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A Literature Review: The Effects of Palm Kernel Expeller on the Carcass Characteristics and Meat Quality of Red Deer and other Species

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1.0 New Zealand Deer Industry

New Zealand is considered one of the largest exporters of venison and velvet antler in the world. According to the DINZ Annual Report (2016-17), Germany, USA and Belgium and the Netherlands are New Zealand's top export markets for Venison (Figure 1). East Asian countries are the main countries of which New Zealand deer farmers export Velvet antlers. Velvet antlers are the antlers that continue to grow until growth has come to a halt and calcification has occurred. As these antlers grow from the pedicle on the skull, they are covered with the velvet which are soft fine hairs. When growth of the antlers has ceased, the bone structure is considered dead and the mature antler is formed and the skin, nerve and blood supply are non-functional.

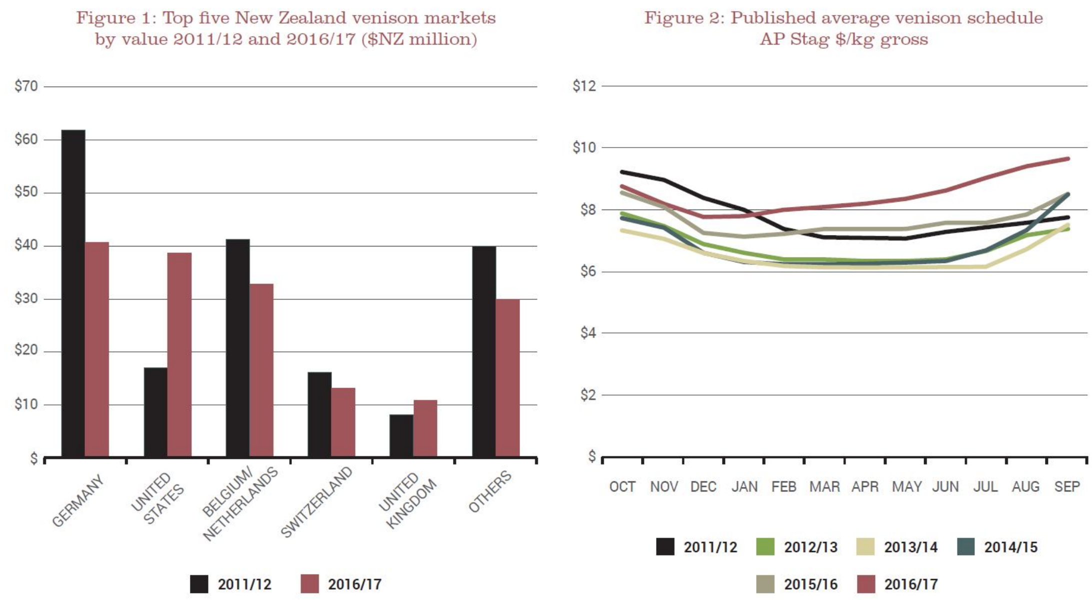

Figure 1: New Zealand venison markets (left) and average seasonal export sales (right)

Source: DINZ Annual Report 2016/17 (Date accessed: 21/12/2018)

In New Zealand, majority of the farmed deer are the European red deer and Northern America wapiti. Typically the New Zealand Deer industry are able to produce premium quality venison all year round, however during the year there are periods of which the supply of venison will be low and high. This is due to the feed used for deer, which is pasture which grows best in certain seasons. According to DINZ Annual Report (2016-17), the height of New Zealand venison export is during summer and fall months (October to March) and the lowest point of venison export would be during the winter months (April to August) (Figure 1). According to Walton (2018), in the 2018 game season, the expected value of New Zealand exported venison to Northern European countries such as Germany, Sweden, Belgium and the Netherlands was around $70 million. This would have be approximately 35% of the total venison exported from New Zealand. Recently the U.S has become one of New Zealand's major market for exported venison for chilled cuts, however the Europe market still remains an important export market for the New Zealand Deer Industry. New Zealand remains a top preference for these markets as the venison comes from farmed-raised deer (Walton, 2018).

2.0 Deer Carcass Characteristics

According to Kudrnáčová, Bartoň, Bureš, & Hoffman (2018), deer species undergoes changes in weight depending on the season. Deer typically gain the most body tissue in the spring and summer months and typically lose weight during the autumn and there is no weight gain during the winter months. The red deer specie is significantly larger in live weight and hot carcass weight (HCW) compared to fallow deer. The adult red deer stag and hind live weight are around 150-300kg and 90-140kg respectively, while the adult fallow deer live weights for bucks and does are around 50-110kg and 20-50kg respectively. It was reported by Purchas, Triumf, & Egelandsdal (2010) that at 20 months the HCW of male red deer were approximately 55.8kg compared to the females which were approximately 52.4 kg. The dressing percentage of the deer carcass is around 55-75% and this very good compared to other ruminant species. The lean meat yield (66-83%) and lean: bone ratio (5:1) for red deer were significantly higher than other farmed ruminant species. The fat content in the carcass in deer species are significantly lower than of other ruminant species. During yearling, the fat content is sometimes between 2 to 10% and this normally increases to 9 to 12% during the second year.

