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Article type : Original Manuscript

Influence of cooking method, fat content and food additives on physicochemical and nutritional properties of beef meatballs

fortified with sugarcane fibre

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This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the <u>Version of Record</u>. Please cite this article as <u>doi: 10.1111/IJFS.14482</u>

Article type: Original paper

### Summary

This study explored effects of different cooking methods, pork fat addition and food additives on physicochemical and nutritional attributes of beef meatballs fortified, or not, with 3% sugarcane fibre. TPA hardness of meatballs with fibre, cooked in boiling water was lower compared to oven-baked and pan-fried (47.11, 56.24 and 59.22 N respectively). Hardness also decreased with increasing fat content (5, 10, 15, 20% fat; 62.07, 56.96, 54.02 and 45.51 N respectively). Tetrasodium pyrophosphate and sodium tripolyphosphate provided similar results for all parameters except ash content where cooked meatballs with the latter were higher (1.98 and 2.22%, respectively). Cooking loss of 20% fat meatballs with fibre was lower (17.14%) compared to without fibre (20.28%). Loss of nutrients after cooking was lower for oven-baked compared to boiling. Using different ingredients to manipulate quality traits of meatballs is an alternative to manufacture suitable products for different market requirements, e.g., for elderly consumers.

Key Words: beef meatball, dietary fibre, cooking, additives, fat content, texture

### Introduction

Consumer demand for healthy meat products with reduced levels of fat, sodium chloride and incorporation of health enhancing ingredients is rapidly increasing worldwide (Zhang et al., 2010). Meat products are an important source of protein, fat, minerals and other nutrients (Biesalski, 2005). However, commercially available products are traditionally low in dietary fibre (DF). Sugarcane fibre is an abundant waste product from sugar production and has low utilization in the food industry (Renouf et al., 2013). Sugarcane fibre is commercially

available in flour form in Australia. The flour contains 87% DF and is tasteless and neutral in colour (Zhao et al., 2015), thus making it appropriate for use in meat products.

Adding value to under-utilised cuts for sensory and nutritional quality improvement is important for the beef industry. One of those underutilised cuts is the topside (also known as top or inside round), which consists of several muscles including *Adductor* and *Semimembranosus*. Both muscles have higher Warner–Bratzler shear force and lower sensory tenderness ratings compared to the *Psoas major* (tenderloin) (Calkins and Sullivan, 2007). A common approach to utilise the 'tough' topside is mince (grind) it for use in processed meat products such as meatballs.

Texture is important to overall acceptance of meat products by consumers (Lee et al., 2018) and their preference in meat products texture varies, e.g., older consumers might prefer a softer texture that facilitates chewing and swallowing. Roininen et al. (2003) showed that older adults preferred foods that can be consumed effortlessly providing an easy eating experience, but at the same time, textures that were too smooth or too soft were not appreciated. Furthermore, chemosensory acuity is negatively affected by factors such as dentures which is associated with the ageing process and this has been shown to lead to negative changes in food appreciation and diet (Baugreet et al., 2017). This vulnerable group demand nutrient dense foods with the precise sensory attributes to improve food intake and digestion hence the need for research in this area. The texture of meatballs can be influenced by many factors including fat content, cooking method and added ingredients during manufacturing. The common amount of fat in the manufacture of ground meat products is 20% (Jiménez Colmenero, 2000, Feiner, 2006).

Pan-frying and oven-baking are traditional cooking techniques for meatballs. Boiling is a less traditional cooking technique for meatballs that uses water or broth at boiling point (Sobral et al., 2018). Cooking affects the nutritional composition of meat and meat products; frying is the cooking method that causes the greatest impact (Domínguez et al., 2015). Choosing the appropriate cooking method can reduce the loss of nutrients. Added ingredients such as salt and binders are important for texture of meatballs. Phosphate is a common ingredient used in processed meat products due to its ability to remove the links between actin and myosin, thus allowing higher water binding and improved texture (Petracci et al., 2013), it also increases pH and ionic strength. Bicarbonates are used to enhance functionality of meat proteins. The

efficacy of bicarbonate salts are attributed to their ability to solubilize myofibrillar proteins and enhance their electrostatic repulsion (Mohan et al., 2016). Sodium bicarbonate, tetrasodium pyrophosphate and sodium tripolyphosphate are the main salts, along with soidum choride, used in the meat industry worldwide.

Colour of meatballs, both raw and cooked, is also important for consumer acceptance (Smith et al., 2000). Meat colour is affected by parameters such as pH, fatty acid content and proteins as muscle fibre composition (Holman et al., 2018). The pH, on its own, is an important parameter that influences the functional properties of proteins and keeping quality of meat and meat products on storage (Talukder, 2015). Water content is also relevant for the quality of meatballs due to its direct impact on texture. Shahiri Tabarestani and Mazaheri Tehrani (2014) explained that the cooking procedure will induce cook loss, as a combination of liquid and soluble matters lost from the meat product during cooking. The main weight loss of meat during cooking is water (Heymann et al., 1990).

