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Impact of curdlan on quality and sensory attributes of canned dodol made from glutinous rice flour

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Abstract

The effects of curdlan concentrations (0, 3, 5, and 7%) on the physical, textural, and sensorial properties of canned dodol (Candol) were investigated. The incorporation of curdlan in canned dodol significantly influenced several attributes of the product, including pH, total soluble solids (TSS), water activity (a_w), moisture content, colour, texture, and microstructure. Curdlan decreased the pH level and increased the TSS level, while decreasing the moisture content and a_w in certain samples. It also impacted the texture of dodol, with one sample (Candol-5) showing a texture similar to commercially available dodol. Additionally, microstructural differences were observed, with Candol-5 exhibiting the smallest pores and a more compact gel structure. Sensory panellists preferred the texture of Candol-5 over Candol-0, and its sensory rating was more similar to that of the commercial dodol, with no significant differences observed. In summary, curdlan could be a beneficial ingredient for improving the quality and acceptability of canned dodol, offering valuable insights for the development of innovative dodol products in the future.

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Introduction

Dodol is a traditional toffee-like confectionery made from coconut milk, glutinous rice flour, table sugar, and palm sugar. Dodol is very popular in Asian countries including Malaysia, Indonesia, the Philippines, Singapore, India, and Sri Lanka (Muhialdin *et al*., 2021). Dodol, a rice-based delicacy, should have a firm texture that does not stick to fingertips, and its textural properties are the primary quality attributes that significantly affect consumer acceptance of the product (Seow *et al*., 2021). Glutinous rice flour, consisting primarily of waxy starch, contributes largely to the elastic and chewy texture of dodol owing to its relatively high amylopectin content (98 - 99%) and low amylose content (Karim and Bhat, 2013; Qiu *et al*., 2018).

Dodol production involves gelatinising starch at temperatures between 57 and 65°C. Dodol has a pH of 5 - 6 and contains approximately 38 g of starch per 100 g. These conditions make dodol susceptible to bacterial and fungal contamination (Muhialdin *et al*., 2021). Typically, dodol is produced in large quantities and it takes approximately 7 - 8 h for the initial liquid batter to become a sticky, dark brown, viscoelastic mass (Seow *et al*., 2021). Preparing traditional dodol requires significant time, energy, and fresh ingredients, and it is exhausting. Furthermore, effort, expertise, and proper techniques are needed to produce the ideal texture and flavour of dodol (Ismail *et al*., 2021). The drawback of commercial dodols is that they are preserved using chemical preservatives. Modern small and medium industries have employed automated equipment in the

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preparation dodol, significantly affecting the preparation time, efficiency, cooking approach, and aroma of dodol. However, the dodol mixture still needs to be stirred continuously throughout the cooking process (Ismail *et al*., 2021).

The potential for enhancing the dodol industry has been identified through the application of thermally resilient hydrocolloids. Curdlan, a water-insoluble polysaccharide produced primarily by soil microorganisms, has been widely utilised in pharmaceuticals, food packaging, biofilms, and the dairy industry due to its high thermal stability, excellent film-forming properties, water insolubility, and biodegradability (Chen *et al*., 2023). It has been approved for use in the food industry by the FDA (Al-Rmedh *et al*., 2023). It forms two gels based on their thermal properties: low-set and high-set gels. In a thermally irreversible process, an aqueous solution of curdlan forms a high-set gel at temperatures greater than 80°C, in which a triple-stranded helix cross-links curdlan micelles *via* hydrophobic interactions (Chaudhari *et al*., 2021).

Canning process involves heating food at a specific temperature, for a specific length of time, within a hermetically sealed container (*e.g*., cans, jars, or soft packages), at a specific pressure, based on the type of food being processed (*e.g*., high or low acid). Heating ensures that microorganisms (*e.g*., *Clostridium botulinum*) and enzymes are killed and inactivated to maintain the sensory quality of canned foods, and ensure their microbiological safety (Zheng *et al*., 2023).

Canned dodol without food preservatives is prepared in the present work to provide a prolonged shelf life alternative while improving the overall sensory experience of canned dodol. This method involved three heating stages: pre-cooking and steaming to trigger essential reactions, followed by retort cooking in hermetically sealed metal cans at 121°C for 15 min. This modification was expected to reduce the production period to approximately 2 - 3 h. Additionally, curdlan, a natural polysaccharide with structure- and texture-modifying properties, would enhance the firmness and elasticity of the dodol. The present work aimed to investigate the effects of curdlan on the physical, textural, and sensorial properties of canned dodol.

Materials and methods

Materials

The essential ingredients of dodol, which are glutinous rice flour (GRF) (Cap Teratai®, Thailand), blended rice flour (Erawan Brand, Bangkok, Thailand), coconut milk (Ayamas Brand, Shah Alam, Malaysia), and palm sugar, were purchased from Home Mart Fresh and Frozen Sdn. Bhd. (Alor Setar, Malaysia). Curdlan was purchased from Gino Gums and Stabilizer (Gino Biotech, Zhengzhou, China). Metal cans of 7.5 × 12 cm (diameter × height) were purchased from Aik Joo Can Factory Sdn. Bhd. (Seberang Perai, Malaysia). Commercial dodol, Dodol Pak Ngah (Warisan Mek Dee Enterprise, Seberang Perai, Malaysia), used as a reference for sensory evaluation and physical analysis, was purchased from local suppliers in Chowrasta Market, Georgetown, Malaysia. Other chemicals used in the present work (analytical grade) were purchased from Sigma-Aldrich (Massachusetts, United States).