There were little literature on the effects of the sex of the red deer on the dressing percentage, proportions of carcass parts and internal organs, however reports on fallow deer found that there were no significant sex-related differences when it came to those carcass characteristics. It was reported that age and diet can affect the deer carcass characteristics. The live weight, dressing %, proportion carcass parts and fat content all higher in older deer and grain-fed diets (Kudrnáčová et al., 2018). It was reported that there is a gender effect on the carcass composition of the red deer which means the muscles, bones, carcass fat and the intramuscular fat (IMF) content varies between the sexes. Kudrnáčová et al. (2010) found that the muscles and bones content were significantly higher and the carcass fat and IMF were significantly lower in males compared to female red deer

3.0 Deer Muscle and Meat Quality

3.1 Muscle fibre composition and proportion

The quality of venison produced from the deer can be greatly affected by the muscle fibre type and composition. This is because the muscle fibres contribute to the metabolic properties of the venison and the conversion of muscle to meat. These fibres are supported by the intramuscular connective tissues called endomysium, perimysium and perimysium (Kudrnáčová et al., 2018). When the meat ages, the endomysium and perimysium connective tissues become weak and contribute to the tenderness of the meat.

There are three types of muscle fibre present in mammals: type I, type IIA and type IIB. Type I fibre is a slow oxidative red fibre that does not fatigue easily. This is because this muscle fibre contains a high amount of myoglobin and a low amount of glycogen. Type IIA is a fast oxidative glycolytic red muscle fibre and therefore is a fast contracting muscle that fatigue slowly. Type IIB is a fat glycolytic white fibre that consists of high amounts of glycogen but low amounts of myoglobin. Because it contains a lack of myoglobin, this white fibre fatigue the fastest of the three muscle fibres (Kudrnáčová et al., 2018).

It has been reported that depending on the muscle fibre type, the pH declining rate can be different in muscles, for example the pH tends to decline quickly when there are a higher amount of Type IIB present in the muscles. And for this reason the ageing of the meat taken place is quick. But if there are more type I and type II oxidative fibres present then the ageing rate will be slower. It has been found that to get the meat really tender, then a higher proportion of type I oxidative red fibre should be present in the muscle, whereas if there were a high proportion of Type IIA present then the meat tenderness will decrease as this type of fibre contributes to the increase in collagen content. The most predominate muscle fibre type present in game animal meat such as venison is type IIB (50-60%). This is good for deer meat as white fibre contributes to a tender and softer meat. The age of the animal also contributes to the type of muscle fibre present in the muscles as Kudrnáčová et al. (2018) reported that older animals tended to have more type I fibre than the younger animals.

Purchas et al. (2010) found that farmed red deer stags typically have significantly shorter sarcomeres than the hinds. It determined that that on average stags had a sarcomere length of 1.60 µm compared to hinds with had a length of 1.69 µm. Hutchison et al. (2014) stated that venison was tenderer when the sarcomeres were stretched and contraction were prevented. Purchas et al. (2010) also found that there were no significant differences in the muscle fibre diameter and myofibrillar fragmentation index (MFI) between the genders. The mean value for the muscle fibre diameter of stags and hinds were respectively 51.8 µm and 54.1 µm and the mean value for the MFI were 98.3 and 98.7 respectively.

3.2 Physical Attributes

3.2.1 pH

The ultimate pH value for meat is the measurement of the muscle carried out 24 hours after slaughtered. This pH indicates the rate of which the pH declines and the quality of the meat. This attribute is essential for the quality of venison and other meats as it provides an indication about the colour, tenderness, water holding capacity and shelf life of the product. The pH is dependent on the temperature and many possible ante- or post-mortem factors (Kudrnáčová, Bartoň, Bureš, & Hoffman, 2018). Dahlan and Norfarizan (2008), reported that the ultimate pH for venison is normally approximately ≤6.0. This value was in agreement with (Kudrnáčová et al., 2018) who stated that the pH of the deer muscle should decline to between pH 6.0 and 5.4. Puchas, Triumf and Egelandsdal found that the ultimate pH of the longissimus muscle was not significantly different between the sexes and found that the red deer stags and hinds (of about 20 months) had pH of 5.44±0.04 and 5.45±0.03 respectively.

3.2.2 Colour and Colour Stability

According to Kudrnáčová, et al. (2018), consumer's associate high quality and fresh venison with an intense red colour. Volpelli et al. (2003) reported that the colour of the venison that consumers have come to recognise as a premium quality lean meat is dark red. The CIE L* a*b* coordinates that the dark red colour corresponds with are L* <40 (lightness), high a* (redness) and low b* (yellowness). Purchas et al. (2010) was in agreement of these CIE colour coordinates for red deer, as the L*, a* and b* values for stags were respectively 39.7±0.3, 12.5±0.3 and 4.14±0.12. Meanwhile the L*, a* and b* values for the hinds were 38.6±0.3, 12.5±0.2 and 4.10±0.12 respectively (Purchas, Triumf, & Egelandsdal, 2010).