Consequently, optimising texture and manufacturing meatballs with added health benefits is of interest to the meat industry. DF contributes to improved digestion and overall health (Ozyurt and Ötles, 2016). The questions this research aims to answer are: is it true that the higher the fat content the softer texture is obtained? Which additive and cooking technique aids to obtain a softer texture? Which cooking method provides a higher texture contrast? How are the nutrients of meatballs affected by those parameters? Therefore, the objectives of this study were to assess the individual and interaction effect of fat level (5, 10, 15 or 20%), food additives (sodium bicarbonate: SB, sodium tripolyphosphate: STPP and tetrasodium pyrophosphate: TSPP) and cooking method (oven, pan or boiling water) on physicochemical and nutritional properties of beef meatballs with or without sugarcane fibre. No studies have shown the relationships of these specific parameters. The ultimate aim is to narrow the gap and contribute to the development of meatballs with lower fat content and added health benefits, such as fibre, targeted to older consumers.

### Materials and methods

Raw material and dry ingredients

Beef topside (5.5 kg per batch) and female pork back fat (1 kg per batch) were purchased from a local market. Added ingredients were sodium chloride (table salt) (SAXA, NSW, Australia), sodium bicarbonate (Woolworths homebrand, Woolworths, Australia), tetrasodium pyrophosphate (P03 Batch No: 41311293) and sodium tripolyphosphate (P02, Batch No: H201702) (both from Hela<sup>®</sup> Spice Pty Ltd, Melbourne, Australia) and sugarcane fibre (Phytocel<sup>TM</sup>) (KFSU Ltd, QLD 4807, Australia, 2.2g protein, 2.6g fat, 87.1g dietary fibre per 100g).

### **Preparation of meatballs**

Each meatball formulation was prepared in randomised order in each experimental replication according to the formulations shown in Table 1. Lean beef meat (water: 74.26, fat: 1.34, protein: 21.80, ash: 1.20 g/100g) and pork fat (water: 17.10, fat: 73.95, protein: 1.80, ash: 0.45 g/100g) were individually minced once through an 8 mm perforated disc of a meat mincer (Kenwood MG450 type MG47, Casula Mall, NSW, Australia). Minced materials were mixed with sodium chloride, sugarcane fibre, additive (either sodium bicarbonate, tetrasodium pyrophosphate or sodium tripolyphosphate) and water. Fibre was added in its dry form without any pre-treatment and the batter was rested at 4 °C for 30 min. Meatballs (15 g  $\pm$  2 g) were formed, placed on wax paper on a flat plastic tray, covered with cling wrap and aluminium foil and stored at -20 °C. The next day, they were vacuum packed in a clear pouch (Multivac pouch, size 165x250 mm, Keilor Park, VIC, Australia) and kept in frozen storage (-20 °C) until analysis. Frozen meatballs were thawed at 4 °C overnight (12 h), cooked and then cooled to room temperature for about 20 min before analysis.

### **Cooking methods**

Three cooking methods were applied to the meatballs including pan-frying (BlueSeal gas system, GT18, Mulgrave, VIC, Australia), oven-baking (Convotherm<sup>®</sup>, IPX5, Mulgrave, VIC, Australia) and boiling water (BlueSeal gas system, GT18, Mulgrave, VIC, Australia). Cooking parameters (setting and time) for the three methods were identified using preliminary experiments and were: oven-baking, 100 °C, dry air, 10 min; pan-frying, stove/pan (370 mm diameter) at medium heat, 21 min; boiling water, saucepan (350 ml volume) with water at 100 °C, 4 min) based on reaching a minimum internal end-point temperature of 75 °C. End- point temperature of the meatballs was recorded at the centre of

the meatballs by inserting a digital thermometer (NORONIX 600N -50 °C to +200 °C, Mitchell Park, VIC, Australia). For the oven-baked samples an internal probe thermometer (Convotherm®, IPX5, Mulgrave, VIC, Australia) was used. Pan-fried meatballs were turned once during the total cooking time to ensure they cook evenly. After the cooking processes were completed the meatballs were cooled to room temperature prior to analysis and sub-sampling described below.

### **Texture Profile Analysis (TPA)**

A double bite compression test was performed using a Lloyd texture analyser (AMETEK<sup>®</sup>, LS5, Largo, FL, USA) fitted with a 20 mm diameter cylindrical probe set to 50% depth, load cell of 50 kg, speed 200 mm/min with 0.1 s delay descents. Measurements were done in triplicate for every sample. Values for hardness (N), cohesiveness, adhesiveness (Nmm), springiness (mm) and chewiness (N) of the meatballs were calculated based on force vs time graphs using the calculations specified in Bourne et al. (1978).

### **Texture contrast**

Texture contrast measurement was performed using the same Lloyd texture analyser (AMETEK<sup>®</sup>, LS5, Largo, FL, USA) fitted with a 6 mm diameter cylindrical probe set to 20% depth, load cell of 50 kg, speed 200 mm/min with 0.1 s delay descents. For texture contrast, meatballs were cut in the middle with a sharp knife and hardness was measured on the inside and on the crust.

### **Colour analysis**

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CIE LAB colour measurements were lightness (L\*) (0 = black, 100 = white), greennessredness (a\*) (-a = green, +a = red) and blueness-yellowness (b\*) (-b = blue, +b = yellow) of the meatball samples and were carried out using a Nix<sup>TM</sup> Pro (Illuminant: D75, Observer: 10°, Aperture Size: 14mm; Nix Sensor Ltd., Hamilton, Ontario, Canada,). Colour measurement was performed on the outside (crust) and inside surface of cooked samples immediately after cutting. Three readings were taken on each sample following the guidelines for colour measurements of the American Meat Science Association (2012).

