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EFFECT OF PROTEIN–STARCH INTERACTION ON RHEOLOGICAL, TEXTURAL, AND SENSORY PROPERTIES OF *KEROPOK LEKOR*

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Abstract

This article considers the effect of protein–starch interaction on the gelling, textural, and sensory properties of *keropok lekor* used as a fish protein–starch model. A two-level factorial design was employed to analyze the quality and acceptability of different formulations of *keropok lekor* crackers depending on the ratios of minced fish (MF, 20–50 g (w/w)), sago starch (SS, 10–40 g (w/w)), and water (W, 10–35 g (w/w)). The parameters measured were the onset (T_0) and peak (T_p) temperatures of gelatinization, storage modulus (G'), and loss modulus during gelatinization (G''). The samples were rated by a group of 30 panelists during texture profile analysis and sensory evaluation. The most preferred samples had the MF : SS : W ratio of 20 : 10 : 10 and were characterized by the lowest onset and peak temperatures of gelatinization. Therefore, this formulation was singled out as optimal for *keropok lekor*.

Keywords: *keropok lekor*, fish sausage, sago starch, protein–starch interaction, gelatinization, storage modulus, sensory evaluation

Introduction

Keropok lekor is a popular Malaysian fried snack [1–3] distinguished by a unique combination of protein to starch [4, 5]. “Fish sausage” is what it is often dubbed, which is the most straightforward description [6]. Originating from the Terengganu state, it is also known as *keropok batang* and *keropok tongkol* in the Kelantan and Pahang states, respectively [7]. The love for this traditional delicacy among Malaysians, regardless of their race and ethnicity, is incredibly strong.

Keropok lekor crackers are made from a variety of fish species, including mackerel, purple-spotted bigeye, yellow goatfish, sardine, threadfin bream, and sea bass [8]. Besides minced fish, the main ingredients are tapioca starch, sugar, salt, crushed ice, sago flour, and an approved flavor enhancer [9]. The traditional way the ingredients are processed for *keropok lekor* differs from contemporary small or medium-scale backyard production.

Understanding the specific synergistic effects of protein-starch interaction in food systems is important to adjust texture and replace certain ingredients [10]. Namely, the gelatinization parameters of starch in blends upon heating vary depending on the presence of other ingredients, such as proteins [11–13]. The latter can inhibit the swelling of starch granules [14–16], thus altering the gelling properties of the final product [17]. Multiple studies have examined the gelling properties that occur when proteins and starch interact in food systems [18], as this interaction determines texture, stability, and mouthfeel [19]. Additionally, it affects thermal properties, especially in the case of fish protein [20–23]. The development and strength of the protein–starch system is influenced by temperature, ingredient concentration, and phase stability [24]. Uncontrolled heating of the protein–starch system can lead to unpredictable changes in gel structure and rheological properties [25], potentially disrupting the overall structure and texture of the system.

This study was performed in the Selangor state (Malaysia) and aimed to investigate the rheological, textural, and sensory properties of *keropok lekor* as a model fish protein–starch system.

1. Material and Methods

1.1. Experimental design. A two-level full factorial experimental design was employed to assess the effect of three independent variables—minced fish (MF), sago starch (SS), and water (W)—on the onset (T_0) and peak (T_p) temperatures of gelatinization, as well as storage (G') and loss (G'') modulus in *keropok lekor*. Texture profile analysis (TPA) and sensory evaluation of the samples were carried out. All statistics (see Table 1) were conducted using Minitab 17 software (Minitab Inc., PA, USA).

1.2. Preparation of *keropok lekor*. *Keropok lekor* samples were prepared as described by Kyaw [26]. First, fish flesh was transferred into a silent cutter (Kinn Shang Hoo Iron Works, Taiwan) and processed for 3 min. Then, crushed ice was added, followed by sago starch. The mixture was blended for 20 min until a dough-like consistency was achieved. Finally, the fish "dough" was pumped into cellulose casings using a sausage stuffer (F. Dick Company, Germany).

1.3. Gelling properties. The dynamic rheological properties of the *keropok lekor* formulations were analyzed by a temperature sweep from 30 to 90 °C for 5 min. Rheological measurements were performed as outlined by Ould Eleya et al. [27], on a RotoVisco RT-20 controlled-strain rheometer (Hakke Inc., Germany) with cone-plate geometry (diameter 35 mm, cone angle 2°). The gel of each *keropok lekor* sample was loaded into the 0.5 mm gap between an upper cone and a lower flat plate. Kerosene oil was applied onto the samples to create a thin film and prevent evaporation during the measurements. The samples were scanned from 30–90 °C at a rate of 12 °C · min^{-1} and held at the final temperature for 5 min. The temperature was maintained by a Peltier heat pump (DS 50, Haake Inc., Germany) situated on the bottom plate of the rheometer. The cooling process from 90 to 30 °C occurred at the same rate as the heating. The measurements were carried out in three repetitions, and the mean values were used for subsequent statistical analysis.

Table 1.