It was reported that there is a colour difference between deer species, sex, muscle type and the environment of which that animals were raised in. It was reported that venison from red deer stags were significantly lighter (L*) than hinds. However the redness (a*) and the yellowness (b*) of the stag meat did not differ significantly compared to the hind meat (Kudrnáčová et al., 2018). Kudrnáčová, et al. (2018) reported that wild stags had a higher b* coordinate and hue angle than the hinds. Purchas et al. (2010) also found a colour difference between the genders, as the stags had a slightly lighter colour (higher L* value) but the a* and b* values were similar compared to the hinds. Another study also found that male deer tend to have higher L* values than female deer (Razmaitė, Šiukščius, Šveistienė, Bliznikas, & Švirmickas, 2017).

Kudrnáčová et al. (2018) mentioned that the feed that deer consume may influence the colour and colour stability of venison. It was reported that venison from grass fed deer had a darker colour compared to venison of concentrate fed farmed deer. This difference may have been a result of either the feed type effecting the concentration of the myoglobin in the muscles or the difference in level of physical activity which may affect the metabolism of the animal. The muscles of wild deer tend to work harder than the muscles of farmed deer and for this reason the myoglobin in the muscles of wild deer will be used up more, making a darker colour in the meat (Kudrnáčová et al., 2018). It was also reported that deer fed concentrate feed had a redder meat colour compared to deer grass- fed (Dahlan & Norfarizan Hanoon, 2008).

Hutchison et al. (2014) found that there were no differences in colour when two different suspension methods were used (Pelvic suspension and Achilles tendon). This result was likely due to the final pH for each method were the same. This study found that for red deer stags the colour coordinates were L*=23.01, a*=11.44 and b*=2.16 (Achilles tendon) and L*=23.19, a*=11.80 and b*=2.05 (Pelvic suspension).

Purchas et al. (2010) stated that colour stability did not differ significantly between red deer stags and hinds. However Kudrnáčová et al. (2018) did mention that deer fed high concentrations of concentrate tend to have a lower colour stability than grass-fed deer. This is because these concentrates tended to contain a higher concentration of pro-oxidants (iron and copper) which promote oxidation and deterioration in the meat colour.

3.2.3 Other Physical attributes

3.2.3.1 Cooking Loss

Kudrnáčová et al. (2018) reported that the cooking loss observed between red deer stags and hinds for both wild and farmed deer were significant. The cooking loss was significantly higher for stags (29.88±0.429%) compared to the hinds (26.25±0.471). According to Purchas et al. (2010), venison from stags also had a higher cooking loss at 70°C and 60°C compared to the hinds. This suggests that cooking losses are dependent on genders. 29.62±0.4% and 28.26±0.39% were the cooking loss observed by Purchas et al. (2010) for the farmed stags and hinds respectively. There were no significant difference in cooking loss observed between free-living and farmed red deer (Razmaitė et al., 2017). In this study, it was determined that the semimembranosus muscle from both red deer types had a higher cooking loss than the longissimus muscle.

3.2.3.2 Drip Loss

According to Kudrnáčová et al. (2018), there was a significant difference in drip loss between farmed and wild red deer. However there was no significant gender effect on the drip loss of the venison. This was also in agreement with Purchas et al. (2010) which reported that while the venison from red deer stags did have a higher drop loss than the hinds, it was not statistically significant. The 48 hour drip loss percentage for farmed red deer stags and hinds were 5.09±0.88 and 4.22±0.66 respectively.

3.2.3.3 Water Holding Capacity

Hutchison et al. (2014), reported that the water holding capacity (WHC) of meat is usually described in terms of drip loss, cooking loss and purge percentage. This means from the results reported by Kudrnáčová et al. (2018) and Purchas et al. (2010), there could be a slight gender effect on the WHC of venison from red deer. This was because the red deer stag had a significantly higher cooking loss and higher a drip loss compared to the hinds. This indicates that the venison from stags have a poor water holding capacity. It is also important to note that the water holding capacity of any meat could decrease significantly following being frozen and stored in freezing conditions (Hutchison, Mulley, Wiklund, Flesch, & Sims, 2014).

3.2.3.4 WBSH/ Shear force

Farmed and Wild red deer stags had significantly higher shear forces compared to the hinds (Purchas et al., 2010). Kudrnáčová et al. (2018) reported that wild red deer stags and hinds had an average shear force of 20.73±0.329 N and 18.38±0.454N. Purchas et al. (2010) reported that the max force required in the compression test for farmed red deer stags and hinds were respectively 58.9±2.9N and 41.5±6.3 N. It was stated that the shear force was also dependent on cooking temperature, which in this study showed that shear forces increased significantly as the temperature increased to 70°C. It was also reported that the shear force of older deer tend to be significantly higher than young deer (Purchas et al., 2010). Research found that raw venison requires less shear than beef and that the shear force indicates the total collagen content and soluble collagen present in the animal muscles (Bureš, Bartoň, Kotrba, & Hakl, 2015)

3.3 Chemical Attributes

According to Bureš et al. (2015), venison tends to have a lower amount of dry matter (257.3 g/kg) and a higher amount of crude protein (221.4 g/kg) than beef. According to Dahlan et al. (2008), the protein content in venison typically ranges between 20.2% and 22.8%. Kudrnáčová et al. (2018) also reported that venison contains between 20% and 25% of protein.