Preparation of canned dodol

Formulation of dodol was prepared according to Seow *et al*. (2021) with modifications. Canned dodol with four different concentrations of curdlan, 0 (Candol-0), 3 (Candol-3), 5 (Candol-5), and 7% (Candol-7), were used (Table 1). To prepare 800 g of dodol, 300 g of palm sugar was chopped into small pieces, and dissolved in 330 g of heated coconut milk in a cooking vessel to form a sugar mixture. The sugar mixture was strained using a sieve. Meanwhile, 146 g

Table 1. Formulations of canned dodol samples.

Sample	Ingredient (g)					
	Glutinous rice flour	Blended rice flour	Coconut milk	Palm sugar	Water	Curdlan
Candol-0	146	24	330	300	200	0
Candol-3	146	24	330	300	200	24
Candol-5	146	24	330	300	200	40
Candol-7	146	24	330	300	200	56

Candol-0: canned dodol with 0% curdlan; Candol-3: canned dodol with 3% curdlan; Candol-5: canned dodol with 5% curdlan; and Candol-7: canned dodol with 7% curdlan.

of glutinous rice flour and 24 g of rice flour were dispersed in 200 g of water to form a batter. The batter was then preheated to 40°C, and stirred continuously for 2 min to initiate starch gelatinisation. Subsequently, the sugar mixture was added, and stirring continued for another 40 min at a temperature of 65 - 70°C. Curdlan (3, 5, or 7% per basic ingredient weight basis, excluding water) was added to the dodol mixture, and then strained using a sieve. Subsequently, the cans and headspace of 10 mm were filled with the mixture. The filled cans were then exhausted by steaming for 30 min. Exhausting was considered complete when the temperature at the centre of the cans reached approximately 75°C. After exhausting, the cans were immediately sealed and subjected to thermal processing at 121°C for a holding time of 15 min in the autoclave (HICLAVE HVE-50, Hirayama Manufacturing Corporation, Tokyo, Japan). Finally, the cans were cooled immediately in cold water. The entire processing duration of the canned dodol was approximately 145 min. The canned dodol samples were pre-shaped by placing them into cylindrical containers (diameter 4.5 cm, height 1.5 cm) before their images were taken by Samsung 108 MP ISOCELL HM3 attached to a Samsung S21 Ultra SM-G998U.

Determination of pH

A homogenous sample solution was prepared using a blender by blending 10 g of the sample in 50 mL of distilled water. Standard pH 4.01, 7.00, and 9.21 buffer solutions were used to calibrate the Mettler-Toledo Delta 320 pH meter (Columbus, United States) before measuring the sample (Chuah *et al*., 2007). Three replications were made for each sample.

Determination of total soluble solid

The total soluble solids of the samples were measured using a Master-93H Refractometer (45.0 - 93.0%) (Atago Co., Ltd., Tokyo, Japan) at ambient temperature. The instrument was calibrated using distilled water before the samples were measured. Three replications were made for each sample.

Determination of water activity (a_w)

The sample was filled into the cylindrical sample dish up to two-thirds, and it was then subjected to an a_w meter (AquaLab Series 3TE, Decagon Devices, Washington, USA). Three replications were made for each sample (Nasaruddin *et al*., 2012).

Determination of moisture content

The oven (Memmert UL40, Berlin, Germany) was pre-set to 105°C before 5 g of homogeneous dodol samples in the Petri dishes were dried until a constant weight was obtained. The dried samples with Petri dishes were cooled in the desiccator for a minimum of 30 min after being removed from the oven before weighing (Nasaruddin *et al*., 2012). Three replications were made for each sample. The moisture content was determined using Eq. 1:

$$\text{Moisture Content (\%)} = \frac{(\text{Weight of wet sample} - \text{Weight of dry sample})}{\text{Weight of wet sample}} \times 100 \qquad \text{(Eq. 1)}$$

Determination of colour

Canned and commercial dodol samples were shaped before colour analysis. They were filled into cylindrical containers (diameter 4.5 cm, height 1.5 cm). The colour of the dodol was determined using a Konica Minolta CM-5 spectrophotometer (Minolta Co., Ltd., Osaka, Japan) with the SpectraMagic NX software. Measurements were performed in triplicate for each sample in reflectance mode with a 10° observer angle using a D65 illuminant and a Ø8 mm target mask. The instrument was first calibrated using a zero-calibration box (CM-A124) and then a white calibration plate (CM-A210). The results obtained followed the CIE L*, a*, and b* colour space, where L* represents lightness, a* indicates red (+) or green (-), whereas b* denotes yellow (+) or blue (-) (Muhialdin *et al*. 2021).

Texture profile analysis (TPA)

Texture profile analysis (TPA) was conducted using the TA-TXPlus texture analyser (Stable Microsystems, Surrey, London, England) with a 5 kg load cell and cylindrical probe of P/20 (Seow *et al.*, 2021). The samples were pre-shaped before analysis by filling cylindrical containers (diameter 4.5 cm, height 1.5 cm) with dodol. Calibration of the probe force and height was performed before the measurement. The target mode of the instrument was set to strain, and a 75% strain was used in the analysis. The other settings, including the pre-test, test, and post-test speeds, were 1.00, 5.00, and 5.00 mm/s, respectively, whereas the trigger force was 5.0 g. The textural parameters of dodol, including hardness, adhesiveness, springiness, cohesiveness, gumminess, and resilience, were measured in ten replications.

Microstructure analysis

The microstructure of the dodol was inspected using a scanning electron microscope (SEM) (Quanta 650 FEG SEM equipped with xT microscope control software, FEI Technologies Inc., Hillsboro, United States) (Seow *et al*., 2021). Three dodol samples, Candol-0, Candol-5, and commercial dodol (used as a reference), were dried in a vacuum oven. They were diced into 1 × 1 × 0.5 cm, and taped on the SEM specimen stub. The samples were coated with gold-palladium in a vacuum using a sputter coater before being examined with a scanning electron microscope (SEM) under 300× and 1,000× magnifications with an accelerating voltage of 20 kV.

