chicken sausage increased the product hardness, with no significant influence on the cohesiveness, while the springiness was also enhanced when the water addition was at 10% level.

3.7 Sensory analysis

Addition of sugarcane fibre did not have a significant influence on the appearance score of chicken sausages (Table 6), which could be due to the similar colour of native sugarcane fibre and chicken meat. The neutral sugarcane fibre colour and similarity to chicken meat might be another advantage of incorporation of this plant fibre into chicken meat products. The relatively lower appearance scores of high water content (15%) sausage samples might be result from their pale colour. In addition, there was no difference (p>0.05) among flavour scores for all sausage samples, suggesting chicken sausages with the incorporation of sugarcane fibre at 3% had a similar flavor to that of pure chicken sausages. The chicken sausage flavor was mainly determined by the commercial seasoning and this ingredient was same to all formulations, which also partly explained that there was no significant flavor difference among all sausage samples.

At the water addition level of 5% and 15%, there was no difference in sensory texture scores among samples at the same water content, when the fibre content increased (Table 6). However, at the water addition level of 10%, addition of sugarcane fibre resulted in significantly higher texture scores (p>0.05, samples Water10-Fibre2 and Water10-Fibre3), probably because of their higher springiness as discussed in section 3.6 and presented in Table 5. The overall liking score of chicken sausages also exhibited similar variations relative to the texture scores, as these two samples had the highest scores. The sensory evaluation suggested that the overall sensory properties of chicken sausages were not influenced by addition of 3% of sugarcane fibre, and these properties could be even enhanced if the water addition was appropriate (10%). However, Choi et al. (2014) reported that addition of brewer's spent grain fibre decreased the sensory scores for colour, flavour, tenderness, juiciness as well as overall liking of chicken sausage. Malav et al. (2015) observed that addition of cabbage powder slightly decreased the sensory scores of mutton patties. The sensory property is a very important indicator to predict the consumer acceptance of a new food product. These researches suggested that addition of plant fibres into meat products may result in negative or positive sensory properties, and therefore selection of appropriate types of plant fibre into appropriate type of meat is of great importance.

Conclusion

In conclusion, when water content was added at 10%, incorporation of 3% sugarcane fibre into chicken sausage improved the product quality as demonstrated by increased cooking yield from 94.20% to 97.52%, increased total phenolic content from 25.43 to 57.09 mg GAE/100g and radical scavenging activity from 28.11% to 60.72%. The lipid oxidation of TBARS value was decreased from 0.535 to 0.428 MDA mg/kg, whereas the consumers' overall liking was not affected. This research demonstrated that application of agricultural byproduct of sugarcane fibre in chicken sausage have the potential to improve the product quality, provide economic benefits to the food and sugarcane industries and health benefits to human.

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Conflicts of interest

None

Reference

Akcan, T., Estevez, M. & Serdaroglu, M. (2017). Antioxidant protection of cooked meatballs during frozen storage by whey protein edible films with phytochemicals from *Laurus nobilis* L. and *Salvia officinalis*. *LWT -- Food Science and Technology* , 77, 323–331.

Alina, A. R., Siti Mashitoh, A., Abdul Salam, B., Maznah, I., Muhyiddin, Y. & Syamsul, K.W. (2012). Effect of rice bran and carboxymethyl cellulose addition on the physicochemical quality of chicken sausage formulated with red palm mid fraction. *World Applied Sciences Journal*, 17, 57–61.

Andrade, M. F. & Colodette, J. L. (2014). Dissolving pulp production from sugar cane bagasse. *Industrial Crops and Products*. 52, 58–64.

Australian Sugar Milling Council (2016) https://asmc.com.au/wp-content/uploads/2013/08/170627-Brochure-on-industry_A4-2016-data.pdf

Buriti, F.C., Freitas, S.C., Egito, A.S. & Dos Santos, K.M. (2014). Effects of tropical fruit pulps and partially hydrolysed galactomannan from *Caesalpinia pulcherrima* seeds on the dietary fibre content, probiotic viability, texture and sensory features of goat dairy beverages. *LWT - Food Science and Technology*, 59, 196–203.

Choi, M., Choi, Y., Kim, H., Hwang, K., Song, D., Lee, S. & Kim, C. (2014). Effects of replacing pork back fat with brewer's spent grain dietary fiber on quality characteristics of reduced-fat chicken sausages. *Korean journal for food science of animal resources*, 34, 158–165.