### pH analysis

pH was measured using a pH meter (Hanna Instruments, HI5221) fitted with a HI1131B glass body pH electrode with BNC connector and a HI7662-T stainless steel temperature probe. One g cut from the centre of the cooked meatball was thoroughly homogenised with distilled water (9 mL) for 1 min using a Polytron Homogeniser at 6,000 rpm.

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### **Cooking yield**

Percentage of cooking yield was determined using the method described by Hsu and Chung (1998) using the equation below. The raw sample was weighed, cooked, cooled down to room temperature for 30 min and then reweighed.

Cooking yield 
$$\% = \left[\frac{Cooked \ weight}{Raw \ weight}\right] x \ 100$$

### **Proximate analysis**

Proximate analysis was performed on both raw and cooked meatball samples. Water content was measured by weight difference before and after hot air oven (Qualtex Solid State Laboratory oven model QM24S, Watson Victor Ltd, QLD, Australia) drying using 10 g of samples at 100 °C until constant weight was obtained (AOAC 950.46, 2005). Crude fat was measured by semi-continuous Soxhlet Extraction with diethyl ether as the solvent (AOAC 960.39, 2005). Ash content was measured using the Direct Method (AOAC 923.03, 2005) by ashing the sample at 550 °C until constant weight was obtained in a muffle furnace. Crude protein concentration was determined using the Leco Dumas method with 6.25 nitrogen conversion factor, which complies with approved test methods AOAC 992.23, AOAC 992.15, AOAC 968.06, AOAC 993.13 for protein determination in foods.

### Minerals content analysis

Minerals (Fe, Na, K, Ca, Mg, Zn, Mn) content was determined using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) (AOAC 984.27, 1995). Elemental concentrations were measured by Perkin Elmer 8300 DV ICP-OES relative to a 5% nitric acid sample matrix. Random and targeted repeat analysis was performed. Multiple emission lines were used to check for spectral interference.

### **Statistical analysis**

The experiment was conducted according to a Randomised Block Design with  $[3\times3+2]\times3$  factorial arrangement with three replications. Data was statistically analysed by Analysis of Variance (ANOVA) using GenStat<sup>®</sup> (18<sup>th</sup> Edition, UK). Nested design was used, i.e., factors

are "fit inside each other". In this case, +fibre and -fibre is only of interest for fat = 20 as all other fat content samples had fibre, so fibre is nested in 20% fat. A confidence level of 5% was used to compare Least Square Means (P<0.05). Significant differences between samples were compared using Fisher's LSD. Variance within treatments was expressed as the standard error of difference (SED) of the Least Square Means.

### **Results and discussion**

### **Proximate analysis**

Water content of raw samples was only influenced by fat content. Raw meatballs with 5% fat had a higher water content than those with 10, 15 and 20% added fat (70.8%, 67.8%, 64.8% and 62.8% respectively; SED=1.02, P<0.001) (Table 2). This was expected as the added fat had less water in it than the meat it replaced (Pietrasik and Duda, 2000, Tobin et al., 2013). For cooked samples, water content was influenced by fat content and cooking method (Table 3). There was a similar pattern to raw meatballs in terms of fat content, as 5% fat had a higher water content than those with 10, 15 and 20% added fat (63.0%. 60.0%, 57.3% and 54.1% respectively; SED=0.59, P<0.001). The lowest water content was found in pan-fried meatballs (57.1%, SED=0.38, P<0.001) in accordance with Sobral et al. (2018). Oven-baked and boiled samples had a similar water content as shown in Table 3.

Crude fat content of raw meatballs was influenced by added fat percentage in the formulation, which was expected as the higher fat added to the formulation, the higher the actual crude fat content should be. However, the actual fat content was lower than expected for 10, 15 and 20% added fat meatballs with fibre regardless of additive type (Table 2), likely because the added pork fat was only 74% lipid. In most cases, fat content of cooked meatballs was either close to the added fat content value (5, 10, 15 and 20%) or slightly higher (Table 3), due to the percentage of cook loss (15% for oven-baked, 18% for boiled and 22% for panfried; SED=0.66, P<0.001) being principally derived from water. Oven-baked meatballs had the lowest fat content compared to boiled and pan-fried (11.1%, 12.3% and 13.0%, SED=0.43, P<0.001). Oven-baking allowed more fat to lost during the cooking process , compared to the other cooking methods, and it could not be reabsorbed by the meatball as a hard crust had already formed. Turp (2016) found a similar result when comparing electrical grilling with electrical pan cooking.

Ash content of raw meatballs was influenced by fat content and additive type (Table 2). Overall, the lower the fat content, the higher the percent of ash as the lean beef content was higher, and lean beef has 2.6 x the ash content of the pork fat as stated in the "Preparation of meatballs" section. Meatballs with 15 and 20% fat had similar ash content. Ash content for cooked meatballs is shown in Table 3. Meatballs cooked through boiling water tended to have the lowest ash content. Sobral et al. (2018) showed that boiling is the method that most contributes to the loss of minerals, which is likely related to minerals leaching into the water from the meatball. However, a significant difference in ash content among formulations was not evident.