Sensory evaluation

Approval was obtained from the Human Research Ethics Committee of USM (JEPeM) (study protocol code: USM/JEPeM/22060390). All participants were provided written informed consent.

Sensory analysis was conducted using a 7-point hedonic test method to measure the level of liking towards five sensory attributes of dodol, including appearance, colour, aroma, texture, and overall acceptability (Seow *et al*., 2021). The sensory panellists consisted of 50 food science undergraduate and postgraduate students from the Food Technology Division, USM who had taken a sensory science course, and passed the screening questionnaire. Candol-0, Candol-5, and commercial dodol (used as a reference) were shaped using a circle ring mould (2.4 cm diameter and 2 cm height), and served on each paper plate labelled with a three-digit random number based on the master sheet. Subsequently, the samples were arranged on a tray, and served to the panellists with a cup of plain water, an empty cup, tissue paper, a pen, and a set of evaluation forms.

Statistical analysis

In this study, all analysis were repeated three times. Results were reported as mean ± standard deviation. Data were analysed using IBM SPSS software version 27 for Windows ($p < 0.05$) (IBM Corp., New York, USA) by performing the one-way analysis of variance followed by Tukey's test except for sensory evaluation. The data obtained from the sensory evaluation were analysed using the Independent Samples T-Test through IBM SPSS software version 27 for Windows ($p < 0.05$) (IBM Corp., New York, USA).

Results and discussion

pH

The pH values of the canned and commercial dodols are illustrated in Figure 1a. Palm sugar, a key ingredient in canned dodol, contributed to acidity due to its low pH. As the curdlan concentration increased, the pH of canned dodol decreased. Candol-7, which had the highest curdlan concentration, showed a significant ($p < 0.05$) lower pH compared to all other dodols. The pH of a curdlan solution, as provided by the manufacturer, ranged from 6 to 7.5, indicating mild acidity to near neutrality. This implied that the mild acidity of curdlan influenced the acidity profile of dodol when used as an ingredient.

Furthermore, preliminary studies have demonstrated a consistent decrease in the pH of curdlan solutions with increasing concentrations of curdlan. This indicated that increased concentrations of curdlan significantly lowered the pH of canned dodol, as evidenced by Candol-7, which had the lowest pH. The pH of cannel dodols added with curdlan were aligned with the pH range of traditional dodol, which is typically reported to be between 5 and 6 (Chuah *et al*., 2007; Nasaruddin *et al*., 2012). However, the pH of the commercial dodol in the present work appeared to be slightly above this range. The various ageing durations of dodol, with the possibility of degradation due to microbial activity, could have affected the pH levels (Muhialdin *et al*., 2021).

Total soluble solid (TSS)

Total soluble solid (TSS) measures solid content that can be dissolved in a liquid. TSS primarily comprises sugar, a small amount of soluble proteins, amino acids, and other organic components (Kusumiyati *et al*., 2020). The TSS of canned dodol and commercial dodol are shown in Figure 1b.

The TSS of commercial dodol was higher than all the canned dodol. The three canned dodols with curdlan concentrations ranging from 3 to 7% exhibited significantly higher TSS levels ($p < 0.05$) than Candol-0. Curdlan, consisting of glucose monomers linked by glycosidic bonds, could undergo