El-Fattah, AA, EL Demerdash, A. G. M., Sadik, W. A. A. & Bedir, A. (2015). The effect of sugarcane bagasse fiber on the properties of recycled high density polyethylene. *Journal of Composite Materials*, 49, 3251–3262.

Elias, R. J., McClements, D. J. & Decker, E. A. (2007). Impact of thermal processing on the antioxidant mechanisms of continuous phase β-lactoglobulin in oil-in-water emulsions. *Food Chemistry*, 104, 1402–1409.

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C. & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*, 124, 411–421.

Hwang, K.E., Choi, Y.S., Choi, J.H., Kim, H.Y., Kim, H.W., Lee, M.A., Chung, H.K. & Kim, C.J. (2011). Effect of ganghwayakssuk (*Artemisia princeps* Pamp.) on oxidative stability of deep fried chicken nuggets. *Food Science and Biotechnology*, 20, 1381–1388.

Karp, S., Wyrwisz, J., Kurek, M. A. & Wierzbicka, A. (2017). Combined use of cocoa dietary fibre and steviol glycosides in low-calorie muffins production. *International Journal of Food Science & Technology*, 52, 944–953.

Kaur, R. & Uppal, S.K. (2015). Structural characterization and antioxidant activity of lignin from sugarcane bagasse. *Colloid & Polymer Science*, 293, 2585–2592.

Kilic, B., Simsek, A., Claus, J., Atilgan, E. & Aktas, N. (2015). Effects of different end-point cooking temperatures on the efficiency of encapsulated phosphates on lipid oxidation inhibition in ground meat. *Journal of Food Science*, 80, C2161–C2169.

Kim, C.J., Kim, H.W., Hwang, K.E., Song, D.H., Ham, Y.K., Choi, J.H., Kim, Y.B. & Choi, Y.S. (2016). Effects of dietary fiber extracted from pumpkin (*Cucurbita maxima* duch.) on the physic-chemical and sensory characteristics of reduced-fat frankfurters. *Korean Journal of Food Science of Animal Resources*, 36, 309–318.

Liutkevičius, A., Speičienė, V., Kaminskas, A., Jablonskienė, V., Alenčikienė, G., Mieželienė, A., Bagdonaitė, L., Vitkus, D. & Garmienė, G. (2016). Development of a functional whey beverage, containing calcium, vitamin D, and prebiotic dietary fiber, and its influence on human health. *CyTA-Journal of Food*, 14, 309–316.

Malav, O.P., Sharma, B.D., Kumar, R.R., Suman, T., Ahmed, S.R. & Irshad, A. (2015). Antioxidant potential and quality characteristics of functional mutton patties incorporated with cabbage powder. *Nutrition and Food Science*, 45, 542–563.

Marangoni, F., Corsello, G., Cricelli, C., Ferrara, N., Ghiselli, A., Lucchin, L. & Poli, A. (2015). Role of poultry meat in a balanced diet aimed at maintaining health and wellbeing: an Italian consensus document. *Food & Nutrition Research*, 59, 1–11.

Michel, L.M., Punter, P.H. & Wismer, W.V. (2011). Perceptual attributes of poultry and other meat products: a repertory grid application. *Meat Science*, 87, 349–355.

Ozyurt, V.H. & Otles, S. (2016). Effect of food processing on the physicochemical properties of dietary fibre. *Acta Scientiarum Polonorum - Technologia Alimentaria*, 15(3), 233–245.

Park, K.S., Choi, Y.S., Kim, H.Y., Kim, H.W., Song, D.H., Hwang, K.E., Choi, S.G. & Kim, C.J. (2012). Quality characteristics of chicken emulsion sausages with different levels of makgeolli lees fiber. *Korean Journal for Food Science of Animal Resources*, 32, 54–61.

Petersson, K., Godard, O., Eliasson, A.C. & Tornberg, E. (2014). The effects of cereal additives in low-fat sausages and meatballs. part 1: untreated and enzyme-treated rye bran. *Meat Science*, 96, 423–428.