Formulation matrix of keropok lekor according to central composite design (CCD)

Treatment runs	Blocks	Minced fish	Sago starch	Water
1	1	20	10	10
2	1	50	40	10
3	1	50	10	35
4	1	20	40	35
5 (C)	1	35	25	22.5
6 (C)	1	35	25	22.5
7	2	50	10	10
8	2	20	40	10
9	2	20	10	35
10	2	50	40	35
11 (C)	2	35	25	22.5
12 (C)	2	35	25	22.5
13	3	20	25	22.5
14	3	50	25	22.5
15	3	35	10	22.5
16	3	35	40	22.5
17	3	35	25	10
18	3	35	25	35
19 (C)	3	35	25	22.5
20 (C)	3	35	25	22.5

C = central points

1.4. Texture profile analysis. The gels were cut into 20 × 20 mm (diameter × length) cylindrical pieces and tested, according to the method of Martinez et al. [28], on a TA-XT2 texture analyzer (Stable Micro Systems, UK) equipped with a cylindrical probe (P/50, diameter 50 mm) connected to a 25 kg load cell. The obtained samples were compressed twice using the probe with the test speed of 2.0 mm/sec, following the standard TPA procedure. The data were collected with the help of Texture Expert 1.17 software (Stable Micro Systems, UK). The parameters calculated were hardness (N)—the maximum force needed to compress the sample, fracturability (N/cm^2)—the force during initial compression at which the material fractures, springiness (m)—the ability of the sample to recover its original shape after the deforming force has been removed, cohesive force—the extent to which the sample could be deformed prior to rupture, and chewing force (N/cm)—the force required to chew the solid sample to a uniform swallowing state.

1.5. Sensory evaluation. The stuffed casings (20 mm) were steamed for 15 min. The resulting gels were then immediately immersed in iced water to prevent shrinkage and to ease separation of the casings. The steamed *keropok lekor* sausages, each 2.5 cm long, from all the formulations were deep-fried in oil for 5 min using a fryer (model DF 30 A 1 T, Japan) adjusted to 180 ^{o}C. The cooked samples were labeled with arbitrary three-digit codes and presented to the panelists (30 students) in a random order under white fluorescent lights according to Ayo et al.'s modified method [29]. The sensory tests were carried out at the Sensory Laboratory, Faculty of Food Science and Technology, Universiti Putra Malaysia. The panelists were asked to rate the texture and overall acceptability of the *keropok lekor* samples on a nine-point scale (dislike extremely (1), neither like nor dislike (5), and like extremely (9)). In between each sample evaluation, the panelists rinsed the mouth with room-temperature water.

1.6. Statistical analysis. The experimental design matrix and ANOVA test were implemented in Minitab 17 software (Minitab Inc., PA, USA). The data were processed using the fish protein–sago starch formulations as the experimental units. The differences were assessed by Duncan's test at 95% confidence level.

2. Results and Discussion

2.1. Effect of protein–starch interaction on T_0 values. T_0 varied from 52.5 to 77.5 °C. Its dependence on the ratio of added minced fish, sago starch, and water is shown in Table 2 and Fig. 1, *a–c*.

Table 2.

Rheological properties of various *keropok lekor* formulations determined as the functions of independent (MF, SS, and W) and dependent (onset temperature of gelatinization (T_0), peak temperature of gelatinization (T_p), storage modulus (G') and loss modulus of gelatinization (G'')) variables measured by rheometer

Formulation	Blocks	Independent variables g (w/w)			Dependent variables			
		MF	SS	W	T_0 (°C)	T_p (°C)	G' (Pa)	G'' (Pa)
F1	1	20	10	10	52.5 ± 0.2^{a}	61.9 ± 0.5^{a}	2.95 ± 0.10^{b}	2.48 ± 0.01^{a}
F2	1	50	40	10	74.0 ± 0.3^{b}	86.0 ± 0.2^{b}	5.70 ± 0.01^{b}	4.48 ± 0.01^{b}
F3	1	50	10	35	74.0 ± 0.3^{b}	82.5 ± 0.1^{c}	4.50 ± 0.01^{c}	3.60 ± 0.34^{c}
F4	1	20	40	35	70.0 ± 0.3^{c}	85.0 ± 02^{d}	4.90 ± 0.01^{c}	4.30 ± 0.01^{b}
F5	1	35	25	22.5	75.0 ± 0.2^{b}	86.0 ± 0.2^{b}	3.90 ± 0.02^{d}	4.00 ± 0.03^{b}
F6	1	35	25	22.5	77.5 ± 0.2^{d}	85.0 ± 0.3^{d}	4.78 ± 0.02^{c}	2.70 ± 0.02^{a}
F7	2	50	10	10	72.0 ± 0.3^{e}	84.0 ± 0.4^{e}	4.60 ± 0.03^{c}	4.00 ± 0.06^{b}
F8	2	20	40	10	67.5 ± 0.2^{f}	82.9 ± 0.1^{c}	4.85 ± 0.02^{c}	4.30 ± 0.56^{b}
F9	2	20	10	35	70.5 ± 0.6^{c}	83.0 ± 0.4^{b}	4.30 ± 0.02^{c}	4.00 ± 0.04^{b}
F10	2	50	40	35	59.5 ± 0.4^{b}	66.0 ± 0.3^{f}	3.78 ± 0.02^{d}	2.85 ± 0.01^{a}
F11	2	35	25	22.5	76.0 ± 0.3^{b}	87.0 ± 0.3^{g}	3.78 ± 0.01^{d}	4.48 ± 0.01^{b}
F12	2	35	25	22.5	76.0 ± 0.4^{b}	86.0 ± 0.3^{b}	3.70 ± 0.03^{d}	3.00 ± 0.02^{c}
F13	3	20	25	22.5	70.0 ± 0.5^{c}	85.0 ± 0.3^{d}	4.48 ± 0.01^{c}	4.31 ± 0.01^{b}
F14	3	50	25	22.5	74.0 ± 0.4^{b}	82.0 ± 0.5^{c}	4.85 ± 0.01^{c}	3.30 ± 0.02^{c}
F15	3	35	10	22.5	70.0 ± 0.4^{c}	88.5 ± 0.1^{h}	3.48 ± 0.02^{d}	2.95 ± 0.01^{a}
F16	3	35	40	22.5	$55.5 \pm 0 .2^{b}$	63.0 ± 0.2^{i}	5.30 ± 0.02^{b}	4.48 ± 0.01^{b}
F17	3	35	25	10	70.5 ± 0.2^{c}	86.0 ± 0.3^{b}	4.30 ± 0.03^{c}	4.00 ± 0.01^{b}
F18	3	35	25	35	58.5 ± 0.2^{g}	62.0 ± 0.4^{a}	3.60 ± 0.02^{d}	2.90 ± 0.03^{a}
F19	3	35	25	22.5	62.5 ± 0.2^{h}	82.7 ± 0.3^{c}	4.60 ± 0.03^{c}	3.42 ± 0.01^{c}
F20	3	35	25	22.5	70.3 ± 0.3^{c}	87.5 ± 0.4^{g}	4.61 ± 0.08^{c}	3.95 ± 0.02^{c}