The formulations 5-SB and 20 + fibre, both oven-baked and boiled, were assayed for protein content. The results obtained were as expected due to formulation composition. The protein content of both raw and cooked meatballs was higher in 5% fat meatballs with fibre compared to 20% fat meatballs (raw; 14.9%, 10.1%, respectively; SED=0.49, P<0.001) (cooked;14,7%, 11.3%, respectively, SED=1.39, P<0.021).

### Minerals content analysis

Minerals content of cooked meatballs is shown in Table 4. Meatballs with 5% fat had higher content of all minerals than 20% fat samples, except for calcium where no difference was found. As expected, boiled meatballs had a lower content of minerals than oven samples (13-26% lower) for Na, K and Mg but not for the other minerals. This finding confirms that boiling promotes loss of some nutrients to the cooking water, likely due to leaching of nutrients from the meatball to the cooking medium and also due to expulsion of water during cooking and associated loss of nutrients. because its structure is damaged by high temperatures. The internal temperature reached during boiling of >61°C is known to significantly affect the mineral content (Tomović et al., 2015). Gerber et al. (2009) also found that boiling cuts of pork and beef decreases the contents of Na, K and Mg, while increasing the contents of Fe and Zn. Divalent minerals are better retained during cooking than Na and K, likely because of their greater association with protein prevents loss during cooking (Sobral et al., 2018). Additives did not influence this parameter.

### pH analysis

Overall, cooked meatballs with 20% fat had a higher pH regardless of the cooking method when compared to 5, 10 and 15% fat (6.3 and 6.1 for all others; SED=0.02, P=0.035), likely due to the higher pH of fat. Meatballs with SB had a higher pH than those with STPP or TSPP (6.2, 6.0, 6.0 respectively; SED=0.02, P<0.001). Mohan et al. (2016) reported that SB reduced drip loss and shear force and improved retention of added water by increasing the pH of ground beef. The ability of bicarbonates to improve water holding capacity (WHC) of processed ground beef have been attributed to an increase in both pH and ionic strength as bicarbonates bind to meat proteins and contribute to the dissociation of actomyosin into actin and myosin (Bouton et al., 1973, Wynveen et al., 2001). Babu et al. (1994) attributed the increase in pH after cooking of chicken meat to increased salt concentration due to loss of water and the change in the net charge of proteins due to denaturation. Puolanne et al. (2001) showed that addition of phosphates increased the pH in cooked sausage even at low concentrations of NaCl.

### Cooking yield

Cooking method affected the amount of weight lost during cooking, which is defined as cook yield, or also called cooking loss. Meat loses volume and weight during the cooking process by expulsion of fluid (Purslow et al., 2016). Water is lost as cooking loss and also fat melts and drips out of the product (Bejerholm et al., 2014) due to heat-induced protein denaturation during cooking of the meat, which causes less water to be held by capillary forces and entrapped within the protein structures (Shahiri Tabarestani and Mazaheri Tehrani, 2014). The highest cook yield was for oven-baked meatballs and the lowest yield was for pan-fried samples (85.2%, 77.9% respectively; 82.0% for boiled; SED=0.66, P<0.001). There was more cooking loss in samples with higher water and protein content. Samples with 5% fat had the lowest yield, compared to 15 and 20% fat samples (80.5%, 82.9% and 82.9% respectively, SED=0.73, P=0.005). Meatballs with 20% fat and fibre had a significantly higher yield than 20% fat meatballs without fibre (82.9%, 79.7% respectively; SED=2.53, P=0.015). However, this is considered a minor difference given that 3% of that difference is the actual weight of the fibre. Past research that used the same method to calculate cooking yield, reported similar results of higher cook yield when plant flours are incorporated into meat products (Dzudie et al., 2002, Pereira et al., 2016, Leonard et al., 2019). In agreement with our results, a significant decrease in cooking loss was reported by Fang et al. (2018)

when 3% sugarcane fibre was added to chicken sausage. However, the magnitude of the difference in cook yield they observed was lower. Additives did not influence cook yield and there were no interactions with factors other than those previously stated.

### **Texture Profile Analysis (TPA)**

Hardness refers to breaking force on first compression, cohesiveness is the ratio of the active work done under the second force-displacement curve to that done under the first compression curve. Springiness consists of the distance the sample recovered after the first compression, chewiness is gumminess x springiness and adhesiveness refers to the force needed to pull out the plunger from the sample after the first compression (Pietrasik and Duda, 2000).

Overall TPA hardness of cooked meatballs was affected by fat, additive type and cooking method. Hardness of meatballs with added fibre decreased with increased level of fat (Fig. 1a). Others have also reported that hardness decreases with increasing fat content in low-fat comminuted products, such as beef/pork frankfurters (Barbut and Mittal, 1996, Bloukas et al., 1997, Sofos and Allen, 1977). On the other hand, addition of fibre made the meatballs harder (Fig. 1b), result also reported by Fang et al. (2018) who showed that hardness of chicken sausage increased with the addition of sugarcane fibre. This is probably due the ability of dietary fibre to become a stronger binding three-dimensional network (Choi et al., 2012, Choi et al., 2009) and possibly the low water content. Despite the fact that the water content was similar for boiled and oven-baked samples, the hardness of the meatballs decreased when boiled compared to oven-baked and pan-fried samples (Fig. 2a) possibly due to a higher heatinduced gelatinization of connective tissue in the meat matrix combined with enzymatic breakdown of proteins (Bejerholm et al., 2014) as the heating profile was different as stated in the "Cooking methods" section. Interestingly, samples with SB were softer than those with STPP or TSPP (Fig. 2b). Recent studies revealed that sodium bicarbonate is able to reduce shear force of poultry marinated meat relative to phosphates (Petracci et al., 2012, Sen et al., 2005) by entrapping more water into myofibrillar spaces and could be used in meat formulations as phosphate replacers (Petracci et al., 2013). Possibly the high pH of SB meatballs had an influence on this. On the other hand, phosphates might have created a stronger and firmer matrix due to heat-induced hydrophobic interactions and to greater solubilization of meat protein.

