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Starch Source as a Determinant of Physical Attributes in Deep-Fried Frozen Keropok Lekor (Malaysian Fish Sausage)

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ABSTRACT

Keropok lekor, a traditional Malaysian fish sausage, is typically prepared using fish and sago starch, with both ingredients strongly influencing its texture and sensory quality. This study investigated the effects of incorporating tapioca starch (TS) and potato starch (PS) into the formulation on the physical attributes of deep-fried frozen keropok lekor. The evaluated properties included colour, moisture content, water-holding capacity, linear expansion, cooking yield and texture. The addition of tapioca starch decreased the L* value while increasing the b* value of the product surface, whereas potato starch reduced the a* value but enhanced the b* value. Keropok lekor made with potato starch exhibited improved moisture content, water-holding capacity and cooking yield. In terms of linear expansion, keropok lekor prepared with tapioca starch showed value comparable to the control made solely with sago starch. However, neither tapioca nor potato starch significantly affected the textural properties. These findings demonstrate that starch source influences the quality of deep-fried frozen keropok lekor, thus offering opportunities for processors to improve product quality.

Keywords: keropok lekor, deep-fried, tapioca starch, potato starch, physical attributes

INTRODUCTION

Keropok lekor (Malaysian fish sausage) is a traditional Malaysian fish-based snack popular along the east coast regions and known for its unique chewy texture and savoury flavour. The product is typically made by mixing minced fish flesh with starch to form a dough, which is then shaped, boiled and deep-fried to produce a snack with a characteristic crispy exterior and elastic interior. In recent years, the frozen par-fried version of keropok lekor has gained popularity due to its extended shelf life and consumer convenience, allowing for rapid preparation with retained sensory qualities (Wan Nur Nai'mah, 2015; Yu, 1991). The production of keropok lekor begins with careful selection of fresh fish, commonly *selayang* (*Decapterus* spp.), which is deboned and finely minced using mechanized equipment for efficiency and consistency. The starches, usually sago or tapioca, are combined with the minced fish, salt, sugar, monosodium glutamate, and water. Starch content in the formulation typically ranges from 30-40%, acting as a binder and texture modifier. Proper mixing and kneading are crucial to obtaining a homogenous dough with adequate water-binding capacity, which influences cooking behaviour and texture development (Fazial et al., 2024; Wan Nur Nai'mah, 2015). After mixing, the dough is portioned and shaped into cylindrical rods approximately 2 cm in diameter and 5 cm in length. Shaping is traditionally done manually by rolling the dough on timber decking, though mechanized shaping devices have been introduced to improve uniformity. For frozen purposes, the shaped rods are then subjected to par-frying. This process develops a partial crust, reducing moisture content, set the starch-protein matrix and improving appearance and texture (Ayob et al., 2022; Wan Nur Nai'mah, 2015). The partial cooking allows the product to be frozen for storage and distribution. At the point of consumption, final deep-frying completes the cooking, enhancing the crispiness and flavour while preserving the chewy interior. Optimization of the par-frying and freezing conditions is essential to maintain product quality after frozen storage (Fazial et al., 2023; Izzi et al., 2023).

Starch plays a fundamental role in the functionality of keropok lekor, primarily affecting its texture, water holding capacity and cooking yield. Sago starch, commonly used in keropok lekor, contributes significantly to its swelling capacity and gelation properties, which are crucial for achieving the desired chewiness and structural integrity after cooking (Yusnita et al., 2017). The gelatinization temperature and granule size of starch influence the hydration and swelling rates, impacting the texture and water retention of the product. Sago starch granules are oval-shaped, relatively large (~30-40 μm) and feature a C-type crystalline pattern. It has moderate amylose and resistant starch content, influencing rheological and gelatinization properties. Sago starch gels exhibit high hardness, adhesiveness, springiness and cohesiveness, making it a potential food stabilizer (Du et al., 2020; Udomrati et al., 2024). Variations in starch type, such as the inclusion of tapioca or potato starch, can alter the physical properties of keropok lekor. Tapioca starch is composed mainly of amylopectin, which forms sticky gels with high swelling capacity and low gelatinization temperature. These properties lend elasticity and moisture retention to the keropok dough, producing a characteristic chewiness while limiting excessive oil uptake during frying. Additionally, tapioca starch's fine granule size contributes to a smooth dough texture and uniform gel matrix (Hsieh et al., 2019). Conversely, potato starch has larger granule sizes and higher water-holding capacity, which can increase expansion and crispiness in fried snacks due to the formation of porous structures during frying. Its gelatinization temperature is slightly higher than tapioca starch, affecting starch transformation dynamics during boiling and frying. Incorporating potato starch into keropok formulations may reduce hardness and enhance crispness, offering potential improvements to sensory appeal (Li et al., 2024; Riley et al., 2023).