MF: minced fish, SS: sago starch, W: water. Means with the same superscript within the column were not significantly different at $p < 0.5$

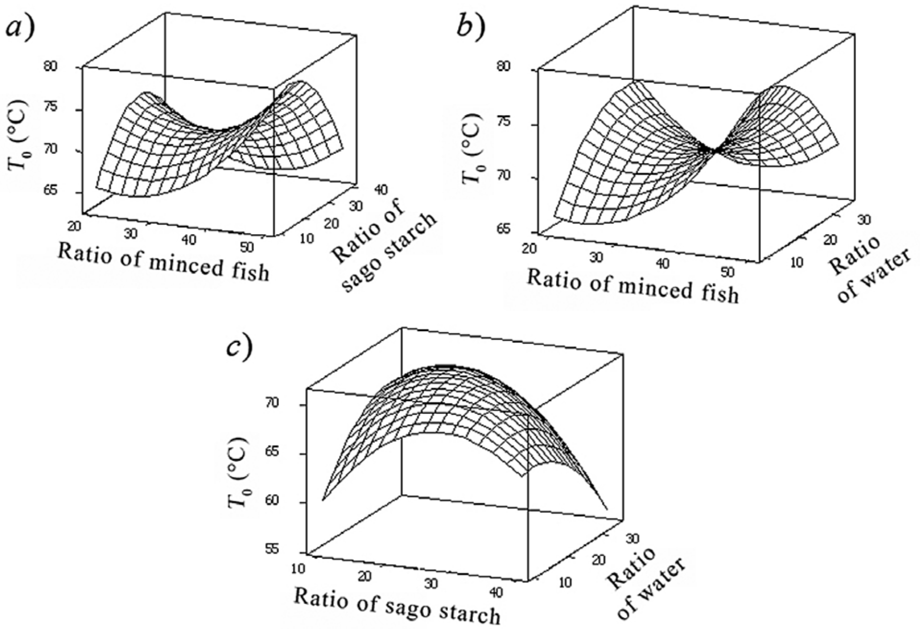

Fig. 1 Response surface plot for the onset temperature of gelatinization of the fish protein–sago starch system as a function of minced fish and sago starch ratios (*a*), minced fish and water ratios (*b*), and sago starch and water ratios (*c*) based on the rheometer measurements.

The lowest T_0 value was observed in the *keropok lekor* samples made with 20 : 10 : 10 minced fish, sago starch, and water, respectively. The highest T_0 value was obtained when these ingredients were mixed in the ratio of 35 : 25 : 22.5. In all the *keropok lekor* formulations, the gelatinization of the fish protein–sago starch system began at T_0 above 50 °C (52.5 °C). This finding fits well with the earlier studies by Kong et al. [30] on the interaction between the fish-meat gel with starch: proteins began to produce a gel when the temperature was higher than 50 °C, which might be due to the changes in the diameter of starch granules binding not only with water but also with fish protein. In Fig. 1, the surface plot demonstrates an upward trend in T_0 as the ratio of minced fish and water increase, while adding more sago starch leads to a decrease in the T_0 value (i.e., the system with the low ratio of water and sago starch had a lower value of T_0). According to Scott and Awika [31], proteins and starch can form complexes through physical interactions, potentially affecting the accessibility of water to starch granules and thus altering the gelatinization process. This interaction might either increase or decrease T_0, depending on the complex nature. Proteins can enclose starch granules [32] in a protective surface coating that determines the ability of water to penetrate starch granules and initiate gelatinization. Depending on the coating size, T_0 may either increase or fall. Therefore, the protein–starch interaction can be synergistic, enhancing the gelatinization properties, or antagonistic, potentially reducing T_0 values [33].