Cohesiveness was only affected by fat content. There was less force required for 15 and 20% fat meatballs (0.33 and 0.31, respectively; SED=0.02, *P*=0.001) compared to lower fat ones, i.e., 5 and 10% (0.39 and 0.37, respectively; SED=0.02, *P*=0.001). Yang et al. (2016) found that as fat content increased from 0 to 3% in pork sausages, cohesiveness values decreased. Adhesiveness, springiness and chewiness of formulations with sugarcane fibre were influenced by fat content, cooking method and additive type (Table 5). In general, boiled meatballs had higher adhesiveness, except for 5% fat pan-fried meatballs with TSPP which was the highest. There was no difference in adhesiveness between additives within ovenbaked meatballs. However, variability in this parameter was too large to observe a clear pattern. Boiled meatballs had the highest values of springiness. Oven and pan-cooking reduced springiness of 5% fat meatballs with TSPP and 15% fat with STPP. According to Ulu (2006), pan frying also led to a decrease in springiness of meatballs. Oven and pan-fried meatballs tended to be chewier, compared to boiled. The chewiness of the oven and pan-fried meatballs was higher than boiled for most of treatments. Cooking is known to lead to a dramatic increase in chewiness in meatballs relative to raw samples (Ulu, 2006).

### **Texture contrast**

Cooking method affected crust hardness. Pan-fried meatballs had a harder crust compared to boiled and oven-baked (7.1 N, 6.4 N and 5.5 N respectively; SED=0.36, P<0.001) which makes sense as cooking meat in a hot pan will sear it resulting in a darker, caramelised colour. In accordance with TPA overall hardness, meatballs formulated with 20% fat and sugarcane fibre developed a harder crust compared to those without fibre (6.3 N, 3.6 N respectively; SED=0.69, P<0.001), possibly due to more Maillard browning driven by the sugars in the fibre (4.6 g/100g). This finding might be a good thing if consumers are looking to have a complex, more dynamic eating experience as opposed to a constant texture. Black et al. (2017) affirmed that the experience of eating can be more pleasurable by enhancing textures. On the other hand, inside hardness was affected by fat content and additive type but not cooking method which is interesting, but also makes sense. Consistent with TPA results for overall hardness, SB meatballs inner texture were softer than those with STPP while TSPP meatballs were statistically the same as SB and STPP (5.1 N, 6.1 N, 5.7 N respectively; SED=0.33, P=0.011). In the same manner, meatballs with 20% fat were internally softer compared to 5 and 10% fat meatballs. However, meatballs with 15% fat did not show a

significant difference compared to 10% and 20% fat (6.2 N, 5.5 N, 5.2 N, 4.5 N respectively; SED=0.33, P<0.001), indicating that a meatball with less fat could have similar texture to the 20% control. Similar results were found by Tobin et al. (2013) when measuring the impact of fat on texture of pork sausages even though they used higher fat concentrations (22.5, 27.5, 32.5, 37.5% w/w).

### Colour analysis

Fat content and additive type did not influence external colour of meatballs but cooking method and fibre inclusion did influence the external colour. Cooking effect was significant for a\* regardless of fat content and additive type (P<0.001) (Table 6). Boiled samples were paler than oven-baked and pan-fried, the latter were the darkest as they were in contact with the hot frying surface thus browning developed further due to the formation of ferrihemochrome pigment (denatured metmyoglobin), which gives a dull-brown colour (Hicks, 2018). Visually, our results showed the external colour of oven and pan-fried meatballs was closer to the red and yellow extremes of the scale while boiled meatballs appeared to be a 'khaki' colour. Fibre addition affected the external colour of 20% fat meatballs. The colour of 20% fat meatballs was lighter (L\*=50.3 for -Fibre and 53.9 for +Fibre, SED=1.60, P<0.031) and more yellow with fibre addition (b\*=13.9 for -Fibre and 15.7 for +Fibre, SED=0.53, P<0.002).

The internal colour of meatballs was influenced by fat content, additive type and cooking method. Pan-fried meatballs were darker internally (lower L\*) compared to boiled and ovenbaked (55.9, 56.9, 57.4 respectively; SED=0.36, P<0.001), most likely due to the lower water content (see above) and a longer cooking time which would concentrate the denatured myoglobin (Toldrá, 2017). Meatballs with SB were redder (higher a\*) than STPP and TSPP samples (8.9, 6.7, 7.1 respectively; SED=0.29, P<0.001). As for b\*, 5% fat samples were more yellowish than 10 and 15% fat but not 20%. In agreement with external colour, 20% fat meatballs with fibre were internally more yellow than without fibre (11.7, 10.9 respectively; SED=0.19, P<0.001) and less red (7.9, 10.0 respectively; SED=0.51, P<0.001) as expected since the sugarcane flour was slightly yellowish. Leonard et al. (2019) also reported higher yellowness for lupin-enriched beef sausages which makes sense as sugarcane flour is visually similar to lupin flour. Internal lightness differed across the three cooking methods by 1.5 units in total, while external lightness differed much more (15.7 units). Most likely the difference in internal lightness between meatballs would not be appreciable to consumers. Consumers are usually mainly concerned if there is any pinkness or redness, indicating that the meatball might be under-cooked.