The total fat content in any meat can vary depending on either the muscle or the specie (Bureš et al., 2015). Dahlan et al. (2008), stated that the total fat content can be different in deer when exposed to different conditions. For example, red deer and fallow deer live in temperate climate and tend to have more fat content than deer that live in tropical climate. It was also reported that the fat content in the deer tends to increase as the animal gets older and lower in deer that graze compared to those who are concentrated-fed (Dahlan & Norfarizan Hanoon, 2008).

According to Purchas et al. (2010), venison from stags tend to have less fat, dry matter and vitamin E compared to the hinds. However the total iron and haem iron present in the venison is not significantly different between the sexes. Kudrnáčová et al. (2018) stated that venison has a good amount of mineral present in it and that it does not differ significantly between the species, sexes or muscles. Venison is considerably high is haem iron, potassium, phosphorous, copper, zinc and calcium compared to other ruminant species.

The cholesterol content in venison is considerably lower than other ruminants (Dahlan & Norfarizan Hanoon, 2008). This study found that venison consisted of around 86 mg/100g of cholesterol and that there is a strong correlation between the cholesterol and fatty acid composition found in diets. It was also reported that the cholesterol level in the meat increases with age. Razmaitė et al. (2017) found that the level of cholesterol content in certain muscles were different. In this study, the longissimus muscle had a higher amount of cholesterol than the semimembranosus muscle. It was also reported that wild red deer tended to have a lower amount of cholesterol than the farmed red deer. There could also be a slight gender effect with the level of cholesterol found in deer, as it was reported that wild stags tended to have a lower cholesterol level than the hinds. However in contrast, farmed stags had a higher level of cholesterol than the hinds (Razmaitė et al., 2017).

According to Bureš et al. (2015), the total collagen and soluble collagen found in red deer were approximately 2.82 g/kg and 392.1 g/kg of total collagen respectively. In comparison with cattle samples, the total collagen in venison is lower, while the amount of soluble collagen is higher in venison. In contrast, Kudrnáčová et al. (2018) reported that the total collagen in venison is very similar compared to beef. This study reported that collagen plays an important role in the intramuscular connective tissue and the tenderness of the meat (Bureš et al., 2015). Kudrnáčová et al. (2018) also noted that it also plays an important role in the nutritional, physical and organoleptic attributes of the meat. It also reported that collagen solubility tends to decrease as the age of the animal increases.

According to Kudrnáčová et al. (2018), the intermuscular fat (IMF) content plays a key role in the juiciness, texture and flavour of the meat. Venison is a lean meat and therefore is low in IMF content compared to other ruminant meats. Kudrnáčová et al. (2018) reported that the IMF content in venison can be between 0.4 and 10.9 g/100g and that factors such as age, sex, nutrition, feed composition and region can all contribute to the IMF content and fatty acid composition of the muscles. According to Razmaitė et al. (2017), the IMF content was higher in muscles of wild red deer than farmed red deer. Bureš et al. (2015) found that along with saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA) content, the IMF content is significantly higher in venison from concentrate-fed deer than from grass-fed deer.

The fatty acids present in venison and other meats contribute significantly to the overall flavour of the meat, especially when cooked. This is because fatty acids undergo lipid oxidation when exposed to heat and volatile compounds, odour and other by-products are produced (Kudrnáčová et al., 2018). This report also found that MUFA contribute greatly to the development of the flavour of the venison and that while PUFA are healthier than SFA, high concentrations may have a negative effect on the oxidation stability of the meat.

According to Bureš et al. (2015), the most common fatty acids found in venison are Palmitic acid (C16:0), Oleic acid (C18:1 n-9), Linoleic acid (C18:2 n-6) and Stearic acid (18:0) (Table 1). It was reported that SFA and MUFA levels are significantly lower in venison compared to beef (Bureš et al., 2015), and that this is because the levels of C16:0 and C18:1 n-9 were low. This finding was supported by Kudrnáčová et al. (2018) which reported that C18:2 n-6 and alpha-Linolenic acid (C18: 3 n-3) are the main fatty acids present in the phospholipid fraction of the IMF and muscle of red deer.

Table 1: Major Fatty Acids present in venison

Major Fatty Acids	Amount per kg
C16:0	226 g
C18:1 n-9	210g
C18:2 n-6	148g
C18:0	146g

Source: Bureš et al. (2015)

According to Razmaitė et al. (2017), the fatty acid profile in venison can vary between muscles. For example C18:0 and Palmitoleic (C16:1 n-9) levels tend to be higher in the semimembranosus muscle than the longissimus muscle. Razmaitė et al. (2017) found that wild deer tended to have a higher amount of total MUFA and C18:1 n-9 fatty acid than the farmed deer. Stags tend to have higher amount of total SFA than the hinds (Razmaitė et al., 2017). Males also had a lower amount of total PUFA compared to hinds. However in contrast, Kudrnáčová et al. (2018) reported that the total PUFA found in males were significantly higher than female deer.