2.2. Effect of protein–starch interaction on T_p values. Table 2 shows that T_p values of the studied *keropok lekor* formulations, increased significantly, from 61.0 to 88.5 °C, depending on the MF : SS : W ratio. It was found that the structure and behavior of starch granules changed considerably during gelatinization. These findings are consistent with previous results. For instance, Aguilera and Rojas [34] studied whey protein–cassava starch gels and reported that starch granules intensively soaked up water while undergoing gelatinization, thereby swelling, and eventually solubilizing. Our data also suggest that a temperature rise of up to 65.5 °C caused starch granules to swell and adsorb heat, resulting in their deformation, disruption and melting, as in [35]. Some interesting observations concern proteins. In Kyaw's experiments on the protein–starch system of *keropok lekor* [26], the temperature of starch gelatinization shifted to a higher value when fish-meat paste was added. Mohamed and Rayas-Duarte [36] explored the effect of starch–protein interaction in hard red spring wheat on the peak temperature of the system and revealed that the peak temperature of starch gelatinization increased with the amount of protein extract added to the starch. In this study, the lowest T_p value was 61.5 °C in the MF : SS : W ratio of 20 : 10 : 10, which indicated a disruption/melting of sago starch granules, as in [37]. Additionally, the gels of most *keropok lekor* formulations had a T_p peak above 80°C, with the highest recorded value being 88.5 °C in the MF : SS : W ratio of 35 : 10 : 22.5.

The response surfaces for the obtained T_p values are shown in Fig. 2, *a–c* to aid visualization. The trend seen in T_0 was also pronounced in T_p, i.e., an increase in the ratios of minced fish and water led to a higher peak of gelatinization temperature.

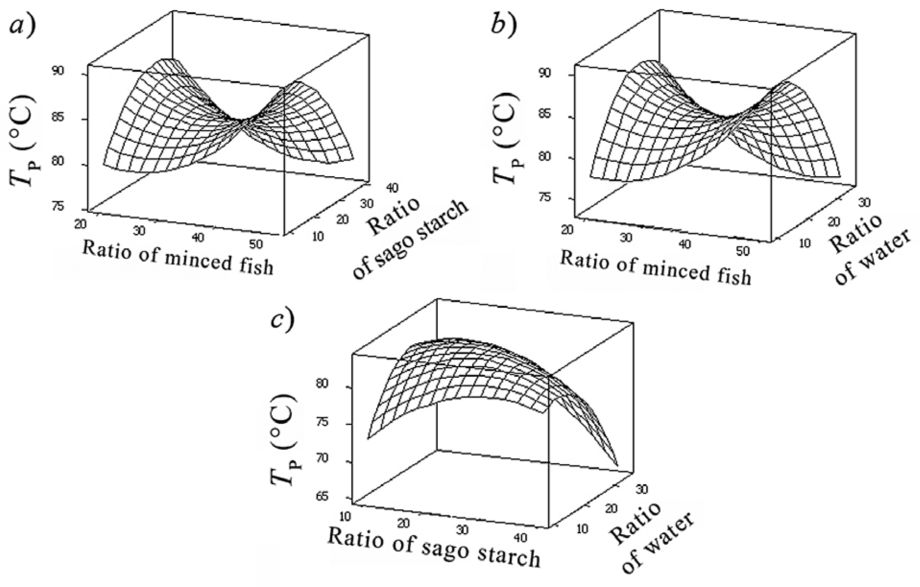

Fig. 2. Response surface plot for the peak temperature of gelatinization of the fish protein–sago starch system as a function of minced fish and sago starch ratios (*a*), minced fish and water ratios (*b*), and sago starch and water ratios (*c*) based on the rheometer measurements

Li [38] reported that the interaction between protein and starch can influence the peak temperature of gelatinization, which is the temperature at which the maximum swelling and viscosity occur during the gelatinization process. This parameter determines the texture, mouthfeel, and other functional properties of food products [39]. Bresciani et al. [40] noticed that the peak temperature of gelatinization may rise if protein–starch complexes are formed. Jia et al. [41] discovered that the presence of protein–starch complexes can alter the water absorption and swelling properties of starch granules, potentially leading to high values of peak temperature. However, when proteins coat the surface of starch granules, they can create a barrier that affects the penetration of water into them. According to Shao et al. [42], this coating may impact the kinetics of gelatinization, potentially influencing the peak temperature of the food system [42].

2.3. Effect of protein–starch interaction on storage modulus (*G′*) during gelatinization. The storage modulus (*G'*) is a measure of a material's elastic or solid-like behavior [43]. In the context of gelatinization, *G'* is commonly used in rheology to describe the stiffness or rigidity of a gel or gelatinized material [44]. As starch granules undergo gelatinization, they absorb water and swell, which ultimately leads to the formation of a gel network [45]. *G'* is a key rheological parameter that reflects the ability of the gel to store and recover energy under deformation [46]. A higher *G'* value indicates a more elastic or solid-like behavior, while a lower *G'* value suggests that the material is viscous or more likely to behave like a liquid [47].