### Conclusions

Results obtained in this study confirmed that physiochemical and nutritional traits of meatballs can be manipulated by formulation and cooking method as it was showed that the use of sodium bicarbonate, more fat and boiling resulted in softer meatballs. Results showed that a 5% fat reduction, from 20% to 15% added fat, might be feasible as most parameters were similar for 15 and 20% added fat meatballs. Pan-frying promoted the formation of a harder crust on meatballs so if the aim is to obtain a product with noticeable internal and external textural differences, this cooking technique might be the most suitable. However, oven-baking is an alternative in order to achieve more control of the cooking temperature and higher water retention, less amount of fat and higher content of some important minerals in the final product. Incorporation of sugarcane fibre at 3% made meatballs harder but increased cooking yield which is important for the food industry as the texture of meatball can be made softer by, for example, adding more water.

### Acknowledgements

The authors wish to thank The University of Melbourne for granting the Melbourne Research Scholarship to undertake the PhD degree under which this study was conducted. In addition, we acknowledge Steve Bonney for providing the phosphates, Dr. Graham Hepworth from the Melbourne Statistical Consulting Centre and Dr. Damir Torrico for providing guidance on the data processing.

Data Availability Statement Research data are not shared.

Ethical Guidelines Ethics approval was not required for this research.

### Funding

University of Melbourne provided funding received for the research.

### **Conflicts of interest**

The authors declare that they have no conflict of interest.

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Ingredients (g/100g)	A				
ingreatents (g/100g)	5%	10%	15%	20%+Fibre	20%-Fibre
Beef meat	81.3	76.3	71.3	66.3	66.3
Pork fat	5.0	10.0	15.0	20.0	20.0
Salt	0.5	0.5	0.5	0.5	0.5
Sugarcane fibre	3.0	3.0	3.0	3.0	0.0
Water	10.0	10.0	10.0	10.0	10.0
Additive*	SB (1), TSPP (2), STPP (3)	SB (4), TSPP (5), STPP (6)	SB (7), TSPP (8), STPP (9)	SB (10)	SB (11)

**Table 1** Formulations for the meatballs with sugarcane fibre and various levels of fat (g/100 g).

\*SB = sodium bicarbonate, TSPP = tetrasodium pyrophosphate, STPP = sodium tripolyphosphate all at 0.20 g/100g. Numbers in brackets represent the 11 formulations prepared.

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Formulation <sup>1</sup>	Water (g/100g)	Fat (g/100g)	Ash (g/100g)
5-SB	70.36 <sup>A</sup>	5.64 <sup>D</sup>	1.64 <sup>BC</sup>
5-STPP	71.12 <sup>A</sup>	4.86 <sup>D</sup>	2.01 <sup>A</sup>
5-TSPP	70.75 <sup>A</sup>	5.16 <sup>D</sup>	$2.00^{A}$
10-SB	67.91 <sup>B</sup>	9.05 <sup>C</sup>	1.50 <sup>BC</sup>
10-STPP	67.78 <sup>B</sup>	8.83 <sup>C</sup>	1.86 <sup>A</sup>
10-TSPP	67.72 <sup>B</sup>	8.93 <sup>C</sup>	$1.78^{AB}$
15-SB	64.81 <sup>C</sup>	12.61 <sup>B</sup>	1.44 <sup>C</sup>
15-STPP	64.60 <sup>C</sup>	12.95 <sup>B</sup>	1.57 <sup>BC</sup>
15-TSPP	64.95 <sup>C</sup>	12.76 <sup>B</sup>	1.55 <sup>BC</sup>
20-SB	62.78 <sup>D</sup>	16.23 <sup>A</sup>	1.42 <sup>C</sup>
SED	0.85	1.08	0.15

**Table 2** Proximate composition analysis of different formulations of raw meatballs with fibre(dry basis). The values are least squares means  $\pm$  Standard Error of Differences (SED).

<sup>1</sup> Meatball formulation: Number represents fat percentage and letters additive type, i.e., SB = sodium bicarbonate, STPP = sodium tripolyphosphate, TSPP = tetrasodium pyrophosphate.

<sup>ABC</sup> Least square means that do not share a letter within a column differ significantly (P<0.05).