The n-6/n-3 PUFA ratio is significantly lower in red deer venison (2.32) than other species (Bureš et al., 2015). Kudrnáčová et al. (2018) reported that the grass-fed deer tended to have a significantly lower n-6/n-3 ratio of 2.1 to 3.3 compared to concentrate-fed deer which had a ratio of 4.5 to 9.6. Razmaitė et al. (2017) also found that this ratio was significantly lower in wild deer compared to farmed deer. This study also reported that there is a possible gender effect on the n-6/n-3 ratio in red deer. It found that the ratio was significantly better in males compared to females (Razmaitė et al., 2017).

Kudrnáčová et al. (2018) stated that venison and other game meat have a high level of alanine, aspartic, glutamic, and leucine and lysine acids. It was reported that alanine is significantly higher in venison compared to beef. Bureš et al. (2015) stated that the PUFA content found in venison is significantly higher compared to beef. The MUFA and PUFA content found in younger deer is significantly lower than older deer and this is related to the increased IMF content found in older deer. There was also a gender effect found between the stags and hinds for the PUFA/SFA ratio. The stags had a significantly higher PUFA/SFA ratio than the hinds.

3.4 Organoleptic Attributes

According to Purchas et al. (2010), venison from male deer was significantly tougher than female deer and that older stags tended to be tougher than younger deer. This result was not in agreement with (Macdougall, Shaw, Nute, & Rhodes, 1979) which found that there was no significant difference between sexes for tenderness, even though the males did have a higher pH than the females. A possible reason for these results could be due to the composition of the connective tissues (Purchas et al., 2010).

Kudrnáčová et al. (2018) reported that flavour, tenderness and juiciness were significantly better when the content of Intramuscular fat was high in the deer. It was also noted that the composition and amount of connective tissue, location and physical activity of the deer and rigor development also contribute to the tenderness of the venison (Hutchison et al., 2014; Kudrnáčová et al., 2018). Hutchison et al. (2014) found that the venison from the pelvic suspension technique was more tender and juicier than the venison from the Achilles tendon suspension technique. Bureš et al. (2015) found that the level of the tenderness of game meat such as venison is normally impacted by the stress and age of the animal at slaughter. For instance, young animals tend to have a less intense flavour compared to adult animals (Kudrnáčová et al., 2018). It was also reported that venison had a better score for tenderness compared to beef (Bureš et al., 2015).

Dahlan and Norfarizan Hanoon (2008), found that consumer panelists were unable to identify any significant difference in the appearance, tenderness, flavour or juiciness between the following deer species: Rusa Javan, Rusa Moluccan, Sambar deer, Red deer and Fallow deer. However they did find that the palatability scores for concentrate-fed deer were greater than the grass-fed deer. This result was also supported by Kudrnáčová et al. (2018) who reported that venison from pasture-fed deer tended to have a higher off-flavour than those of which were supplemented with pellets. They suggested that these palatability scores were closely related to the diet of the animal and in particular the fat and fatty acid composition that the deer consume (Dahlan & Norfarizan Hanoon, 2008). In the study carried out by Bureš et al. (2015), the trained panelists determined that there were significant differences between the meat of the red deer, fallow deer and Holstein cattle for the following sensory attributes: aroma, tenderness, flavour, juiciness and chewiness.

Venison tends to have a higher aroma and flavour intensity compared to beef (Kudrnáčová et al., 2018 and Bureš et al., 2015). The differences in meat aroma and flavour of the deer species and cattle could be explained by the lipid oxidation and chemical reactions such as Maillard reactions (Bureš et al., 2015). The fatty acid compositions in the muscle could also play a role in flavour and aroma differences between deer species, in particular, if the muscles have a high content of unsaturated fats. Dahlan and Norfarizan Hanoon (2008), agreed that the fatty acid content and compositions played key roles in sensory properties of meat flavours. It was reported that saturated fatty acids contribute to positive sensory properties compared to unsaturated fatty acids. The sensory properties of meat are typically more positive when the levels of intramuscular fat present in the animal muscles is high (Dahlan & Norfarizan Hanoon, 2008 and Bureš et al., 2015).

4.0 Palm Kernel Expeller

4.1 Chemical composition

Palm Kernel Expeller (PKE) is a palm kernel by-product that is produced when oil from the fruit of the palm is extracted by screw presses. PKE is considered a medium quality energy feed that is high in dietary fibre and is a good source of protein. The following tables show the chemical composition of PKE and Palm kernel Cake (PKC) (another palm kernel by-product) analysed by Alimon (2004) and Lyu et al. (2018). Lyu et al. (2018) also analysed PKE with Oat bran and Wheat bran as a comparison. Alimon (2004) also stated that the PKE composition is comparable to corn gluten and rice bran.