Table 2 and Fig. 3, *a–c* show how different ratios of the ingredients used in *keropok lekor* affected the *G′* values in this study depending on the temperature variations. A gradual increase in the *G′* values was noted, indicating enhanced elasticity while the system was heated [48]. The storage modulus increased with the higher ratios of both minced fish and sago starch, but decreased as more water was added. This finding is consistent with that of Chen et al. [49]. The higher storage modulus suggested that the starch–protein interaction in *keropok lekor* led to the formation of a network structure during the gelation of the system by heating [50]. In the work by Hoti et al. [51], the storage modulus increased progressively with higher density of the cross-link system. However, in the HPMC enhanced horse mackerel surimi, the storage modulus increased with temperature and decreased with higher water content [52].

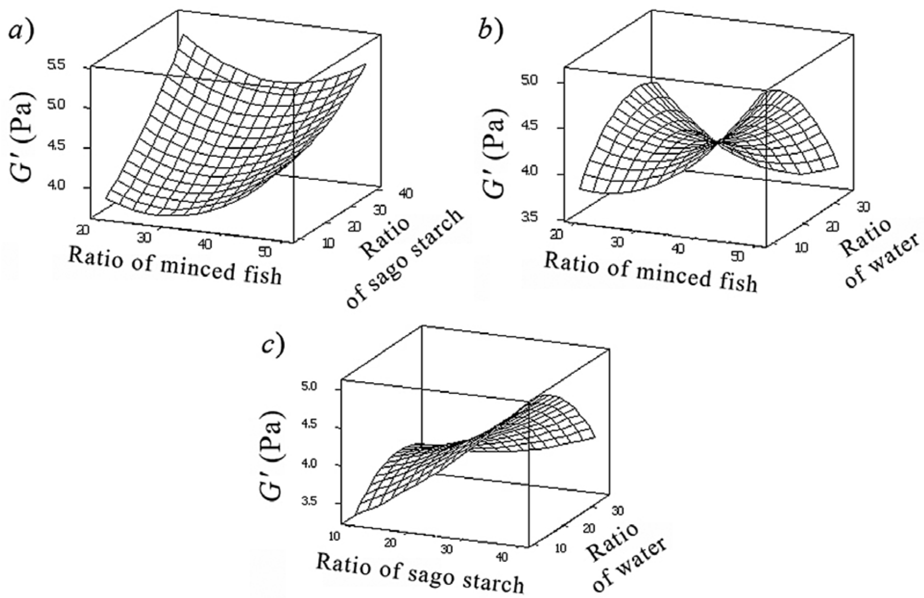

Fig. 3. Response surface plots for the storage modulus of the fish protein–sago starch system as a function of minced fish and sago starch ratios (*a*), minced fish and water ratios (*b*), and sago starch and water ratios (*c*) based on the rheometer measurements.

2.4. Effect of protein–starch interaction on loss modulus (*G″*) during gelatinization. The loss modulus, often denoted as *G″*, is a measure of the viscous or dissipative properties of a material in the context of rheology. Starch gelatinization entails the disruption of hydrogen bonds within the starch granules, allowing water molecules to penetrate and swell them. The loss modulus (*G″*) of the *keropok lekor* formulations is presented in Table 2 and Fig. 4, *a*–*c*: *G″* exhibited a pattern similar to *G′*. The system showed an initial increase in *G″* at 2.48 Pa and reached the maximum value of 4.48 Pa. The same trend was observed by Matou et al. [53] in their study of starch–meat composite, where the higher ratios of minced fish and water resulted in the lower modulus values of *keropok lekor*. Increasing the ratios of sago starch led to a significant rise in the loss modulus value ($p < 0.05$) (Fig. 4, *a*–*c*). Li and Yeh [54] studied the effect of high amylose and waxy corn starch, tapioca starch, potato starch, sweet potato starch, pea starch, mung bean starch, and rice starch on the rheological properties of starch–meat complexes. They claimed that the higher loss modulus was associated with the temperature sweep increase. The addition of 30% starch to meat in the starch–meat complex with 76 ± 0.5% adjusted water resulted in an increase in the loss modulus value for starch and starch–meat composite, and the starch–meat complexes yielded a high *G″*, which is associated with the gelatinization of starch. The maximum *G″* (5.3 kPa) was observed at 69.3 °C. In Kerry et al. [55], a similar increase in *G″* was found by adding modified potato starch in whey protein concentrate.

