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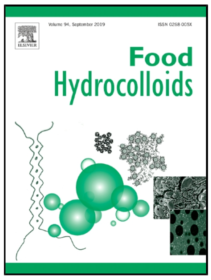

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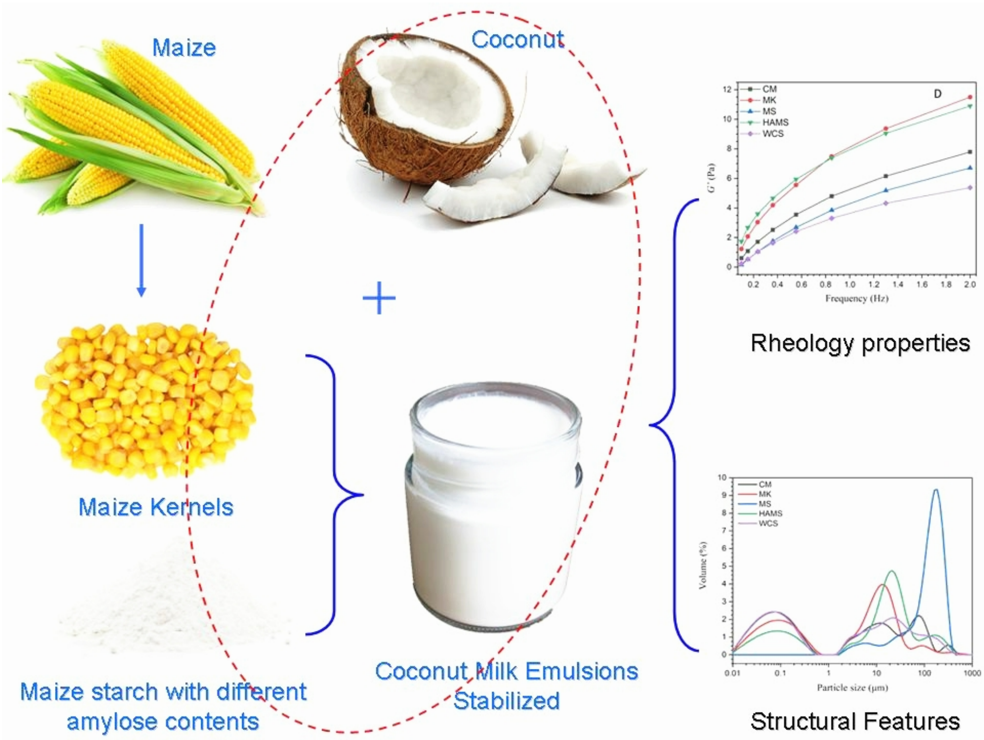
Maize
Coconut
Maize Kernels
Maize starch with different amylose contents
Coconut Milk Emulsions Stabilized
Rheology properties
Structural Features
CM
MK
MS
HAMS
WCS
D
Frequency (Hz)
G' (Pa)
Volume (%)
Particle size (μm)

Rheological Properties and Structural Features of Coconut Milk Emulsions Stabilized with Maize Kernels and Starch

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Abstract: In this study, maize kernels and starch with different amylose contents at the same concentration were added to coconut milk. The nonionic composite surfactants were used to prepare various types of coconut milk beverages with optimal stability, and their fluid properties were studied. The steady and dynamic rheological property tests show that the loss modulus (*G″*) of coconut milk is larger than the storage modulus (*G′*), which is suitable for the pseudoplastic fluid model and has a shear thinning effect. As the droplet size of the coconut milk fluid changed by the addition of maize kernels and starch, the color intensity, *ζ*-potential, interfacial tension and stability of the sample significantly improved. The addition of the maize kernels significantly reduced the size of the droplets ($p<0.05$). The potential values of zeta (*ζ*) and the surface tension of the coconut milk increased. Based on the differential scanning calorimetry (DSC) measurement, the addition of maize kernels leads to an increase in the transition temperature, especially in samples with a high amylose content. The higher transition temperature can be attributed to the formation of some starches and lipids and the partial denaturation of proteins in coconut milk, but phase separation occurs. These results may be helpful for determining the properties of maize kernels in food-containing emulsions (such as sauces, condiments, and beverages) that achieve the goal of physical stability.