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

Renouf, M.A., Pagan, R.J. & Wegener, M.K. (2013). Bio-production from Australian sugarcane: an environmental investigation of product diversification in an agro-industry. *Journal of Cleaner Production*, 39, 87–96.

Rituparna, B., Verma, A.K., Das, A.K., Rajkumar, V., Shewalkar, A.A. & Narkhede, H.P. (2012). Antioxidant effects of broccoli powder extract in goat meat nuggets. *Meat Science*, 91, 179–184.

Sangnark, A. & Noomhorm, A. (2004). Effect of dietary fiber from sugarcane bagasse and sucrose ester on dough and bread properties. *LWT - Food Science and Technology*, 37, 697–704.

Sante-Lhoutellier, V., Aubry, L. & Gatellier, P. (2007). Effect of oxidation on in vitro digestibility of skeletal muscle myofibrillar proteins. *Journal of Agricultural and Food Chemistry*, 55, 5343–5348.

Sen, A.R., Naveena, B.M., Muthukumar, M. & Vaithiyanathan, S. (2014). Colour, myoglobin denaturation and storage stability of raw and cooked mutton chops at different end point cooking temperature. *Journal of Food Science and Technology*, 51, 970–975.

Serpen, A., Gokmen, V. & Fogliano, V. (2012). Total antioxidant capacities of raw and cooked meats. *Meat Science*, 90, 60–65.

Song, H., Bae, J. & Park, I. (2013). Effect of heating on DPPH radical scavenging activity of meat substitute. *Preventive Nutrition and Food Science*, 18, 80–84.

Turkmen, N., Sari, F., & Velioglu, Y. S. (2005).The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. *Food Chemistry*, 93, 713–718.

Verma, A.K., Rajkumar, V., Rituparna, B., Biswas, S. & Das, A.K. (2013). Guava (*Psidium guajava* L.) powder as an antioxidant dietary fibre in sheep meat nuggets. *Asian-Australasian Journal of Animal Sciences*, 26, 886–895.

Viuda-Martos, M., Ruiz-Navajas, Y., Fernandez-Lopez, J. & Perez-Alvarez, J.A. (2010). Effect of added citrus fibre and spice essential oils on quality characteristics and shelf-life of mortadella. *Meat Science*, 85, 568–576.

Xiong, Z., Sun, D., Pu, H., Xie, A., Han, Z. & Luo, M. (2015). Analytical methods: Non-destructive prediction of thiobarbituricacid reactive substances (TBARS) value for freshness evaluation of chicken meat using hyperspectral imaging. *Food Chemistry*, 179, 175–181.

Yadav, S., Malik, A., Pathera, A., Islam, R. & Sharma, D. (2016). Development of dietary fibre enriched chicken sausages by incorporating corn bran, dried apple pomace and dried tomato pomace. *Nutrition and Food Science*, 46, 16–29.

Zhao, Y, Chen, M. S., Zhao, Z. G., Yu, S. J. (2015). The antibiotic activity and mechanisms of sugarcane (*Saccharum officinarum* L.) bagasse extract against food-borne pathogens. *Food Chemistry, 185*, 112–118

Zhuang, X., Han, M., Kang, Z., Wang, K., Bai, Y., Xu, X. & Zhou, G. (2016). Effects of the sugarcane dietary fiber and pre-emulsified sesame oil on low-fat meat batter physicochemical property, texture, and microstructure. *Meat Science*, 113, 107–115.

Table 1. Formulations of chicken sausages (per 100 g) with incorporation of sugarcane fibre (each formulation includes 1 g of seasoning and 1 g of salt).

Formulations	Chicken thigh (g)	Fibre (g)	Water (g)
Water5-Fibre0	93	0	5
Water5-Fibre2	91	2	5
Water5-Fibre3	90	3	5
Water10-Fibre0	88	0	10
Water10-Fibre2	86	2	10
Water10-Fibre3	85	3	10
Water15-Fibre0	83	0	15
Water15-Fibre2	81	2	15
Water15-Fibre3	80	3	15