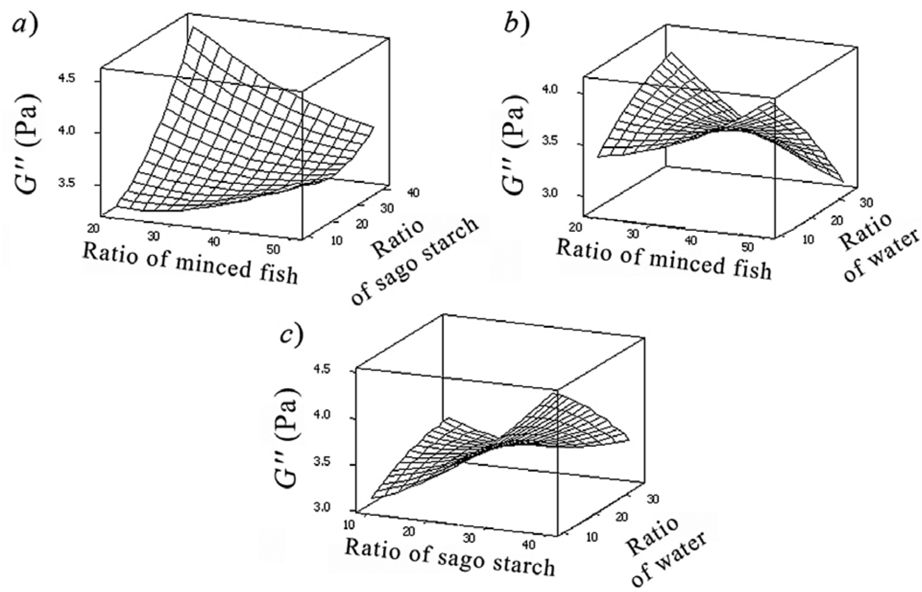

Fig. 4. Response surface plot for the loss modulus of the fish protein–sago starch system as a function of (a) minced fish and sago starch ratios, (b) minced fish and water ratios, and (c) sago starch and water ratios based on the rheometer measurements.

2.5. Texture profile analysis. The results of the texture profile analysis (TPA) for different *keropok lekor* formulations are shown in Table 3. The variations in the TPA values among them are associated with the differences in hardness, fracturability, springiness, cohesiveness, and chewiness.

Table 3

Texture profile analysis parameters of the fish protein–sago starch system formulated with different protein and starch ratios.

Formu-lation	MF:SS:W	Hardness (N)	Fracturability (N/cm^2)	Springiness (cm)	Cohesiveness (ration)	Chewiness (N/cm)
F1	20:10:10	30.0 ± 0.4^a	27.0 ± 0.1^a	0.72 ± 0.01^a	0.32 ± 0.02^a	5.0 ± 1.6^a
F2	50:40:10	50.9 ± 0.9^b	30.3 ± 0.6^b	0.75 ± 0.30^a	0.31 ± 0.03^a	11.6 ± 2.0^b
F3	50:10:35	30.1 ± 0.5^c	6.2 ± 0.1^c	0.79 ± 0.05^a	0.33 ± 0.01^a	5.5 ± 0.6^c
F4	20:40:35	35.4 ± 0.8^d	22.4 ± 0.4^d	0.76 ± 0.02^a	0.32 ± 0.02^a	8.0 ± 1.9^d
F5	35:25:22.5	36.4 ± 0.6^e	NA	0.85 ± 0.02^b	0.41 ± 0.01^b	8.1 ± 0.1^d
F6	35:25:22.5	32.1 ± 0.2^f	NA	0.80 ± 0.01^b	0.40 ± 0.01^b	6.3 ± 0.5^e
F7	50:10:10	33.7 ± 0.4^a	21.0 ± 0.8^e	0.66 ± 0.01^c	0.22 ± 0.02^c	4.8 ± 1.2^f
F8	20:40:10	35.7 ± 0.4^d	18.0 ± 0.3^f	0.67 ± 0.01^c	0.31 ± 0.04^a	6.5 ± 2.1^e
F9	20:10:35	33.2 ± 0.8^a	18.0 ± 0.7^f	0.67 ± 0.03^c	0.22 ± 0.01^c	5.3 ± 2.9^c
F10	50:40:35	43.0 ± 0.4^g	25.8 ± 0.2^g	0.68 ± 0.02^c	0.32 ± 0.03^a	7.6 ± 1.9^b
F11	35:25:22.5	36.3 ± 0.3^e	NA	0.82 ± 0.04^b	0.42 ± 0.02^b	7.7 ± 1.6^b
F12	35:25:22.5	33.9 ± 0.5^a	21.2 ± 0.8^e	0.64 ± 0.02^c	0.23 ± 0.02^c	5.2 ± 0.9^c
F13	20:25:22.5	30.3 ± 0.9^h	18.7 ± 0.1^f	0.74 ± 0.03^a	0.34 ± 0.03^a	7.6 ± 0.5^b
F14	50:25:22.5	30.2 ± 0.3^h	20.1 ± 0.1^e	0.66 ± 0.02^c	0.22 ± 0.01^c	6.1 ± 0.7^f
F15	35:10:22.5	32.8 ± 0.7^f	NA	0.76 ± 0.03^a	0.32 ± 0.01^a	5.3 ± 0.1^c
F16	35:40:22.5	45.0 ± 0.2^i	29.3 ± 0.6^a	0.68 ± 0.05^c	0.33 ± 0.04^a	9.2 ± 0.7^b
F17	35:25:10	33.3 ± 0.5^a	22.1 ± 0.5^d	0.68 ± 0.01^c	0.23 ± 0.01^c	5.0 ± 0.5^c
F18	35:25:35	38.1 ± 0.4^j	24.7 ± 0.3^g	0.64 ± 0.04^c	0.22 ± 0.03^c	5.6 ± 1.7^c
F19	35:25:22.5	34.0 ± 0.9^k	NA	0.77 ± 0.03^a	0.42 ± 0.04^b	6.7 ± 0.1^e
F20	35:25:22.5	36.0 ± 0.3^d	23.2 ± 0.8^h	0.64 ± 0.03^c	0.23 ± 0.04^c	5.4 ± 1.3^c