Frozen storage of par-fried keropok lekor adds complexity through ice crystal formation, moisture migration and starch retrogradation, which can alter texture and sensory attributes after thawing and final frying. Choosing the right starch blend can enhance freeze-thaw stability, maintain desirable textures and reduce oil absorption inconsistencies during consumer preparation. Thus, investigating starch effects on frozen par-fried versions is critical for improving product quality and shelf life (Fazial et al., 2023). Research on the effects of incorporation of tapioca and potato starch in frozen par-fried keropok lekor remains limited. The frying process in frozen par-fried products involves unique thermal and mass transfer phenomena compared to freshly fried products. This study aims to fill this knowledge gap by evaluating the physical properties of deep-fried frozen par-fried keropok lekor formulated with of tapioca and potato starches (Izzi et al., 2023; Wang et al., 2021). The findings from this research are expected to provide critical insights into starch selection and formulation strategies for the frozen par-fried keropok industry. Improved understanding of starch interactions during processing will help enhance product texture, sensory quality and shelf stability, offering benefits to manufacturers and consumers seeking high-quality, convenient traditional snacks.

MATERIALS AND METHODS

Materials

Frozen Japanese scad (*Decapterus maruadsi*) fish flesh was purchased from Kilang Cap Aye in Besut, Terengganu. Sago starch (Cap Bintang, Thye Huat Chan Sdn Bhd, Pulau Pinang, Malaysia), tapioca starch (Bestari, Symerchem Food Processing Sdn Bhd, Selangor, Malaysia), potato starch (Bestari, Symerchem Food Processing Sdn Bhd, Selangor, Malaysia), salt (Adabi, Adabi Consumer Industries Sdn Bhd, Selangor, Malaysia), sugar (Prai, MSM Prai Berhad, Pulau Pinang, Malaysia) and flavour enhancer were purchased from local supermarkets in Besut, Terengganu.

Production of *keropok lekor*

All ingredients for making keropok lekor were weighed according to the formulation provided in Table 1. Keropok lekor made with sago starch served as the control (S), while half of the sago starch was substituted with either tapioca starch (S:TS) or potato starch (S:PS). The ingredients were mixed in a mixer (K3 Mini-Luxury Cutting Machine, Kinn Shang Hoo Iron Works, Taiwan) for 3 minutes until they were uniform. The dough was shaped and rolled into a sausage-like piece about 20 cm long. Then, they were par fried at 165 °C for 1 min. The par-fried keropok lekor were placed on trays to cool room temperature. They were packed in vacuum bags and stored in a freezer at -18°C. The frozen keropok lekor samples were thawed for 15 min before being deep-fried at 160°C for 3 min. They were left to cool to room temperature for 10 min before physical analysis.

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Table 1. Keropok lekor formulated with different blends of starches

Ingredients (%, w/w)	Sago starch (S)	Sago starch:Tapioca starch (S:TS)	Sago starch:Potato starch (S:PS)
Fish flesh	77	77	77
Sago starch	20.8	10.4	10.4
Tapioca starch	-	10.4	-
Potato starch	-	-	10.4
Salt	1.5	1.5	1.5
Sugar	0.5	0.5	0.5
Flavour enhancer	0.2	0.2	0.2

Determination of colour

The colour of keropok lekor was measured using a colorimeter (Chroma Meter CR-400, Konica Minolta Sensing, Inc, Tokyo, Japan) based on three values: L* (which indicates darkness to lightness), a* (which indicates greenness to redness) and b* (which indicates blueness to yellowness). Before taking measurements, the colorimeter was calibrated with a white plate. Each keropok lekor was measured five times and an average value was recorded.