Keywords: coconut milk; starch; maize; amylose; emulsion; stability

1. Introduction

Coconut milk, which is a type of oil-in-water natural emulsion, is a coconut processed product prepared by crushing, squeezing, extracting and other processing of mature coconut endosperm. Coconut milk consists of coconut proteins (globulin and albumin) and phospholipids. In coconut milk emulsions, the coconut protein adheres to the surface of coconut oil as an emulsifier, preventing the coconut oil from flocculating and merging. Coconut milk is rich in proteins, vitamins, sugars, amino acid compounds, minerals, etc. Coconut milk contains 35.2% fat and 3.8% protein (Ariyaprakai & Tananuwong, 2015; Raghavendra & Ksms, 2010). Coconut milk has become both an important food emulsion and cooking material due to its unique flavor and rich nutritional value (Iguttia, Pereira, Fabiano, Silva, & Ribeiro, 2011). However, natural coconut milk, like most emulsions, is unstable and exhibits stratification. During storage, due to its high fat content, natural coconut milk often exhibits a floating fat layer, protein flocculation, sediment, etc. Even after repeated homogenization, multiple layers (whey layer, cream layer, oil layer, etc.) appear once the product is left to stand. The stratification of water and emulsion in coconut milk has always been an unacceptable physical defect in the processing and production of coconut milk (S. P. Ng, Lai, Abas, Hong, & Tan, 2014).

Studies have shown that the fat particle size, droplet size and the degree of homogenization have significant effects on the stability of coconut milk. In addition, the denaturation of coconut milk proteins caused by heating temperatures above 80°C is among one of the factors affecting the stability of the coconut milk system

(Jirapeangtong, Siriwatanayothin, & Chiewchan, 2008; Nattapol & Johnn, 2009). ChanthimaPhungamngoen, et al. studied the influence of homogenization steps (before and after high temperature sterilization) on the quality of coconut milk, and the results showed that compared with homogenization before single sterilization, rehomogenization after sterilization can reduce the fat particle size of a coconut milk system, thus improving the stability of coconut milk(Phungamngoen, Asawajinda, Santad, & Sawedboworn, 2016). Jiang, et al. studied the effects of different temperature treatments on the stability of coconut milk emulsions. The results showed that the freezing treatment of coconut meat could effectively reduce the droplet size of the emulsion, thus improving the stability of the emulsion. However, chemical stabilizers are still commonly used to maintain the stability of beverage products due to their advantages of low cost and simplicity of operation(Jiang, Xiang, & Wang, 2016). Yalegama et al. applied pasteurization technology at a low sterilization temperature to coconut milk processing and searched for the optimum technology and stabilizer to reduce the stratification of coconut milk under this processing condition. The results showed that the stability of coconut milk could be effectively improved by adding 0.5% sodium caseinate and 0.5% sodium stearoyllactylate as stabilizers and sterilizing for 20-30 min at 72°C(Phungamngoen, et al., 2016). Currently, the variety of coconut milk beverages is small, and compound beverages involving grain (corn, rice, the seed of Job's tears, wheat, etc.) represent a breakthrough in dairy beverage development. Understanding and controlling the stability of grains in coconut milk systems are critical for the development of such beverages.