Table 2: Proximate analysis of Palm Kernel Cake

PKC composition	% of each component
Dry matter	88-94.5
Crude protein	14.5-19.6
Crude fibre	13.0-20.0
Ether extract	5.0-8.0
Ash/minerals	3.0-12.0
Nitrogen-free extract	46.7-58.8
Neutral detergent fibre	66.8-78.9
Metaboliseable energy (MJ/Kg)	10.5-11.5

Source: (Alimon, 2004)

Table 3: Proximate analysis of Palm Kernel Expeller in comparison to oat bran and wheat bran

Composition	PKE	Oat bran	Wheat bran
Dry matter (%)	90.0	91.4	92.0
Crude protein (%)	15.6	22.0	15.1
Ether extract (%)	5.8	7.4	3.2
Starch (%)	11.9	27.0	15.2
Crude fibre (%)	12.7	6.8	10.5
Total dietary fibre (%)	46.6	34.5	43.0
Soluble dietary fibre (%)	0.6	10.7	1.1
Insoluble dietary fibre (%)	46.0	23.8	41.8
Neutral detergent fibre (%)	50.9	39.1	46.7
Acid detergent fibre (%)	24.6	8.8	13.5
Ash (%)	5.20	5.56	5.56
Calcium (%)	0.2	0.10	0.10
Total phosphorus (%)	0.62	1.20	0.99

Source: (Lyu et al., 2018)

4.2 Effects of Palm Kernel by-products on the Carcass Characteristics and Meat quality

The current studies on the effects of PKE on the meat quality of venison are very limited and therefore for this review, the effects of other Palm kernel by-products on other species were reviewed. Some Palm Kernel by-products that have been used as feeds include Palm Kernel Expeller (PKE), Palm Kernel Cake (PKC) and Palm Kernel Meal (PKM).

4.2.1 Carcass Characteristics

According to Freitas et al. (2017), the hot carcass weight (HCW), cold carcass weight (CCW) and the dressing percentage did not change significantly with increasing amounts of PKC added to the lamb diet. In contrast, Santo et al. (2017) reported that as the PKC concentration in the lamb diet increased the HCW and CCW decreased. The only significant change in the carcass that was observed by Freitas et al. (2017) was that the carcass shrink decreased as the PKC increased. Okeudo, Eboh, Izugboekwe, & Akanno (2005) determined that the addition of PKC to Broiler chicken diets had no significant effects on the live weights or the average growth rate of the chickens. They also found that PKC did not have a significant effect on the slaughter weight or the dressing percentage of the chickens.

Another study found that PKC did not significantly affect the slaughter weight, HCW or the CCW of goats (Ribeiro, Oliveira, et al., 2018). However they did notice that the hot carcass yield and the cold carcass yield did decrease with the addition of PKC. The addition of PKC also did not significantly affect the tissue proportion in the hind legs, which means that the muscle, bone and fat content on the hind leg did not change significantly (Ribeiro, Oliveira, et al., 2018). According to Samsudin et al. (2017) PKC did not affect the final body weight or the weight of the organs of the Cherry Valley ducks significantly. The only significant changes observed were that the dressing percentage decreased and the feed intake was higher when the concentration of PKC in the diet increased. This increase in feed intake was due to the PKC having a higher fibre content which makes the nutrients less digestible and therefore the ducks required more PKC (Samsudin et al., 2017).

4.2.2 Meat Quality

4.2.2.1 Physical Attributes

4.2.2.1.1 pH

According to Ao et al. (2011) the addition of PKM to the diet of pigs did not significantly affect the pH. It was reported that the ultimate pH did not change significantly in Nellore bulls, goat kids or cherry valley ducks (Filho et al., 2016, Ribeiro, Medeiros, et al., 2018 and Samsudin et al., 2017). This indicates that the rate of pH decline is more likely affected by the pre-slaughter and post-slaughter procedures than diet-related causes. In each of these studies, the animals were exposed to the same pre- and post slaughter conditions, so the final pH of each treatment were expected to be similar

(Ribeiro, Medeiros, et al., 2018). In An et al. (2017) study, the pH of the muscles of pigs treated with PKM had a lower pH range than the controlled pigs, therefore this was not in agreement with the other literature. According to Fiho et al. (2016), if the ultimate pH were to increase in the muscles, this would be likely due to the glycogen store being low in the muscles and this could have an effect on the quality of the meat.

4.2.2.1.2 Colour and Colour Stability

The meat colour of Nellore bulls, goat, lamb and cherry valley ducks were not significantly affected by the addition of PKC in their diets (Filho et al., 2016, Ribeiro, Medeiros, et al., 2018, Santos et al., 2017 and Samsudin et al., 2017). This result was expected as the colour of the meat is directly related to the pH of the muscle and as mentioned in section 4.2.2.1.1, there were no significant changes in the pH. Ao et al. (2011) also agreed with these findings as the meat colour of the pigs fed PKM did not change significantly. Filho et al. (2016) stated that no changes in the colour were likely observed as the breed and age of the animals were similar at slaugther (Filho et al., 2016).

However these results were not in agreement with An et al (2017), which found that the colour of the pork was significantly different between pigs fed PKM and the control pigs. This study found that the a*and b* colour coordinates did not change but the L* coordinate did change significantly with the addition of PKM. The L* value decreased with the addition of PKM and this was likely due to the increase in pH observed in the meat. Research found that as the pH increases in the muscles, the water holding capacity of the meat reduces, which means less water is available on the surface of the meat. The decrease in surface water may have resulted in a decrease in reflected light and therefore may have caused the decrease in L* colour. Some sources have reported that antioxidant supplementation such as by-products of Palm kernel may increase the a* value and extend the colour stability of the meat (An et al., 2017).