Determination of moisture content

Moisture content of keropok lekor was determined using the oven drying method (AOAC, 1999) at 105°C. The moisture content was calculated using Eqn. 1:

$$Moisture\ content\ (\%) = \frac{Initial\ weight\ of\ sample - Final\ weight\ of\ sample}{Initial\ weight\ of\ sample} \times 100 \qquad \textbf{Eqn. 1}$$

Determination of water holding capacity

Water holding capacity was measured using the method from Murad et al. (2017) with some modifications. Distilled water (10 ml) was homogenised with 5 g of keropok lekor samples. This mixture was then centrifuged at 2000 rpm for 10 min. The supernatant was collected and weighed. WHC was calculated using Eqn. 2:

$$WHC\ (\%) = \frac{Weight\ of\ sample\ before\ centrifuge\ -\ Weight\ of\ sample\ after\ centrifuge}{Weight\ of\ sample} \times 10 \quad \textbf{Eqn. 2}$$

Determination of cooking yield

Cooking yield was determined as the percentage of weight before and after deep frying of keropok lekor (Santana et al., 2013). The cooking yield was calculated using Eqn. 3:

$$Cooking\ Yield\ (\%) = \frac{Weight\ of\ cooked\ keropok\ lekor}{Weight\ of\ raw\ keropok\ lekor} \times 100 \quad \textbf{Eqn. 3}$$

Determination of linear expansion

Expansion of keropok lekor was measured by comparing the diameter of keropok lekor before and after deep frying with a vernier calliper (Huda et al., 2012). The linear expansion was calculated using Eqn. 4:

$$Linear\ Expansion\ (\%) = \frac{Diameter\ after\ boiling - Diameter\ before\ boiling}{Diameter\ before\ boiling} \times 100 \quad \textbf{Eqn. 4}$$

Texture profile analysis

Texture Profile analysis (TPA) of keropok lekor was carried out using a texture analyzer (TA-XTPlus, Stable Microsystems, Survey, UK) according to the method by Hayes et al. (2005). A Compression Platen (SMS P/75) with a heavy-duty platform equipped with a 5 kg load cell and a prefixed strain at 50% was used for the analysis. A sample, with a thickness of 2.5 cm, was placed horizontally on the platform and then compressed at a pre-test speed and post-test speed of 10 mm/s, test speeds of 5 mm/s and a distance of 10 mm. The textural parameters of keropok lekor were measured as hardness and chewiness.

Statistical analysis

All analyses were performed in triplicate, except for colour measurements, which were based on five readings. Significant differences among formulations were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test at a significance level of 5%, performed with the Statistical Package for the Social Sciences (SPSS) software version 20 (IBM, Illinois, USA). The results are expressed as mean ± standard deviation.

RESULTS AND DISCUSSION

Physical attributes of deep-fried keropok lekor

The colour attributes (L*, a* and b*) of deep-fried keropok lekor were significantly influenced by the type of starch incorporated (Figure 1). Samples incorporated with tapioca starch (S:TS) exhibited the lowest L* values, indicating a darker surface compared to the control (S) and potato starch formulation (S:PS). The darker appearance of S:TS may be attributed to the higher amylopectin content of tapioca starch, which promotes rapid starch gelatinisation and crust formation, allowing greater heat transfer and surface dehydration and thus indirectly promoting Maillard and caramelisation reactions that responsible for darker colour during frying

(Hoover, 2001; Zhu, 2015). In contrast, S:PS maintained a higher L* value, likely due to the larger granule size and higher water retention capacity of potato starch, which delays surface dehydration and limits excessive browning (Singh et al., 2003).

The a* and b* values further demonstrate the difference in the colour of deep-fried keropok lekor. The control sample (S) recorded the highest a* value, suggesting a greater red-brown intensity. In contrast, the addition of tapioca or potato starch reduced a* values while increasing b* values, resulting in a more yellow hue. Compared to the control, the sample containing potato starch exhibited a relatively lower a* value. This can be explained by the ability of potato starch to retain water and form a denser gel matrix, thereby lowering surface temperature and reducing Maillard-driven red pigmentation (Singh et al., 2003). For b*, both S:TS and S:PS showed higher values than the control, possibly due to greater oil absorption and accumulation of yellow-brown compounds from lipid degradation and sugar breakdown during frying (Krokida et al., 2001; Martins et al., 2000). These results highlight that starch source modulates thermal and mass transfer during frying, ultimately influencing the surface colour and visual quality of keropok lekor.