Corn, which is also known as Yumai, has a high nutritional value and is often used as an ideal food for the elderly, patients and infants. Research by the German Nutrition and Health Association shows that corn is currently the most nutritious and healthful cereal among all staple foods. In addition, corn contains lutein and zeaxanthin, which can delay visual aging, is rich in dietary fiber and has a mild taste. In the food field, corn is mainly used in fresh foods; quick-freezing, starch-making and corn oil; and corn fresh-pressed and corn-processed beverages; however, the sale of fresh-pressed beverages is limited because of their high cost. Research investigating corn beverage processing is limited, and corn coconut milk or other corn drinks have not entered large-scale production to date. Furthermore, few studies have investigated the stability and texture of this cereal compound beverage. Therefore, it is of great significance to study the stability and texture of corn in coconut milk systems for the development of compound cereal dairy products(L. Lin, et al., 2016).

The starch content in the corn dry base is as high as 71~74% and includes both amylose and amylopectin. Due to the low gelatinization temperature and retrogradation characteristics of starch, the dispersion of maize starch into a uniform and stable system in aqueous solution is difficult and has become an important factor affecting the stability of corn cereal beverages(L. Lin, et al., 2016; Xu Lu, et al., 2019). Therefore, in this study, coconut milk was used as a liquid system, and maize granules, common maize starch, waxy corn starch and high-amylose maize starch were added to the coconut milk system. By studying the static and dynamic rheological properties of coconut milk products, the effects of corn additives on the texture (particle size, color difference, zeta potential, DSC, surface tension and stability) of a coconut milk system were analyzed, providing a reference for studies investigating the structure of cereal beverage solution systems.

2. Materials and methods

2.1. Materials

UHT-processed and aseptically packed coconut cream (Kara brand, Pt PulauSambuGuntung Ltd., Indonesia, 30.8% fat, 3.9% protein, and 1.1% carbohydrate), maize kernels (artificial stripping of fresh corn cobs; corn was purchased from a local supermarket in Fuzhou, China), maize starch (Xinxiang Liang Run Grain Foods Co., Ltd., Henan, China), high-amylose maize starch (Penford Australia Pty Ltd., Lane Cove, NSW, Australia), and waxy corn starch (Qinhuangdao Lihua Starch Co., Ltd., Hebei, China) were used. All chemicals and solvents were of analytical grade.

2.2. Preparation of coconut milk complex

The sample types are divided into the following five groups: (1) pure coconut milk without maize kernels and starch made of coconut cream (CM); (2) coconut milk with the addition of corn products (MK); (3) coconut milk with the addition of maize starch products (MS); (4) coconut milk with the addition of high-amylose maize starch products (HAMS); and (5) coconut milk with the addition of waxy corn starch products (WCS).

The process used adopted the following commercialized coconut milk formula: 6% (v/v) UHT coconut cream, sucrose (7%, w/v), sodium bicarbonate (0.038%, w/v), sodium citrate (0.05%, w/v), D-sodium erythorbate (0.05%, w/v), EDTA (0.025%, w/v) and 1 L water with the addition of a certain quantity of fresh corn kernels and maize starch with different amylose contents (the nutritional components of each maize starch sample are shown in Table 1). The determination of the starch content added to MS, HAMS or WCS in coconut milk was carried out using samples with the same starch content in coconut milk with maize kernels based on the AOAC Method 2002.02. The amount of starch released from the corn coconut milk was 3.956 g/L. Based on the amount of maize starch, different amylose contents in the MS, HAMS or WCS groups and compound emulsifiers were applied (the proportions are shown in Table 2). The optimal stability formula of the five groups of samples was obtained by optimizing the ratio of the composite emulsifier using the response surface method. Subsequently, amylose and the compound emulsifiers were mixed in a high-shear blender (13500 rpm, 3 min, Ultra Turrax T25, IKA, Germany) to prepare the coconut milk emulsion oil-in-water beverage. Then, the coconut milk was canned, sealed, and sterilized at 115°C for 20 min under high pressure in an autoclave (Zealway, G154DWS, Xiamen, China). Furthermore, testing was performed after cooling.

2.3. Rheological analysis

The rheological properties of the coconut milk were assessed using a rotational rheometer (Physical MCR 301; Anton Paar, Co., Ltd., Stuttgart, Germany) with a parallel plate sensor (60 mm diameter, 1 mm gap). The temperature was maintained at 25 °C during these rheological measurements.