4.4.2.1.3 Other Physical Attributes

4.4.2.1.3.1 Water holding Capacity

The water holding capacity (WHC) of meat from Nellore bulls did not change significantly with the addition of PKC (Filho et al., 2016). This finding was in agreement with Ao et al. (2011) which found that the WHC did not change with increasing amounts of PKM to the pig diets. In these studies, the ultimate pH of the animal did not change significantly with the addition of the palm kernel by-products. For this reason the WHC was not influenced by the diet change as the pH correlates with the WHC of the meat (An et al, 2017).

4.4.2.1.3.2 Cooking Loss

Ribeiro et al. (2018) found that the cooking loss of goat meat did not change significantly with increasing amounts of PKC. This result was supported by Samsudin et al. (2017) findings, which found that the cooking loss of duck did not change with the addition of PKC. For both studies the PKC meat samples were subjected to the same cooking temperature and conditions as the control samples and the final pH of the meat did not change significantly. According to Bouton et al. (1976), the cooking loss of meat are greatly affected by the temperature of which the meat is cooked at and the final pH of the muscle. The length of muscle fibres can also have a major effect on the cooking losses, in the Bouton et al. (1976) study, it was determined that cold-shortened semitendinosus muscle samples had a greater cooking loss value than the stretched muscle samples.

4.4.2.1.3.3 WBSH/Shear force

The shear force (WBSH) of the meat from Nellore Bulls, Cherry valley ducks and Lamb did not change significantly with the addition of PKC (Filho et al., 2016, Samsudin et al., 2017 and Santos et al., 2017). It was reported that there were no changes to the shear forces because the animals were the same age and size (Filho et al., 2016). Santos et al. (2017) also mentioned that the shear force can also be affected by the decrease in temperature and pH until the point of rigor mortis has been reached.

4.4.2.1.3.4 Drip Loss

Ao et al. (2011) reported that the drip loss of pork was not significantly influenced by the addition of PKM. This finding was supported by Samsudin et al. (2017), which found the drip loss of duck meat did not change significantly with the addition of PKC. Samsudin et al. (2017) suggested that because the final pH values were not significantly different, the drip loss did not change significantly. This is because the final pH strongly influences the water holding capacity of the meat and therefore influences the amount of tissue juice extruded out the meat. This explanation was also supported by (Fischer, 2007) who also added that the shortening of sarcomeres by the muscle temperature and rigour development can also influence the total drip loss of the meat product.

4.2.2.2 Chemical Attribute

According to An et al. (2017), Palm oil normally contains high concentrations of C16:0 and C16:1 and because of these fatty acids, it has been reported that C12:0 and C14:0 concentrations may increase in animals. This study found that in pigs, PKM caused the Palmitic acid (C16:0) to increase (An et al., 2017). However in contrast, Freitas et al. (2017) noticed that in lamb when the amount of PKC increased the concentration of C16:0 decreased. The results of these studies disagreed with Abubakr et al. (2017) which found that there were no significant difference in the concentration of C16:0 or C18:0 between the control and PKC samples for goat. Possible reasons for these disagreements could be that the C16:0 and C18:0 fatty acids can be internally synthesized in animals and therefore cannot be affected by supplements (An et al., 2017).

Reports have found that the main component of fatty acids in Palm kernel oil is Lauric acid (C12:0) and that there are a high amount of C18:3: n-3 present too (Abubakr et al., 2017). This result was supportive by An et al. (2017), who determined that PKM has a high concentration of medium chained fatty acids which can cause alteration in the total saturated fatty acid content in the meat. For this reason, the PKC consumed by goats caused the C12:0 concentration to be higher than in the control sample. This result was not unexpected as the C12:0 and C14:0 fatty acids are mostly sourced from the diet and therefore the concentration in the animals is greatly affected by any dietary change (An et al., 2017). This literature was supported by the results of Ribeiro et al., (2011) which found that the addition of PKC into the lamb diet resulted in an increase of C12:0 and C14:0 fatty acids.

Freitas et al. (2017) and Teye, Apori, & Ayeida. (2015) reported that the fat content and composition in the animals did not change significantly with the addition of the palm kernel by-products. This indicates that the high energy density from the palm kernel by-product did not increase the fat content in the muscles of the animals. The total saturated and polyunsaturated fatty acids did change significantly with increasing amounts of PKM in the pig diet. An et al. (2017) found that the total saturated fatty acids was greater in pigs fed 12% PKM compared to the control and 4% PKM samples. This study also found that total polyunsaturated fatty acids was significantly lower in the 12% PKM sample compared to the control sample. Abubakr et al. (2015) also found the sum of saturated fatty acids was significantly lower in the *longissimus dorsi* muscle of the control goat sample. It was reported that the increased saturated fatty acid in the goat meat could be due to the palmitic acid which also increased when PKC was added. This study also mentioned that an increase in saturated fatty acid could be due to increase in dietary fibre. Research has found that higher levels of fibre consumed in diets can increase rumen activity and cause the increase in bio-hydrogenation of the polyunsaturated fatty acids by the microbes present in the rumen (Abubakr, Alimon, Yaakub, Abdullah, & Ivan, 2015).