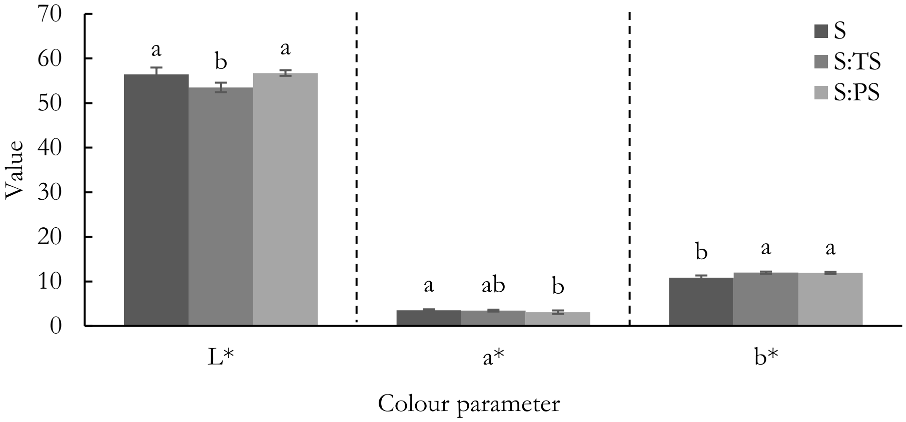

Fig. 1. Colour parameters of deep-fried keropok lekor formulated with different starch blends.

The moisture content, water holding capacity, cooking yield and linear expansion of the deep-fried keropok lekor are summarised in Table 2. The moisture content and water holding capacity of deep-fried keropok lekor differs significantly with starch type, with S:PS demonstrating the highest values. This is likely due to the distinct physicochemical properties of potato starch, which has larger granules and a higher amylopectin content, enhancing its ability to retain water by swelling more during gelatinization, thereby increasing water holding capacity and retaining more moisture during frying. Tapioca starch, with its smaller granules and high amylopectin, also exhibits strong water retention but slightly had less moisture content than potato starch. In contrast, sago starch has a comparatively lower swelling capacity leading to lower water holding capacity. These differences in moisture retention influence the texture and overall quality of the deep-fried keropok lekor, with potato starch contributing to a moister product and tapioca starch leading to drier, potentially crisper outcomes. This phenomenon aligns with findings from previous studies on starch water retention and frying behaviour, where starch granule size, hydration properties and gelatinization dynamics critically determine moisture levels in fried starchy foods (Bordin et al., 2013; Izzi et al., 2023; Wang et al., 2021). The freeze-thaw stability in frozen keropok lekor might also influenced by the type of starch used. According to Tee et al. (2017), adding tapioca or potato starch to fish balls improved their texture and freeze-thaw stability, resulting in firmer, chewier products with less drip loss and a more stable matrix after freezing and thawing.

Cooking yield was also influenced by starch source (Table 2). The highest cooking yield was observed in the potato starch formulation (S:PS, 93.39%), followed by the control (S, 90.50%) and tapioca starch formulation (S:TS, 89.16%). The superior yield in S:PS may be due to the stronger water-holding capacity of potato starch, which retains more water during the frying process, thereby reducing cooking loss (Ratnayake & Jackson, 2006; Singh et al., 2003). In contrast, tapioca starch, with its less dense granule structure and weaker gel strength, may have allowed greater moisture loss during frying, resulting in a lower yield (Charles et al., 2004). This indicates that potato starch enhances product juiciness and retention of mass after frying, while tapioca starch contributes more towards expansion rather than yield.

As listed in Table 2, the linear expansion of deep-fried keropok lekor was also affected by the type of starch incorporated. The control with only sago starch (S) exhibited the highest expansion (2.50%), followed by the formulation with tapioca starch (S:TS, 2.27%), while potato starch (S:PS) showed the lowest value (0.97%). The greater expansion in the sago and tapioca-containing formulations can be attributed to their higher amylose content compared to potato starch. During frying, amylose leaches out and forms a rigid gel matrix around the granules, which traps steam more effectively and thereby promoting puffing and expansion (Zhu, 2015). In contrast, potato starch that high in amylopectin, contains large granules with high phosphorus content, which tend to restrict expansion due to the formation of a more rigid gel network (Hoover, 2001; Singh et al., 2003). This observation indicates that starch granule structure and composition play crucial roles in determining the expansion behaviour of fried products.