2.3.1. Steady rheology measurements

The steady-state shear experiments were carried out at a shear rate (γ) range of 0.001–100 s^{-1} for 300 s in the CR mode (controlled shear rate) at 25 °C using different annular gap sizes between the parallel plate geometry with gaps of 1.0 mm in parallel plate geometries with grooved surfaces. The steady-state shear experiments investigating the coconut milk were carried out at a shear rate range of 0.01–100 s^{-1} for 300 s in the CR mode at 25 °C with an annular gap size of 1.0 mm in parallel plate geometries with smooth surfaces. The experimental data of the flow curve were obtained and fitted using the Herschel–Bulkley model.

$\tau=\tau_0+K\gamma^n$ (1)

where τ is the shear stress (Pa), τ_0 is the yield stress (Pa), γ is the shear rate (s^{-1}), K is the consistency coefficient ($Pa \cdot s^n$) and n is the flow behavior index.

2.3.2. Dynamic rheology measurements

Frequency sweep measurements: The frequency sweep tests were performed at a frequency range of 0.1–2 Hz with constant deformation (0.5% strain) within the linear viscoelastic range. The 0.5% strain was within the linear viscoelastic region according to the strain sweep results. The mechanical spectra, which recorded the storage modulus (G'), loss modulus (G''), and loss tangent ($\tan \delta = G''/G'$) as functions of the frequency (Hz), were obtained.

2.4. Particle size distribution (PSD) analysis

The particle size was determined using the laser diffraction particle size analyzer MasterSizer 3000 (Malvern Instruments Ltd., Malvern, Worcestershire, UK) equipped with a wet sample dispersion unit (Malvern Hydro MV, UK). The background and sample integration times were 20 and 10 s, respectively. The optical properties were defined as a refractive index of 1.549 (olive oil) and 1.330 (dispersant water) and absorption index of 0.001 using a normal instrument. Across a dynamic spanning range of 0.01-3500 μm, before the analysis, all samples were shaken sufficiently to ensure sample uniformity. In the sample port, the samples were dispersed in distilled water at 2000 rpm until an obscuration of 8–25% and polarization intensity differential scattering of 8~15% were achieved. The analysis of the samples was performed in triplicate. The surface-area-based mean diameter (D[3,2]) and volume-based mean diameter (D[4,3]) were also obtained. Among these particle diameters, the mode diameter represents the most common particle size observed; regarding the mean diameters, D[4,3] is highly influenced by large particles, and D[3,2] is more influenced by smaller particles. The size distribution was expressed as the surface-weighted mean diameter as follows:

$$\mathrm{D}[4,3] = \frac{\sum_i n_i d_i^4}{\sum_i n_i d_i^3} \qquad (2)$$

$$\mathrm{D}[3,2] = \frac{\sum_i n_i d_i^3}{\sum_i n_i d_i^2} \qquad (3)$$

where n_i is the number of droplets of diameter d_i. Additionally, the dispersion index (Span) was calculated.

2.5. Color analysis

The color measurements were performed using a CS-200 Spectrophotometer (Hangzhou CHNSpec Technology Co., Ltd., Hangzhou, China). White calibration was used for the instrument standardization. The samples were placed in glass cells, and the measurement was performed. The L^*, a^*, b^* color space was used for the measurement. The L^*, a^*, and b^* values indicate luminosity, chromaticity on a green (−) to red (+) axis, and chromaticity on a blue (−) to yellow (+) axis, respectively. For each treatment, the color of three samples was measured. The total color change (ΔE) was calculated using the following formula:

$$\Delta E = \sqrt{(L^* - L_0{}^*)^2 + (a^* - a_0{}^*)^2 + (b^* - b_0{}^*)^2} \qquad (4)$$

where subscript '0' indicates the initial color of the coconut milk without maize.