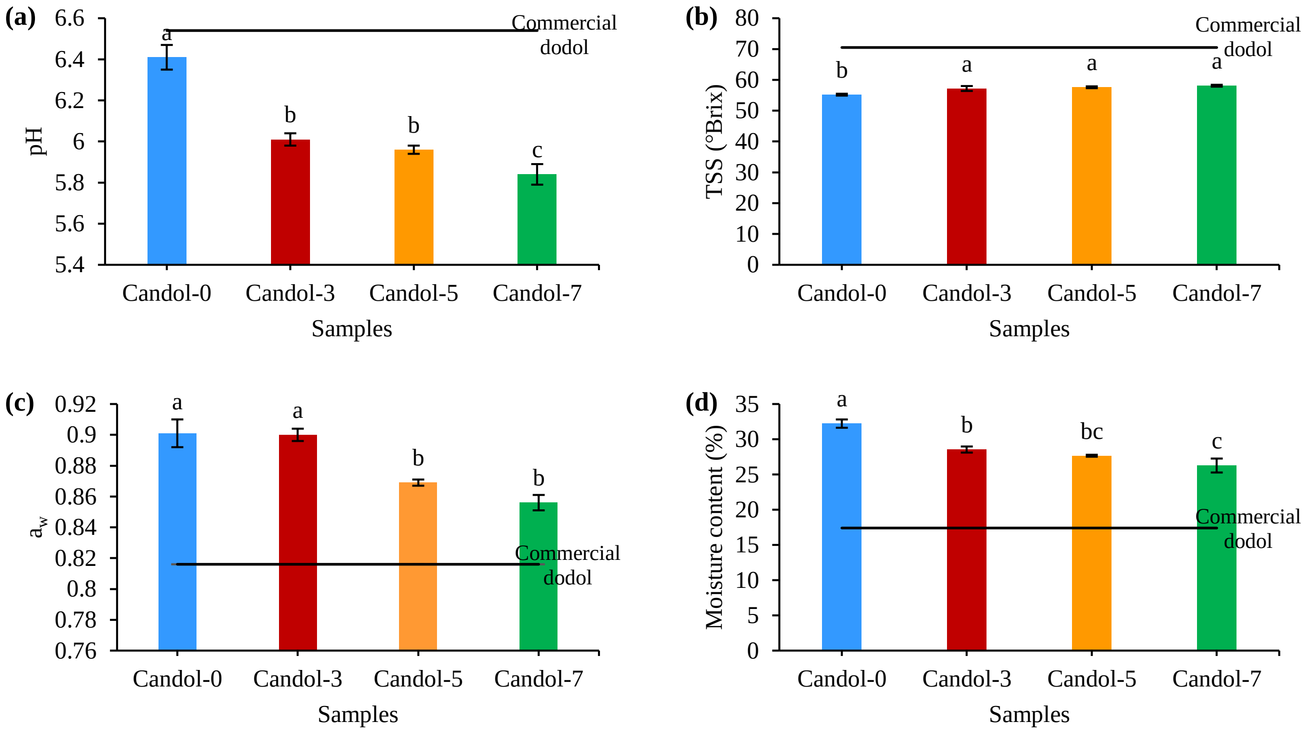

Figure 1. Physical properties of dodol samples. **(a)** pH, **(b)** TSS, **(c)** water activity (a_w), and **(d)** moisture content of dodol samples. Error bars indicate standard deviations of triplicate ($n = 3$). Different lowercase letters indicate significant differences ($p < 0.05$) between samples. Commercial dodol was used as a reference, and not included in the statistic. Candol-0: canned dodol with 0% curdlan; Candol-3: canned dodol with 3% curdlan; Candol-5: canned dodol with 5% curdlan; and Candol-7: canned dodol with 7% curdlan.

hydrolysis at elevated temperatures in water (Qiu *et al*., 2018). Consequently, curdlan hydrolysis may result in the formation of soluble oligosaccharides or subunits, which could slightly increase the TSS content. Furthermore, the increase in TSS might be attributed to the formation of a thermoreversible hydrogel by curdlan, which effectively encapsulated the soluble ingredients in dodol. Gel strength was positively correlated with curdlan concentration (Chen *et al*., 2016). Incorporating curdlan into the noodle dough inhibited the leaching of soluble ingredients (Xin *et al*. 2018). However, there was no significant difference ($p > 0.05$) among the canned dodol containing curdlan concentrations ranging from 3 to 7%.

The variety of formulations used in commercial dodol could increase the content of various sugars, resulting in higher levels of soluble monosaccharides like glucose, sucrose, and fructose. The processing method used in the present work for canned dodol was insufficient to achieve a TSS level similar to commercial dodol, primarily due to its relatively shorter pre-cooking duration, which may have resulted in lower levels of soluble solids.

Water activity (a_w)

The a_w of canned dodols ranged from 0.856 to 0.901 (Figure 1c). The growth of most of bacteria could be inhibited, as the minimum a_w required for survival is above 0.91 (Tapia *et al*., 2020). Despite inhibiting bacterial growth, canned dodol remains susceptible to the growth of yeasts and moulds, which can proliferate at lower a_w values starting from 0.60, indicating a potential risk of spoilage. Therefore, preservatives are commonly added to most commercial dodol products to lower their water activity and prolong their shelf life (Amrulloh and Umami, 2018). Canned dodol, produced from retort cooking, and sealed in hermetically sealed metal cans, could offer the advantage of extended shelf life without adding preservatives. Candol-5 and Candol-7 exhibited significantly ($p < 0.05$) lower a_w values than the other samples, indicating that curdlan formed a gel network with dodol ingredients, and demonstrated remarkable water-binding properties. This property tightly binds free water, leading to a decrease in a_w. This result corroborated a previous study, which the addition of curdlan in a myosin gel model resulted in a significant decrease in free water, from 5.66 to 1.89% (Li *et al*., 2019). Commercial dodol produced from longer cooking duration exhibited the lowest a_w within the typical range of traditional dodol, which falls between 0.65 - 0.90 (Nurhayati *et al*., 2019).

Moisture content

The moisture content of dodol is closely related to its textural quality. Generally, dodol has a moisture content of 10 - 40% (Nurhayati *et al*., 2019). The moisture content of canned dodol was 26.27 to 32.22% (Figure 1d). As the curdlan concentration increased, the moisture content of the canned dodol decreased. Candol-7 exhibited a significantly (p < 0.05) lower moisture content than the other samples. The decreased moisture content in Candol-7 and other samples might be attributed to curdlan's remarkable ability to absorb moisture, up to 100 times its weight, during heating in water (Nakao *et al*., 1991). To the best of our knowledge, there are no studies that have directly investigated the correlation between curdlan concentration and moisture content in food products. According to Li *et al*. (2019), the pork-curdlan mixed gel's water-holding capacity (WHC) showed improvement, which may be attributed to the development of a stable and strong gel structure that can capture substantial amounts of water.

Furthermore, when the curdlan concentration increased from 0 to 4%, the WHC of fish muscle-curdlan gels demonstrated a significant (p < 0.05) increase (Hu *et al*., 2015). Indeed, the results obtained in the present work were contrary to previous findings because WHC is usually positively associated with the moisture content of food products. Commercial dodol had the lowest moisture content, likely because it was produced from hours of simmering, which allowed the gradual evaporation of moisture into the surrounding environment.