Means with the same superscript within the column were not significantly different at $p < 0.5$. Readings were means of triplicate measurements. NA: not available, N: Newton (kg·m/s^2), MF: minced fish, SS: sago starch, W: water

The *keropok lekor* samples with the MF : SS : W ratio of 5 : 4 : 1 had the highest hardness value (50.9 N). The second highest hardness value (45.0 N) was observed in the formulation with the MF : SS : W ratio of 3.5 : 4 : 2.25. This could be attributed to the higher proportion of minced fish, as in [3] where the *keropok lekor* texture strengthened as the fish content was increased from 30 to 70%. In Kyaw et al. [48], there was a notable rise in the hardness of *keropok lekor* (from 9.9 N to 15.4 N) when the fish content in the product was from 30 to 50%. Being rich in protein, fish boosts the hardness of food products by increasing their viscoelastisity. Another crucial point here is that the lowest hardness value (20.1 N) was recorded in the sample formulated with the MF : SS : W ratio of 5 : 1 : 3.5, followed by 22.1 N in another sample, which might be related to the low ratio of starch. In the work by Kyaw [26], the reinforcing effect of starch in the composite was not significant when the starch matrix contained too much fish protein (60–80 %), thereby leading to the disruption of the matrix continuity. Increasing the MF ratio enhanced the hardness of *keropok lekor*. Hardness is closely linked to cohesiveness, which refers to the strength of the internal bonds making up the body of the sample [56]. In this study, cohesiveness was positively correlated with the ratio of minced fish, but this relationship was not significant ($p > 0.05$). In most food systems, the adhesion force is a combination of adhesive and cohesive forces, and a food material is perceived as being sticky when its cohesive force is low [57]. The cohesiveness values in all the analyzed samples were not close to 1.0, which may indicate that increasing the minced fish and sago starch ratios in the system decreased the recovery of the samples after the first compression. This finding aligns with the study by Tabilo-Munizaga and Barbosa-Cánovas [58], in which the cohesiveness value in the texture profile of the samples was close to 1, indicate sample recovery after the first compression. Allais et al. [59] added starch to frankfurters and found that an increase in the starch content improved the hardness and chewiness, decreased the springiness, but had no significant effect on the cohesiveness values. Hughes et al. [60] revealed the higher gel strength in frankfurters formulated with added starch. As the starch granules within the protein gel matrix swell, they contribute to the formation of stronger heat-induced structures. Chen et al. [61] suggested that this phenomenon could increase the water-binding capacity of the gel matrix, resulting in a firmer, more compact structure after cooking.

2.6. Sensory evaluation. The scores given for the sensory attributes of the *keropok lekor* samples are given in Table 4.

Table 4.

Scores attributed to the texture and overall acceptability of the fish protein–sago starch system in the sensory evaluation.

Formulation	MF:SS:W	Taste	Texture	Color	Flavor	Overall acceptability
F1	20:10:10	5.4 ± 1.2^{b}	5.6 ± 1.2^{b}	5.4 ± 1.2^{b}	6.3 ± 0.8^{b}	6.6 ± 0.8^{b}
F2	50:40:10	4.8 ± 1.1^{a}	4.8 ± 1.1^{a}	4.8 ± 1.1^{a}	5.3 ± 1.2^{a}	5.3 ± 1.2^{a}
F3	50:10:35	4.8 ± 1.0^{a}	4.8 ± 1.0^{a}	4.8 ± 1.0^{a}	5.5 ± 1.1^{a}	5.5 ± 1.1^{a}
F4	20:40:35	3.9 ± 1.3^{c}	3.6 ± 1.3^{c}	4.3 ± 1.3^{c}	5.1 ± 1.1^{a}	5.1 ± 1.1^{a}
F5	35:25:22.5	5.4 ± 1.2^{b}	5.4 ± 1.2^{b}	5.5 ± 1.2^{b}	6.0 ± 0.7^{b}	6.0 ± 0.7^{b}
F6	35:25:22.5	4.7 ± 1.4^{a}	4.7 ± 1.4^{a}	4.7 ± 1.4^{a}	6.1 ± 0.9^{b}	6.1 ± 0.9^{b}
F7	50:10:10	5.3 ± 1.1^{b}	5.3 ± 1.1^{b}	5.3 ± 1.1^{b}	5.5 ± 0.9^{a}	5.5 ± 0.9^{a}
F8	20:40:10	5.0 ± 1.3^{b}	5.0 ± 1.3^{b}	5.0 ± 1.3^{b}	5.6 ± 1.0^{a}	5.6 ± 1.0^{a}
F9	20:10:35	4.8 ± 1.4^{a}	4.8 ± 1.4^{a}	4.8 ± 1.4^{a}	5.8 ± 0.9^{a}	5.8 ± 0.9^{a}
F10	50:40:35	5.3 ± 1.3^{b}	5.3 ± 1.3^{b}	5.3 ± 1.3^{b}	5.9 ± 0.8^{b}	5.9 ± 0.8^{b}
F11	35:25:22.5	4.7 ± 1.4^{a}	4.7 ± 1.4^{a}	4.7 ± 1.4^{a}	5.9 ± 0.9^{b}	5.9 ± 0.9^{b}
12	35:25:22.5	5.0 ± 1.2^{b}	5.0 ± 1.2^{b}	5.0 ± 1.2^{b}	6.0 ± 0.8^{b}	6.0 ± 0.8^{b}
F13	20:25:22.5	4.8 ± 1.1^{a}	4.8 ± 1.1^{a}	4.8 ± 1.1^{a}	5.5 ± 1.1^{a}	5.5 ± 1.1^{a}
F14	50:25:22.5	4.8 ± 1.5^{a}	4.8 ± 1.5^{a}	4.8 ± 1.5^{a}	4.9 ± 1.0^{c}	5.2 ± 1.0^{c}
F15	35:10:22.5	5.2 ± 1.1^{b}	5.2 ± 1.1^{b}	5.2 ± 1.1^{b}	5.8 ± 0.9^{a}	5.8 ± 0.9^{a}
F16	35:40:22.5	4.9 ± 1.5^{a}	4.9 ± 1.5^{a}	4.9 ± 1.5^{a}	5.6 ± 1.2^{a}	5.6 ± 1.2^{a}
F17	35:25:10	5.2 ± 1.1^{b}	5.2 ± 1.1^{b}	5.2 ± 1.1^{b}	5.8 ± 0.9^{a}	5.8 ± 0.9^{a}
F18	35:25:35	5.3 ± 1.5^{b}	5.3 ± 1.5^{b}	5.3 ± 1.5^{b}	5.6 ± 1.0^{a}	5.6 ± 1.0^{a}
F19	35:25:22.5	5.0 ± 1.5^{b}	5.0 ± 1.5^{b}	5.0 ± 1.5^{b}	6.2 ± 0.8^{b}	6.4 ± 0.8^{b}
F20	35:25:22.5	5.2 ± 0.9^{b}	5.2 ± 0.9^{b}	5.2 ± 0.9^{b}	6.2 ± 0.8^{b}	6.2 ± 0.8^{b}