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<u>ot</u>	W	ater (g/100g)			Fat (g/100g)		Ash (	(g/100g)	
Formulation <sup>1</sup>	Boiled	Oven	Pan	Boiled	Oven	Pan	Boiled	Oven	Pan
5-SB	$65.00^{\mathrm{aA}}$	64.15 <sup>aAB</sup>	59.81 <sup>bA</sup>	6.18 <sup>aF</sup>	6.75 <sup>aD</sup>	7.15 <sup>aD</sup>	1.52 <sup>aBC</sup>	2.37 <sup>bB</sup>	$2.07^{abAB}$
5-STPP	63.55 <sup>aAB</sup>	65.09 <sup>aA</sup>	59.62 <sup>bA</sup>	6.59 <sup>aF</sup>	6.39 <sup>aD</sup>	$8.14^{aD}$	2.18 <sup>aA</sup>	2.21 <sup>aB</sup>	$2.27^{aAB}$
5-TSPP	64.34 <sup>aA</sup>	$64.76^{aA}$	60.96 <sup>bA</sup>	$7.75^{aEF}$	$5.70^{\mathrm{aD}}$	5.98 <sup>aD</sup>	2.19 <sup>aA</sup>	2.20 <sup>aB</sup>	$2.34^{\mathrm{aA}}$
10-SB	59.56 <sup>aD</sup>	62.80 <sup>bAB</sup>	59.09 <sup>aAB</sup>	12.06 <sup>aCD</sup>	9.68 <sup>aC</sup>	11.38 <sup>aC</sup>	1.56 <sup>aAC</sup>	1.84 <sup>aB</sup>	$1.98^{aAB}$
10-STPP	61.03 <sup>bB</sup>	59.81 <sup>abC</sup>	57.77 <sup>aBC</sup>	10.33 <sup>aCE</sup>	11.68 <sup>aC</sup>	10.55 <sup>aC</sup>	$2.08^{aAB}$	3.15 <sup>bA</sup>	$2.08^{aAB}$
10-TSPP	61.32 <sup>aBC</sup>	$62.09^{\mathrm{aB}}$	56.55 <sup>bC</sup>	10.57 <sup>aCE</sup>	10.36 <sup>aC</sup>	12.46 <sup>aC</sup>	1.71 <sup>aAC</sup>	1.94 <sup>aB</sup>	$2.26^{aAB}$
15-SB	58.35 <sup>aD</sup>	59.48 <sup>aC</sup>	55.31 <sup>bCD</sup>	15.01 <sup>aB</sup>	14.95 <sup>aAB</sup>	16.85 <sup>aB</sup>	1.33 <sup>aC</sup>	$1.57^{\mathrm{aC}}$	$1.79^{aAB}$
15-STPP	$58.26^{\mathrm{aD}}$	$57.50^{\mathrm{aCD}}$	54.67 <sup>bD</sup>	14.67 <sup>aBD</sup>	$14.55^{aAB}$	16.01 <sup>aB</sup>	$1.67^{aAC}$	2.16 <sup>aB</sup>	2.21 <sup>aAB</sup>
15-TSPP	$58.97^{\mathrm{aCD}}$	60.02 <sup>aC</sup>	53.23 <sup>bDE</sup>	$14.89^{abB}$	12.32 <sup>aBC</sup>	16.99 <sup>bB</sup>	$1.44^{\mathrm{aBC}}$	$1.79^{\mathrm{aBC}}$	$1.95^{aAB}$
20-SB	$54.98^{\mathrm{aE}}$	55.46 <sup>aD</sup>	51.82 <sup>bE</sup>	19.61 <sup>aA</sup>	16.23 <sup>bA</sup>	21.58 <sup>aA</sup>	1.34 <sup>aC</sup>	1.53 <sup>aC</sup>	$1.72^{aAB}$
SED		1.26			1.41			0.33	

**Table 3** Proximate composition analysis of different formulations of cooked meatballs with fibre, subjected to three cooking methods (drybasis). The values are least squares means  $\pm$  Standard Error of Differences (SED).

<sup>1</sup> Meatball formulation: Number represents fat percentage and letters additive type, i.e., SB = sodium bicarbonate, STPP = sodium tripolyphosphate, TSPP = tetrasodium pyrophosphate.

<sup>abc</sup> Least square means that do not share a letter within a row differ significantly (P<0.05).

<sup>ABC</sup> Least square means that do not share a letter within a column differ significantly (P<0.05).

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**Table 4** Mineral contents (mg/100g of dry weight) of cooked meatballs with fibre as influenced by cooking method and fat content. The values are least squares means  $\pm$  Standard Error of Differences (SED).

Mineral		Cooking method		Fat Content (%)	
		Roilad	Oven	5	20
		Bolled	Oven	5	20
Fe	0	$7.19 \pm 0.23^{a}$	$6.86 \pm 0.23^{a}$	$8.74 \pm 0.21^{b}$	$6.00 \pm 0.25^{\circ}$
Na	$\tilde{\mathbf{\Omega}}$	$759\pm38.4^{\rm a}$	$956\pm38.4^b$	$927\pm33.8^{b}$	$755\pm41.6^a$
K		$805\pm40.2^{\rm a}$	$1016\pm40.2^{b}$	$1074\pm35.4^{b}$	$754\pm43.6^{\rm a}$
Ca		$17.3\pm2.57^{ab}$	$16.5\pm2.57^{ab}$	$20.1\pm2.26^{\text{b}}$	$15.3\pm2.78^{ab}$
Mg		$60.4\pm2.74^{\rm a}$	$67.7\pm2.74^{b}$	$77.8\pm2.41^{c}$	$51.0\pm2.97^{\text{d}}$
Zn	З	$9.29\pm0.59^a$	$8.94\pm0.59^{\rm a}$	$10.6\pm0.52^{\text{b}}$	$7.23\pm0.64^{c}$

<sup>abc</sup>Least square means that do not share a letter within a row and within a treatment (cooking method or fat content) differ significantly (P<0.05).