Colour analysis

Figure 2 presents the result of colour analysis conducted on canned and commercial dodols. Generally, dodol appears to be dark caramel brown or black due to the induction of browning reactions, namely, the Maillard reaction and sugar

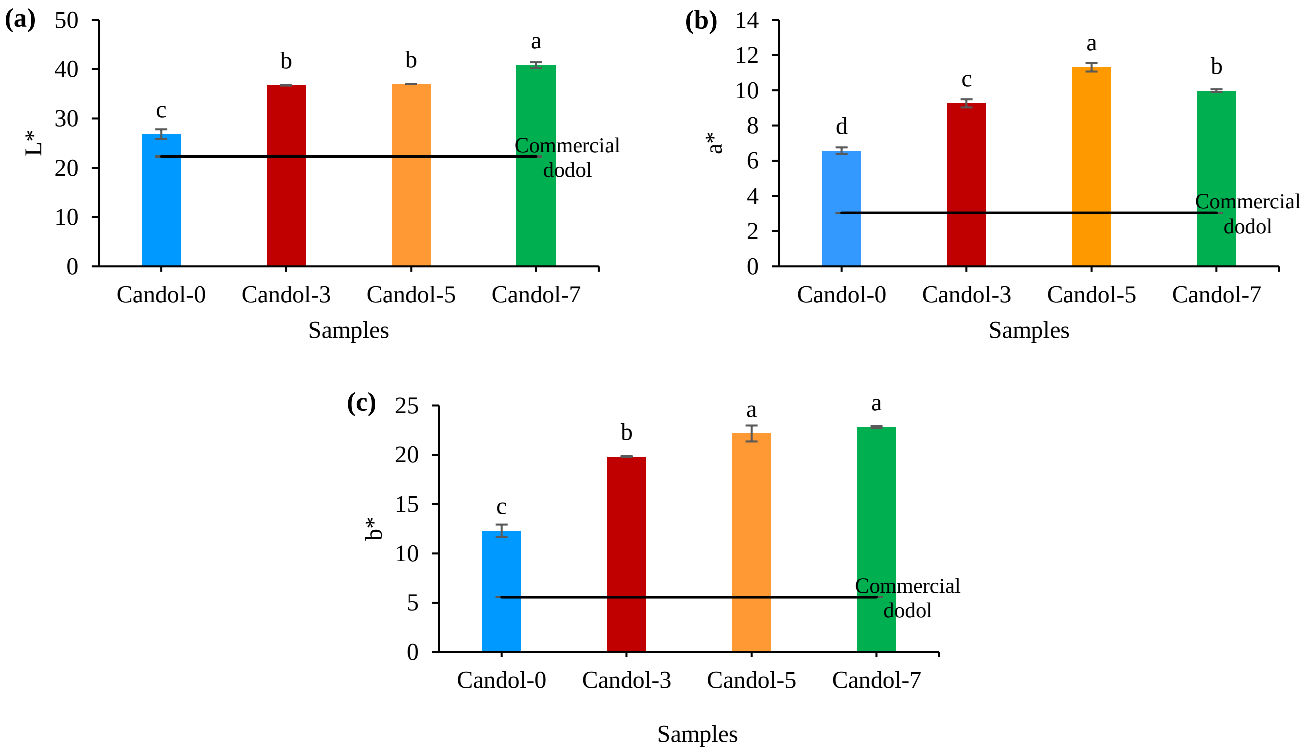

Figure 2. Colour values of dodol samples. **(a)** L* (lightness), **(b)** a* (redness), and **(c)** b* (yellowness). Error bars indicate standard deviations of triplicate (n = 3). Different lowercase letters indicate significant differences (p < 0.05) between samples. Commercial dodol was used as a reference, and not included in the statistic. Candol-0: canned dodol with 0% curdlan; Candol-3: canned dodol with 3% curdlan; Candol-5: canned dodol with 5% curdlan; and Candol-7: canned dodol with 7% curdlan.

caramelisation, during the long cooking process (Nurhayati *et al*., 2019). The CIE L* values of canned dodol ranged between 26.80 to 40.81 (Figure 2a). Interestingly, the CIE L* value of Candol-7 was significantly ($p < 0.05$) higher than those of the other samples. The higher CIE L* value of Candol-7 could be attributed to its lower moisture content, and a slight increase in TSS (Figure 1b) resulting from the addition of curdlan. As a result, higher reflectance led to a lighter colour appearance in Candol-7. Commercial dodol demonstrated a darker brown colour, which could be visually observed with the naked eye, as indicated by its relatively lower CIE L* value. Further heating during the pre-cooking stage may be required in canned dodol to achieve a colour characteristic similar to that of commercial dodol.

Previous studies have shown that the level of curdlan can impact the colour of food products, with an increase in curdlan concentration leading to a more pronounced yellow colour, as indicated by higher CIE b* values (Lee and Chin, 2019). This could be due to the natural yellow hue of curdlan. Wang *et al*. (2010) also obtained a similar pattern of results in potato starch noodles containing 0.1 - 1.0% curdlan, where curdlan concentrations ranging from 0.1 to 0.5% led to a more prominent lightness, while 1.0% concentration intensified the yellowness.

In the present work, the CIE a* values ranged from 6.57 to 11.31 (Figure 2b), and the CIE b* values ranged from 12.29 to 22.80 (Figure 2c). Although significant differences ($p < 0.05$) in CIE a* values were observed among all canned dodols, there was no apparent trend. As mentioned, the increase in CIE b* could be related to the natural yellow hue in curdlan itself. Candol-5 and Candol-7 exhibited significantly ($p < 0.05$) higher CIE b* values than the other samples, indicating more pronounced yellow colouration. Compared with canned dodol, commercial dodol showed relatively low CIE a* and b* values, suggesting that it had a less red and yellow appearance. The colour appearances of the canned dodol samples and commercial dodol are shown in Figure 3.