Table 2. Physical attributes of deep-fried keropok lekor formulated with different starch blends

Parameter	**Sago starch (S)**	**Sago starch:Tapioca starch (S:TS)**	**Sago starch:Potato starch (S:PS)**
Moisture content (%)	43.93 ± 1.61^{b}	43.11 ± 0.97^{b}	48.52 ± 1.15^{a}
Water holding capacity (%)	109.60 ± 6.80^{b}	120.15 ± 2.27^{a}	121.58 ± 2.04^{a}
Cooking yield (%)	90.50 ± 1.32^{b}	89.16 ± 0.42^{b}	$93.\pm0.30^{a}$
Linear expansion (%)	2.50 ± 0.71^{a}	2.27 ± 0.51^{a}	0.97 ± 0.01^{b}

$^{a\text{-}b}$ Mean ± SD in same row with different superscript indicates that there are significant different ($p<0.05$)

Textural properties of deep-fried keropok lekor

Figure 2 illustrates the effect of tapioca starch and potato starch substitution on the hardness and chewiness of deep-fried keropok lekor, compared to a control containing only sago starch. The hardness and chewiness parameters remain statistically similar across all treatments, suggesting that the partial replacement of sago starch with tapioca or potato starch does not significantly alter these textural attributes in deep-fried keropok lekor (Izzi et al., 2023; Tee & Siow 2017). Both tapioca and potato starches can form cohesive gels, which helps preserve hardness and chewiness. During deep frying, rapid starch gelatinization and moisture loss promote crust formation and change the matrix' structure, but the substitution levels and interactions between protein and starch were not sufficient to overcome the dominant textural effects of sago starch in the formulation. Similar conclusions were reported by Izzi et al. (2023), who found that neither tapioca nor potato starch alone led to significant differences in the hardness and chewiness of boiled keropok lekor, suggesting that the intrinsic protein matrix and overall starch content are more critical than starch source alone.

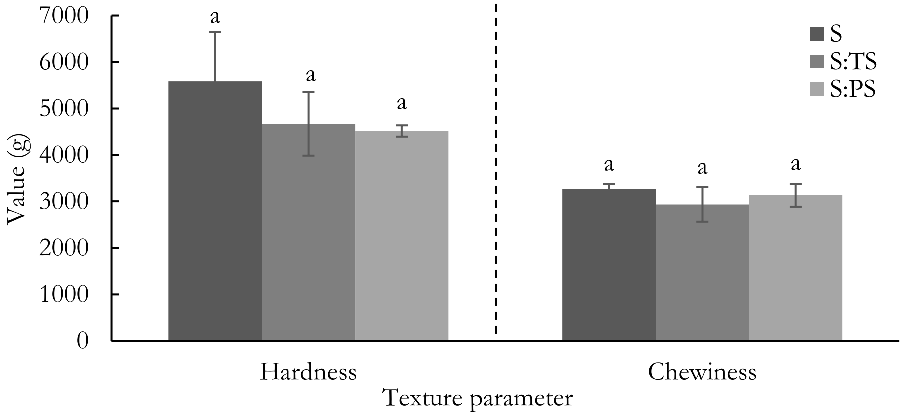

Fig. 2. Hardness and chewiness of deep-fried keropok lekor formulated with different starch blends.

CONCLUSION

These findings highlight the contrasting functional roles of tapioca and potato starch in keropok lekor. Tapioca starch enhances puffiness and expansion, whereas potato starch improves water retention and cooking yield. Colour attributes were also shifted with starch type, where both potato and tapioca starch reduced surface redness (a*) and increased yellowness (b*) compared to the control sample. Interestingly, despite these differences, the hardness and chewiness of keropok lekor remained unaffected across all formulations. This suggests that the protein–starch network formed during gelation and frying is sufficiently stable to maintain the core texture, regardless of starch substitution. The stability in hardness and chewiness indicates that starch modification mainly impacts moisture dynamics and surface properties rather than the structural integrity of the product. From an industrial perspective, the results can guide the formulation of keropok lekor with targeted traits, such as greater puffiness for a lighter and more appealing texture or enhanced moisture retention for improved yield and shelf life. Processors may strategically select or blend starch sources to optimize product characteristics while balancing cost and functionality. Beyond keropok lekor, these insights can be applied to other fried surimi-based or starch–protein composite products, supporting innovation in product development with consistent texture and better frying efficiency. For future research, studies could explore the synergistic effects of blending tapioca and potato starches in different ratios to fine-tune both expansion and moisture retention in keropok lekor. In addition, exploring the influence of starch type on storage stability, freeze–thaw resistance and sensory acceptance would be valuable for commercial scale-up.

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