Different superscript letters within the columns are significant differences ($p < 0.05$). MF: minced fish, SS: sago starch, W: water

Their values were statistically different ($p < 0.05$) and ranged as follows: 3.9–5.4 for taste; 3.6–5.6 for texture; 4.3–5.4 for color; 4.9–6.5 for flavor, and 5.2–6.6 for overall acceptability. The sample formulated with the MF : SS : W ratio of 20 : 10 : 10 received the highest scores across all attributes. The lowest score for the texture attribute was obtained in the sample formulated with the MF : SS : W ratio of 20 : 40 : 35, mainly because of the excess starch content (twice as much as the fish ratio) causing the texture to turn firmer after frying. Local producers add more starch while making *keropok lekor* to maximize their profits. The panelists generally preferred the formulations with the MF : SS ratios of 20 : 10 and 35 : 25. According to Kyaw [26], *keropok lekor* crackers should contain 60% minced fish, 30% sago starch, and 10% tapioca starch.

Conclusions

The rheological, textural, and sensory properties of *keropok lekor* can be improved by adjusting the amounts of its key ingredients—fish protein, sago starch, and water. Among the formulations tested, the one with the MF : SS : W ratio of 20 : 10 : 10 was marked by the lowest onset and peak temperatures of gelatinization, as well as the lowest values of hardness and chewiness. With the highest scores in overall acceptability, this particular formulation was identified as the optimal and preferred choice for *keropok lekor*.

Institutional Review Board Statement. The study was conducted in accordance with the Declaration of Helsinki (2000).

Informed Consent Statement. Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest. The authors declare no conflicts of interest.

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ОРИГИНАЛЬНАЯ СТАТЬЯ

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Взаимодействие белка и крахмала в рыбных крекерах *керопок лекор* и его влияние на их реологические, текстурные и органолептические свойства

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Аннотация

В статье рассматриваются особенности взаимодействия белка и крахмала и его влияние на гелеобразующие, текстурные и органолептические свойства системы рыбный белок – крахмал на примере традиционного малазийского блюда *керопок лекор*. Методом двухфакторного анализа изучены рецептурные составы крекеров *керопок лекор* с различным соотношением рыбного фарша (MF, 20–50 г от общей массы), крахмала саго (SS, 10–40 г от общей массы) и воды (W, 10–35 г от общей массы). Рассчитаны их начальная (T_0) и пиковая (T_p) температуры желатинизации, динамический модуль упругости (G'), а также модуль потерь упругости при желатинизации (G''). Органолептические и текстурные свойства образцов оценивали в ходе дегустации с привлечением 30 респондентов. Наивысшую оценку получили образцы, в которых соотношение рыбного фарша, крахмала саго и воды составило 20 : 10 : 10. По результатам проведенного исследования именно этот вариант рецептуры был выбран в качестве наиболее оптимального для приготовления *керопок лекор*.

Ключевые слова: *керопок лекор*, рыбный крекер, крахмал саго, взаимодействие белка и крахмала, желатинизация, модуль упругости, органолептическая оценка

Заключение Комитета по этике. Исследование проведено в соответствии с Хельсинкской декларацией 2000 г.

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