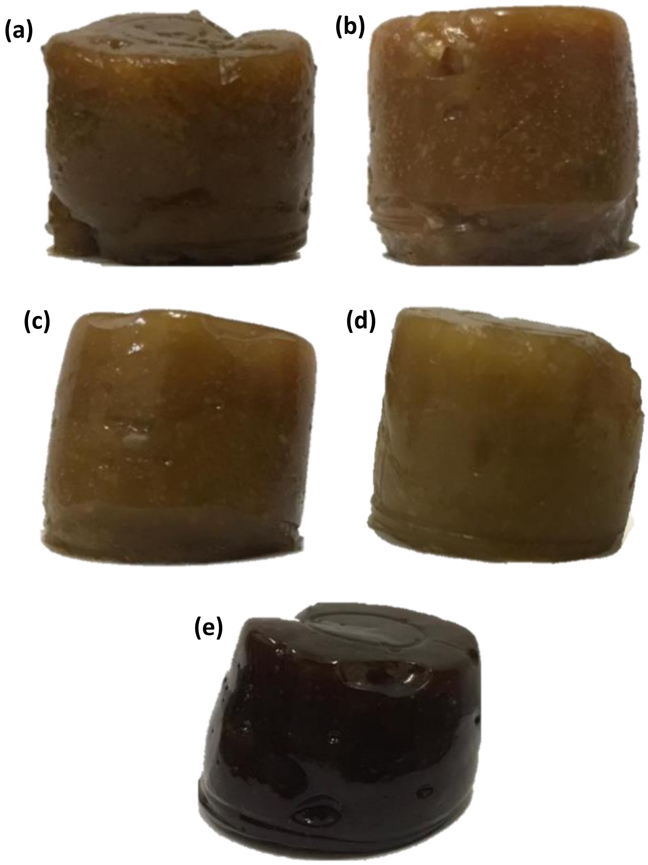

Figure 3. Colour appearance of dodol samples. **(a)** Candol-0, **(b)** Candol-3, **(c)** Candol-5, **(d)** Candol-7, and **(e)** commercial dodol. Candol-0: canned dodol with 0% curdlan; Candol-3: canned dodol with 3% curdlan; Candol-5: canned dodol with 5% curdlan; and Candol-7: canned dodol with 7% curdlan.

Texture profile analysis (TPA)

Table 2 presents the textural properties of the canned and commercial dodols. Prior studies have reported that an increase in moisture content and a_w might decreased the firmness of dodol (Muhialdin *et al.*, 2021). The results of the present work were consistent with this pattern. The hardness values of Candol-0 and Candol-3 were significantly ($p < 0.05$) lower than those of the other samples due to their higher moisture content and a_w (Figures 1c and 1d). Additionally, the significantly higher hardness observed in Candol-5 and Candol-7 aligned with a previous study by Xin *et al*. (2018), who reported an increase in the firmness of tofu noodles with higher curdlan concentration. This result can be attributed to curdlan's gelation, which enhanced the canned dodol's hardness. Candol-5 exhibited an optimal hardness level as it fell within a range similar to commercial dodol, suggesting that it achieved a desirable texture comparable to commercially available products.

No significant difference ($p > 0.05$) was observed in the springiness of canned dodol. Similarly, the results indicated no significant difference ($p > 0.05$) in cohesiveness among the three canned dodol samples with curdlan concentrations ranging from 3 to 7%. Cohesiveness provides insight into the resistance of food products to deformation, and reflects the difficulty in disassembling the internal gel structure (Peleg, 2019). Despite that, the cohesiveness of the three canned dodol samples with curdlan addition was significantly higher ($p < 0.05$) than that of Candol-0. Curdlan facilitated the formation of a gel with a more uniform and denser structure (Wei *et al.*, 2018). Consequently, the enhanced gel strength led to a more notable resistance in deforming the gel structure, ultimately resulting in higher cohesiveness in dodol.

A positive trend in the chewiness and gumminess of canned dodol was also observed with increasing curdlan concentrations. Chewiness and gumminess refer to measuring the energy needed to adequately disintegrate food for swallowing (Peleg, 2019). The chewiness and gumminess of Candol-5 and Candol-7 were significantly ($p < 0.05$) higher than those of the other samples. They had higher firmness, indicating that they required significant energy to disintegrate before being suitable for swallowing. However, the chewiness and gumminess of commercial dodol were notably higher than those of all the canned dodol samples.

No clear trends were observed in the adhesiveness and resilience of the canned dodol samples. The adhesiveness value for Candol-7 was significantly the lowest among all canned dodol samples. As the concentration of curdlan increased, the adhesiveness decreased due to curdlan's ability to absorb water to form a gel network. Resilience is the ability of food to regain its initial height after being compressed or deformed (Wee *et al.*, 2018). The resilience value of Candol-5 was comparable to that of the commercial dodol.

Microstructure analysis

The microstructures of the cross-sections of the vacuum-dried canned dodols and commercial dodol are illustrated in Figure 4. SEM analysis revealed the presence of a porous structure in Candol-0, Candol-5, and commercial dodol, which led to physical and textural differences. The formation of pores in dodol may be attributed to the loss of water content during the pre-cooking and vacuum-drying processes. Water removal creates voids, resulting in a porous structure in the final product. A microstructure with a larger porosity microstructure often characterises vacuum-dried food (Ngamwonglumlert and Devahastin, 2018). Vacuum drying involves the removal of moisture under reduced pressure, which can lead to the development of a more porous and open structure in the final product. This porosity can affect vacuum-dried foods' texture, appearance, and rehydration properties.