The sum of saturated, monounsaturated and trans-fatty acids were not significantly affected by the addition of PKC in the *biceps femoris* muscle of goats. The sum of monounsaturated and trans-fatty acids also did not change in the *infraspinatus* muscle of goats (Abubakr et al., 2015). These results were comparable with Ribeiro, Medeiros, et al. (2018), who found that there were no significant changes in the fatty acid composition of the *longissimus dorsi* muscle of the goats fed PKC. The sum of saturated, monounsaturated and polyunsaturated fatty acids were not significantly affected by the addition of PKC (Ribeiro, Medeiros, et al., 2018). It is possible that palm kernel by-products may have the ability to increase the unsaturated fatty acids concentration in meat as research has found that it can inhibit lipolysis in the rumen.

Ribeiro, Medeiros, et al. (2018) stated that the sum of omega 3 and 6 fatty acids did not change significantly with the addition of PKC in the goat diet. This was in an agreement with Abubakr et al. (2015) which found the omega 3 fatty acid did not change significantly in the muscles with the addition of PKC. However in this study, the sum of omega 6 fatty acids did change significantly as was significantly higher in the control sample (Abubakr et al., 2015).

Ribeiro, Medeiros, et al. (2018) also found that the omega 6/omega 3 fatty acid (n-6/n-3) ratio in goats did not change significantly with the addition of PKC. However while the n-6/n-3 ratio in the *longissimus dorsi* muscle did not change significantly, the n-6/n-3 ratios were significantly lower in the PKC samples of the *biceps femoris* compared to the control samples (Abubakr et al., 2015). The unsaturated fatty acids/ saturated fatty acids (UFA/SFA) ratio and the polyunsaturated fatty acid /saturated fatty acid (PUFA/SFA) ratio were not significantly affected by the PKC in the goat diet (Ribeiro, Medeiros, et al., 2018). However according to Freitas et al. (2017), the PUFA/SFA ratio in grazing lambs increased as the amount of PKC increased. In contrast, Abubakr et al. (2015) noticed that the PUFA/SFA ratio decreased when PKC was added to the diet.

An et al. (2017) used TBARS to measure the Malondialehyde (MDA) present in the pork, and found that while the values were significantly higher in the control sample at day 0, there were no significant differences in the TBAR value after days 3 and 7 for the PKM and control samples. Following day 7 the TBARS values decreased, this indicates that a possible bacterial metabolic reaction may have occurred in storage. This reaction could have caused the TBARS to react with the amines produced by the bacteria instead the MDA present in the samples. Ao et al. (2011) also measured the MDA present in the pork samples and found no significant differences between the control and PKM samples. Overall the TBARS values for both samples were below 1 which indicates low level of rancidity (odour and taste) (An et al., 2017).

Filho et al. (2016) and Ribeiro et al. (2018) found that the moisture, protein and ash content in the meat did not change significantly with the addition of PKC. Filho et al. (2016) stated that because the animals were the same breed, age and sex, the moisture, protein and ash content would not have change significantly.

4.2.2.3 Organoleptic Attributes

An et al. (2017) found that the addition of PKM to pig diets had no significant effect on the taste or overall acceptability of the pork loin. However they did find that pork from pigs fed 4% PKM had a higher flavour and overall acceptability score compared to pork from pigs fed 8% PKM. The 4% PKM pork loin also had a higher acceptability score than the 12% PKM pork loin. In terms of colour, tenderness and off-odour, they found that there were no significant differences between the control pork and the increasing amounts of PKM. Research found that pork from pigs fed 60% PKC had increased juiciness and overall acceptability than pork fed on a maize diet (Oluwafemi, 2015). However they did find that the tenderness and flavour of the 60% PKC pork did decrease compared to the control sample.

Ao et al. (2011) also reported the effects of PKM on the meat quality of pork and they found that the marbling score decreased when the pigs were fed 5% PKM. This difference could be because PKM has a higher fibre content, which may lead to a decrease in the intramuscular fat in the pig. They also notice that the firmness of the pork did not change significantly with the addition of the PKM (Ao et al., 2011). Filho et al. (2016) reported that the flavour, tenderness, global acceptance and preference of the Nellore bull meat did not change significantly with the addition of PKC.

The tenderness and juiciness of the chicken did not change significantly when increasing amount of PKC were added to the broiler diet (Okeudo, Eboh, Izugboekwe, & Akanno, 2005). The consumers found the tenderness of the meat to be moderate to very tender and the juiciness of the meat to be slight to moderate juicy. However the consumers did find that that the flavour of the control samples were significantly lower than the PKC samples. They reported that a possible cause of this flavour change could be that the degree of marbling in chicken has changed as a result of the addition of PKC (Okeudo et al., 2005).

Riberio, Mederios, et al. (2018) reported that the panellist found that the goat meat appearance did not change significantly with increasing amount of PKC. They did judged to colour of the meat being quite light, which is a good indication for consumers who judge lighter meat as being high quality. The aroma and flavour of the goat meat also did not change significantly with the addition of PKC to the diet (Ribeiro, Medeiros, et al., 2018).

5.0 References

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