552 Table 2. Cooking properties of chicken sausages with incorporation of sugarcane fibre

Formulations	Yield (%)	Water loss (%)	Fat loss (%)
Water5-Fibre0	93.43±0.82^{def}	3.52±0.17^{c}	3.05±0.11^{b}
Water5-Fibre2	95.77±0.80^{bc}	2.38±0.12^{e}	1.85±0.12^{e}
Water5-Fibre3	97.14±0.24^{ab}	1.52±0.09^{f}	1.34±0.07^{f}
Water10-Fibre0	94.20±0.69^{de}	3.27±0.05^{d}	2.53±0.07^{c}
Water10-Fibre2	97.23±0.24^{a}	1.65±0.10^{f}	1.12±0.10^{g}
Water10-Fibre3	97.52±0.46^{a}	1.33±0.06^{g}	1.15±0.04^{g}
Water15-Fibre0	92.12±1.05^{f}	4.52±0.08^{a}	3.36±0.06^{a}
Water15-Fibre2	93.17±1.04^{ef}	3.87±0.06^{b}	2.96±0.11^{b}
Water15-Fibre3	94.70±0.90^{cd}	3.23±0.07^{d}	2.07±0.05^{d}

553 Formulations refer to Table 1.

554 Values with different superscripts within the same column indicate significant difference ($p<0.05$).

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Table 3. Colour values (L*, a*, b*) of fresh and cooked chicken sausage with incorporation of sugarcane fibre.

Formulations	Fresh sausage			Cooked sausage		
	L*	a*	b*	L*	a*	b*
Water5-Fibre0	64.68±0.37^{e}	7.49±0.22^{a}	8.00±0.45^{d}	71.58±0.12^{bc}	5.18±0.74^{b}	7.35±0.29^{d}
Water5-Fibre2	65.85±0.75^{cd}	7.04±0.34^{abc}	10.80±0.30^{ab}	71.64±0.73^{bc}	4.21±0.15^{cd}	9.06±0.29^{b}
Water5-Fibre3	66.45±0.87^{abc}	6.77±0.36^{bcd}	10.85±0.75^{ab}	72.21±0.73^{abc}	3.99±0.37^{cd}	9.33±0.11^{ab}
Water10-Fibre0	64.73±0.65^{de}	7.58±0.37^{a}	8.47±0.54^{c}	70.99±0.88^{c}	6.25±0.26^{a}	8.32±0.34^{cd}
Water10-Fibre2	66.22±0.53^{bc}	6.54±0.15^{cd}	11.10±0.34^{a}	71.94±0.37^{bc}	4.26±0.22^{cd}	9.16±0.31^{b}
Water10-Fibre3	67.03±0.40^{ab}	6.36±0.16^{d}	10.71±0.24^{ab}	72.59±0.54^{ab}	3.05±0.37^{e}	9.36±0.35^{ab}
Water15-Fibre0	65.58±0.72^{c}	7.29±0.46^{ab}	8.91±0.43^{bc}	71.70±0.51^{bc}	4.63±0.30^{bc}	8.45±0.44^{c}
Water15-Fibre2	66.88±0.56^{abc}	6.80±0.20^{bcd}	10.11±0.47^{b}	72.00±1.04^{bc}	3.70±0.28^{de}	9.09±0.29^{b}
Water15-Fibre3	67.43±0.31^{a}	5.58±0.16^{e}	10.65±0.85^{ab}	73.41±0.65^{a}	3.73±0.14^{d}	9.79±0.26^{a}

Formulation refer to Table 1.

Values with different superscripts within the same column indicate significant difference ($p<0.05$).

Table 4. Total phenolic content (TPC), DPPH radical scavenging activity (RSA), and TBARS value of fresh and cooked chicken sausages with incorporation of sugarcane fibre.