The pore size of the dodol samples followed an ascending sequence: Candol-5 < Candol-0 < commercial dodol. Candol-5 exhibited a smoother surface than the other samples, with the microstructure revealing a pore size range from 0.77 to 8.405 µm (Figure 4d). The compact and firm gel structure observed in Candol-5 can be attributed to the interaction of curdlan with other dodol ingredients. Consequently, the hardness of Candol-5 was significantly higher ($p < 0.05$) than those of Candol-0 and commercial dodol (Table 2). These findings suggested that the presence of curdlan reinforced the gel matrix continuity in canned dodol. This aligned with observations in sterilised fresh rice noodles, where progressive densification of the network and a reduction in average pore size were

Table 2. TPA parameters of dodol samples.

Samples	Hardness (N)	Adhesiveness (g·s)	Springiness*	Cohesiveness	Gumminess	Chewiness	Resilience
Candol-0	603.62 ± 56.57^{b}	-91.18 ± 2.96^{a}	0.96 ± 0.00	0.63 ± 0.02^{b}	383.53 ± 25.48^{b}	367.64 ± 26.16^{b}	0.25 ± 0.01^{a}
Candol-3	$618.02 \pm 3\ 2.46^{b}$	-236.48 ± 40.13^{b}	0.96 ± 0.00	0.70 ± 0.04^{a}	433.03 ± 28.21^{b}	416.78 ± 27.64^{b}	0.14 ± 0.00^{c}
Candol-5	841.98 ± 102.40^{a}	-171.69 ± 10.64^{ab}	0.96 ± 0.00	0.68 ± 0.02^{ab}	570.84 ± 55.81^{a}	549.24 ± 53.95^{a}	0.20 ± 0.00^{b}
Candol-7	894.47 ± 104.45^{a}	-369.87 ± 63.57^{c}	0.96 ± 0.00	0.67 ± 0.01^{ab}	601.06 ± 69.46^{a}	577.77 ± 65.51^{a}	0.13 ± 0.00^{c}
Commercial dodol	834.23 ± 48.82	-195.16 ± 27.38	0.98 ± 0.00	0.75 ± 0.05	626.85 ± 20.02	614.99 ± 20.27	0.18 ± 0.03

Values are mean ± standard deviation ($n = 10$). Means followed by different lowercase superscripts in a column are significantly different ($p < 0.05$) between samples. Commercial dodol was used as a reference, and not included in the statistic. *No significant difference ($p > 0.05$) was reported in springiness. Candol-0: canned dodol with 0% curdlan; Candol-3: canned dodol with 3% curdlan; Candol-5: canned dodol with 5% curdlan; and Candol-7: canned dodol with 7% curdlan.