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	Adhesiveness (Nmm)			Springiness (mm)			Chewiness (N)		
Formulation <sup>1</sup>	Boiled	Oven	Pan	Boiled	Oven	Pan	Boiled	Oven	Pan
5-SB	26.6 <sup>aAB</sup>	9.6 <sup>aA</sup>	16.1 <sup>aA</sup>	-2.7 <sup>aB</sup>	-2.5 <sup>abAB</sup>	-1.9 <sup>bA</sup>	11.7 <sup>aA</sup>	18.2 <sup>bB</sup>	19.4 <sup>bB</sup>
5-STPP	8.6 <sup>aA</sup>	17.7 <sup>aA</sup>	0.1 <sup>aA</sup>	-1.1 <sup>aA</sup>	-2.9 <sup>bBC</sup>	-2.4 <sup>cAB</sup>	32.9 <sup>aC</sup>	16.2 <sup>bA</sup>	20.1 <sup>bB</sup>
5-TSPP	$0.05^{aA}$	$0.1^{aA}$	50.6 <sup>bB</sup>	-2.7 <sup>aB</sup>	-1.9 <sup>bA</sup>	-2.1 <sup>abA</sup>	15.3 <sup>aB</sup>	23.7 <sup>bC</sup>	22.5 <sup>bB</sup>
10-SB	37.2 <sup>aB</sup>	6.3 <sup>bA</sup>	5.8 <sup>bA</sup>	-2.7 <sup>aB</sup>	-2.3 <sup>aAB</sup>	-2.4 <sup>aAB</sup>	12.2 <sup>aA</sup>	15.9 <sup>aA</sup>	16.3 <sup>aAB</sup>
10-STPP	$40.9^{\mathrm{aB}}$	11.2 <sup>bA</sup>	$0.07^{bA}$	-2.6 <sup>aB</sup>	-2.3 <sup>aAB</sup>	-2.4 <sup>aAB</sup>	13.8 <sup>aA</sup>	$18.7^{bB}$	20.4 <sup>bB</sup>
10-TSPP	9.0 <sup>aA</sup>	14.9 <sup>aA</sup>	11.5 <sup>aA</sup>	-2.7 <sup>aB</sup>	-2.4 <sup>aAB</sup>	-2.5 <sup>aAB</sup>	14.7 <sup>aB</sup>	16.2 <sup>aA</sup>	$18.1^{\mathrm{aB}}$
15-SB	12.5 <sup>aA</sup>	6.8 <sup>aA</sup>	$26.6^{\mathrm{aAB}}$	-2.8 <sup>aB</sup>	-2.6 <sup>aBC</sup>	-2.6 <sup>aB</sup>	9.6 <sup>aA</sup>	12.3 <sup>aA</sup>	14.8 <sup>aA</sup>
15-STPP	7.5 <sup>aA</sup>	23.8 <sup>aA</sup>	$26.6^{\mathrm{aAB}}$	-3.1 <sup>aB</sup>	-2.3 <sup>bAB</sup>	-2.7 <sup>abB</sup>	$10.9^{\mathrm{aA}}$	16.7 <sup>aA</sup>	14.8 <sup>aA</sup>
15-TSPP	$48.7^{\mathrm{aB}}$	$0.2^{bA}$	0.3 <sup>bA</sup>	-2.8 <sup>aB</sup>	-2.2 <sup>aAC</sup>	-2.6 <sup>aB</sup>	11.5 <sup>aA</sup>	18.7 <sup>bB</sup>	$17.0^{abAB}$
20-SB	8.6 <sup>aA</sup>	7.9 <sup>aA</sup>	11.0 <sup>aA</sup>	-2.9 <sup>aB</sup>	-2.3 <sup>aAB</sup>	-2.4 <sup>aAB</sup>	7.5 <sup>aA</sup>	$10.4^{\mathrm{aA}}$	11.5 <sup>aA</sup>
SED		14.49			0.30			3.16	

**Table 5** Effects of fat content, cooking method and additives on TPA textural measurements of cooked meatballs with added sugarcane fibre.

 The values are least squares means ± Standard Error of Differences (SED) for the three-way interaction (fat content\*additive\*cooking method) are shown.

<sup>1</sup> Meatball formulation: Number represents fat percentage and letters additive type, i.e., SB = sodium bicarbonate, STPP = sodium tripolyphosphate, TSPP = tetrasodium pyrophosphate.

<sup>abc</sup> Least square means that do not share a letter within a row differ significantly (P<0.05).

<sup>ABC</sup> Least square means that do not share a letter within a column differ significantly (P<0.05).

CIE Lab Cal		Cooking metho	d	
CIE Lab Cor	Boiled	Oven	Pan	
L*	$61.3 \pm 0.84^{a}$	$50.4\pm0.84^{b}$	$45.6\pm0.84^{\rm c}$	
a*	$5.8\pm0.30^{\mathrm{a}}$	$9.0\pm0.30^{b}$	$9.3\pm0.30^{b}$	
b*	$13.5\pm0.28^{\rm a}$	$14.1\pm0.28^{\text{b}}$	$17.3\pm0.28^{\rm c}$	

**Table 6** Effect of different cooking methods on external colour of cooked meatballs. Thevalues are least squares means  $\pm$  Standard Error of Differences (SED).

<sup>abc</sup> Least square means that do not share a letter within a row differ significantly (P<0.05).

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**(b)** 



### Figure 2