Formulations	TPC (mg GAE/ 100g)		RSA (%)		TBARS (MDA mg/kg)	
	Fresh	Cooked	Fresh	cooked	Fresh	Cooked
Water5-Fibre0	29.84±1.25^{g}	32.65±1.11^{g}	35.54±0.47^{g}	41.00±0.25^{f}	0.582±0.014^{a}	0.817±0.016^{a}
Water5-Fibre2	49.11±1.04^{d}	52.64±0.72^{d}	57.88±0.44^{c}	62.37±0.48^{c}	0.489±0.037^{c}	0.647±0.024^{cd}
Water5-Fibre3	60.73±0.82^{a}	65.88±0.61^{a}	63.21±0.35^{a}	67.24±0.32^{a}	0.463±0.009^{cd}	0.606±0.017^{de}
Water10-Fibre0	25.43±0.49^{h}	30.19±0.83^{h}	28.11±0.32^{h}	32.28±0.31^{g}	0.535±0.027^{b}	0.735±0.013^{b}
Water10-Fibre2	46.43±0.53^{e}	50.77±0.57^{e}	55.12±0.44^{e}	61.25±0.51^{d}	0.456±0.022^{cde}	0.603±0.020^{de}
Water10-Fibre3	57.09±0.53^{b}	62.80±0.57^{b}	60.72±0.51^{b}	65.06±0.52^{b}	0.428±0.015^{def}	0.567±0.038^{ef}
Water15-Fibre0	21.46±0.88^{i}	27.39±0.65^{i}	22.19±0.24^{i}	26.42±0.58^{h}	0.479±0.022^{c}	0.667±0.015^{c}
Water15-Fibre2	44.19±0.84^{f}	48.37±0.55^{f}	53.07±0.35^{f}	58.25±0.35^{e}	0.412±0.029^{ef}	0.566±0.038^{ef}
Water15-Fibre3	54.71±0.72^{c}	60.67±0.74^{c}	57.05±0.21^{d}	62.18±0.44^{c}	0.386±0.025^{f}	0.524±0.011^{f}

Formations refer to Table 1.

Values with different superscripts within the same column indicate significant difference ($p<0.05$).

Table 5. Texture properties of chicken sausages with incorporation of sugarcane fibre

Formulations	Hardness (N)	Cohesiveness	Springiness (mm)
Water5-Fibre0	45.58±2.07^{d}	0.384±0.037^{a}	0.475±0.097^{ab}
Water5-Fibre2	55.83±2.74^{b}	0.354±0.032^{ab}	0.389±0.078^{bc}
Water5-Fibre3	64.33±1.64^{a}	0.333±0.064^{abc}	0.283±0.068^{c}
Water10-Fibre0	41.82±2.83^{e}	0.365±0.026^{ab}	0.381±0.087^{bc}
Water10-Fibre2	47.19±2.85^{d}	0.320±0.058^{abcd}	0.513±0.105^{ab}
Water10-Fibre3	50.93±2.75^{c}	0.308±0.052^{bcd}	0.591±0.094^{a}
Water15-Fibre0	30.05±1.95^{g}	0.319±0.064^{abcd}	0.453±0.117^{b}
Water15-Fibre2	35.33±2.47^{f}	0.276±0.076^{cd}	0.429±0.108^{b}
Water15-Fibre3	37.43±2.12^{f}	0.255±0.051^{d}	0.258±0.074^{c}

Formulations refer to Table 1.

Values with different superscripts within the same column indicate significant difference ($p<0.05$).

Table 6. Sensory scores (0-9) of chicken sausages with incorporation of sugarcane fibre

Formulations	Appearance	Flavour	Texture	Overall liking
Water5-Fibre0	6.33±0.88^{ab}	6.20±0.76^{a}	5.87±1.61^{abc}	5.73±1.14^{bc}
Water5-Fibre2	6.37±0.96^{ab}	6.10±0.66^{a}	5.97±0.81^{abc}	5.70±0.90^{bc}
Water5-Fibre3	6.40±0.97^{ab}	6.07±1.05^{a}	6.07±1.08^{abc}	5.67±1.06^{bc}
Water10-Fibre0	6.20±1.03^{ab}	6.13±1.20^{a}	5.43±1.14^{c}	5.27±0.69^{c}
Water10-Fibre2	6.60±0.93^{a}	6.10±0.80^{a}	6.57±1.10^{ab}	6.37±1.13^{ab}
Water10-Fibre3	6.80±1.06^{a}	6.07±1.11^{a}	6.83±1.34^{a}	6.73±1.36^{a}
Water15-Fibre0	5.67±0.96^{b}	5.93±1.05^{a}	5.53±1.57^{c}	5.20±1.63^{c}
Water15-Fibre2	5.73±0.69^{b}	5.70±0.95^{a}	5.60±1.00^{bc}	5.33±0.84^{c}
Water15-Fibre3	6.10±1.52^{ab}	5.63±1.40^{a}	5.63±1.45^{bc}	5.37±1.27^{c}

Formulations refer to Table 1.

Values with different superscripts within the same column indicate significant difference ($p<0.05$).