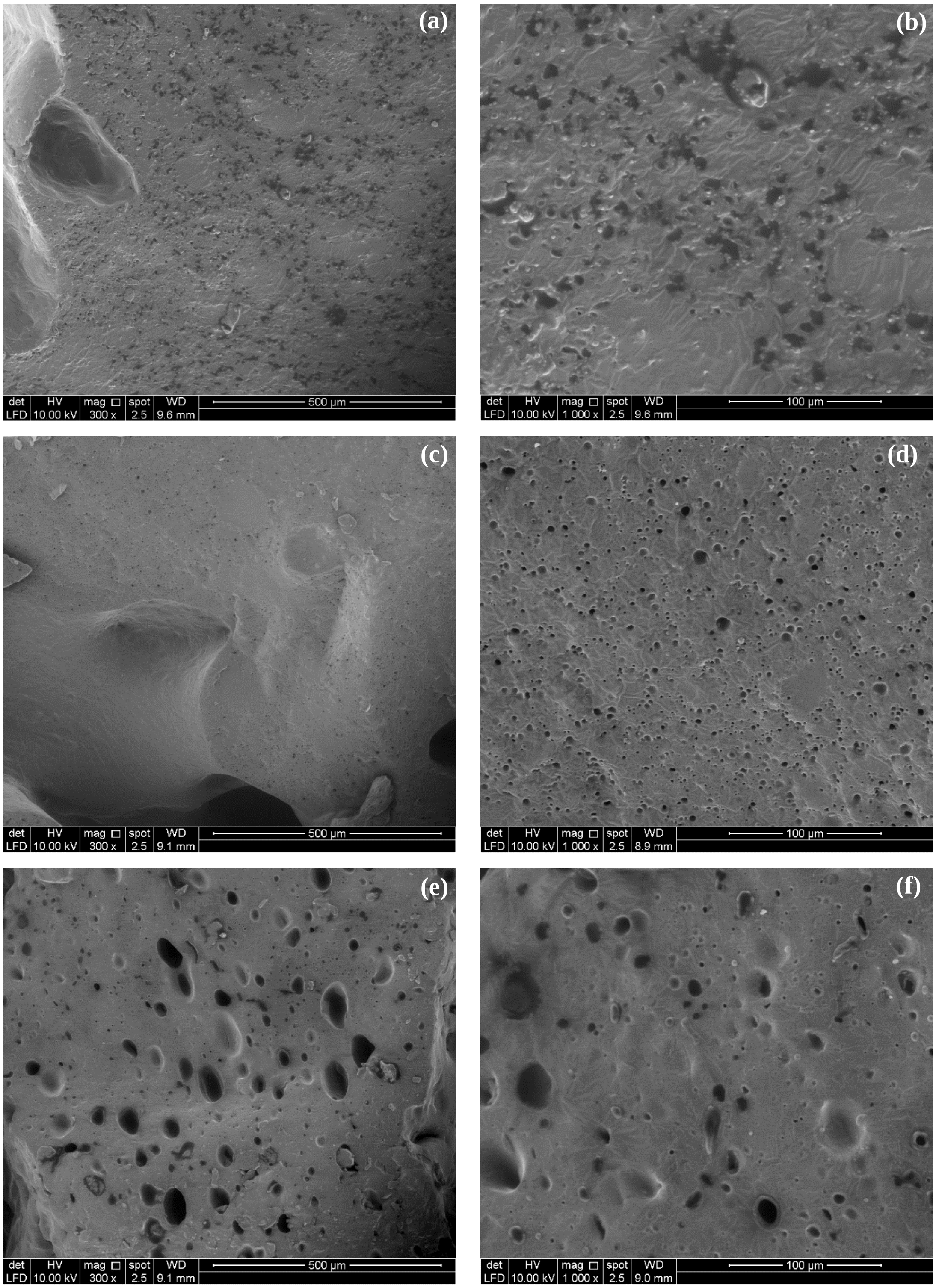

Figure 4. SEM morphological images at 300× and 1,000× magnifications of vacuum-dried dodol samples. **(a)** and **(b)** Candol-0, **(c)** and **(d)** Candol-5, and **(e)** and **(f)** commercial dodol. Scale bar = 500 µm. Candol-0: canned dodol with 0% curdlan; and Candol-5: canned dodol with 5% curdlan.

noted with higher curdlan content (Gao *et al*., 2024). In addition, SEM analysis revealed that the microstructure of the dough containing 0.5% curdlan displayed a uniform and condensed gluten network structure (Zhao *et al*., 2024).

The SEM analysis of Candol-0 revealed numerous surface pores with bigger pore sizes than Candol-5, ranging from 1.54 to 17.69 µm. This resulted in a weak network structure, contributing to Candol-0 having the lowest hardness value among the samples (Table 2). The lack of compactness and firmness made Candol-0 prone to deformation, in contrast to the denser structures seen in Candol-5 and commercial dodol.

Commercial dodol exhibited a surface with fewer but larger pores, with pore sizes ranging between 2.308 μm and 29.1 μm (Figure 4f). Despite having larger surface pores than Candol-0, the network structure in commercial dodol was denser than that of Candol-0. This denser structure contributed to its higher hardness value, which surpassed that of Candol-0 (Table 3).

Table 3. Sensory evaluation parameters for different types of dodol.

Sample	**Appearance***	**Colour***	**Aroma***	**Texture**	**Overall acceptability***
Candol-0	4.58 ± 1.43	4.84 ± 1.18	4.88 ± 1.26	4.18 ± 1.62[b]	4.66 ± 1.14
Candol-5	4.82 ± 1.56	4.88 ± 1.55	5.26 ± 1.26	4.84 ± 1.63[a]	5.04 ± 1.29
Commercial dodol	5.02 ± 1.44	4.68 ± 1.58	5.30 ± 1.39	5.76 ± 1.42	5.63 ± 1.16

Values are mean ± standard deviation ($n = 50$). Means followed by different lowercase superscripts in a column are significantly different ($p < 0.05$) between samples. Commercial dodol was used as a reference, and not included in the statistic. *No significant differences ($p > 0.05$) were reported in appearance, colour, aroma, and overall acceptability. Candol-0: canned dodol with 0% curdlan; and Candol-5: canned dodol with 5% curdlan.

Sensory evaluation

The results of the sensory evaluation are presented in Table 3. There were no significant differences ($p > 0.05$) in acceptability among the three types of dodol in terms of appearance, colour, aroma, and overall acceptability, even though Candol-5 showed higher L*, a*, and b* values than Candol-0 in colour analysis (Figure 2). The browning of foods, induced by the Maillard reaction and sugar caramelisation during cooking, produces flavour compounds and the characteristic aroma of dodol (Seow *et al.*, 2021). This browning was evident in the darker colour of commercial dodol, as indicated by the low CIE L* value of 27. Therefore, it is plausible to hypothesise that there may be a positive correlation between the darkness of dodol and its aroma intensity and overall quality. A darker colour in dodol indicates a more attractive aroma. Surprisingly, the commercial dodol with darker colours received higher scores in aroma and lower scores in colour attributes compared to the other samples. However, the sensory panellists did not prefer the dark colour of commercial dodol. This highlights the significance of colour in visual evaluation as it influences consumers' perceptions of quality and acceptability (Seow *et al*., 2021).

Candol-5 received significantly ($p < 0.05$) higher scores in texture than Candol-0, implying that sensory panellists preferred texture over Candol-5 to Candol-0. The sensory score of Candol-5 was closer to that of commercial dodol, which aligned with the results of the TPA analysis (Table 2), where the hardness, adhesiveness, and resilience of Candol-5 were similar to those of commercial dodol. Textural quality is crucial in determining the final evaluation and consumer acceptability of dodol (Seow *et al*., 2021). According to the panellists, Candol-0 was perceived as being too sticky on the fingers, resulting in it receiving the lowest scores in texture attributes and overall acceptance. This stickiness likely negatively affected the sensory experience, leading to a less favourable evaluation of the product than the other samples. However, there was no significant difference in the overall acceptability between the canned dodol samples and commercial dodol, indicating that both were equally well-liked by the sensory panellists.

Conclusion

Including curdlan in canned dodol significantly affected various aspects of the product, including its pH, total soluble solids (TSS), water activity (a_w), moisture content, colour, texture, and microstructure. Curdlan decreased the pH, increased the TSS levels, and decreased the moisture content and a_w in certain samples. Curdlan also affected the texture of dodol, with one sample (Candol-5) demonstrating texture scores similar to those of commercial dodol. Microstructural differences were observed, with Candol-5 displaying the smallest pores and most compact gel structure. The sensory panellists favoured the texture of Candol-5 over that of Candol-0. Moreover, the sensory score of Candol-5 was more similar to the score of the commercial dodol. Overall, curdlan could be a beneficial ingredient for enhancing the quality and acceptability of canned dodol, providing valuable insights into developing improved, innovative dodol products.

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