2.6. Surface tension analysis

The surface tension was measured by a BZY-1 automatic surface tension meter (Shanghai Equity Instruments Co., Ltd., Shanghai, China) at 25°C. The BZY-1 meter employs the Wilhelmy plate principle, *i.e.*, the maximum tensile force competing with the surface tension is measured when the bottom edge is parallel to the interface and touches the liquid. The temperature and surface tension measurement ranges are (268.15–383.15) K and (0.1–400.0) $mN \cdot m^{-1}$, respectively. The uncertainty is ±0.1 $mN \cdot m^{-1}$. The size-volume of the different samples used in BZY-1 m was 20 mL. During the experiments, the copper pan in the host of BZY-1 m was connected to a thermostatic bath (CH-1006, uncertainty is ±0.1 K). Via the circulation of the water, the temperature of the water in the copper pan was kept the same as that in the thermostatic bath. The aqueous solution was placed in a solution container immersed in the copper pan, and its temperature was measured by a thermocouple. The scale reading of the thermocouple had been well calibrated by a mercury thermometer.

2.7. ζ-potential analysis

Each sample (1 mL) was added to the sample pool, and the particle charge of the coconut milk (ζ-potential) was determined using a Zetasizer Nano-ZS (Mastersizer X, Malvern Instrument Ltd., Worcestershire, U. K.) based on laser Doppler velocimetry. All experiments were carried out at 25°C. The analysis of the samples was performed in triplicate.

2.8. Differential scanning calorimetry (DSC)

The coconut milk was also analyzed using Netzsch DSC 204 F1 Phoenix® (Netzsch Group, Selb, Germany) equipment, and the phase transitions were tracked. Aliquots of protein dispersions (20 μL) were accurately injected into aluminum pans that were sealed with a Tzero hermetic lid. An empty pan was used as a reference. The DSC sample pans were heated from 30 to 100°C at 10°C/min. All DSC analyses were performed under nitrogen at dynamic purge and protective flows of 20 mL/min. Proteus® Software for Thermal Analysis ver. 6.1.0 (Netzsch Group, Selb, Germany) was used for the acquisition and processing of the DSC data.

The onset (T_0) and offset (T_e) temperatures are defined as the intersections between the tangents of the peak and the extrapolated baseline, and the peak denaturation temperature (T_p) is defined as the temperature at the maximum/minimum of the thermal event. These temperatures were obtained from a corresponding thermogram, while the denaturation enthalpy (ΔH) was obtained from an integration of the thermogram. The analyses were carried out in triplicate.

2.9. Compound system stability

The creaming stability of the emulsions was evaluated using a multisample analytical centrifuge (Lumifuge, LUM GmbH, Berlin, Germany). Coconut milk (425 μL) was transferred to rectangular cells (2 × 8 mm) and analyzed by a light beam emitted at a near infrared wavelength (880 nm) that scanned the sample cells over the total length. The charge-coupled device (CCD) line sensor received the light transmitted through the sample, which showed the pattern of light flux as a function of the radial position, providing a macroscopic fingerprint of the sample at a given time; based on this pattern, emulsion instability, including creaming, sedimentation, and droplet aggregation, could be detected. In the current study, the samples were centrifuged at 4000 rpm (2320 × g) and 25 °C at a scanning rate of once every 60 s for 1 h, simulating approximately 4 months of separation under normal gravity.

The separation rates were determined using the software package SepView 4.1 (L.U.M GmbH). The velocities of the separation of individual particles (mm/d) were measured from the measurement results. Following the test, curves of the integrated transmitted light against time were plotted, and the slope of each curve was considered the Creaming Index (*CI*).

2.10. Statistical analysis

The statistical analysis was performed using OriginPro 8.0 (Origin Lab Corporation, USA), and the data are expressed as the mean values ± standard deviation. All measurements were repeated three times. All statistical analyses were performed using Data Processing System software (DPS, V9.05, Science Press, Beijing, China). One-way ANOVA, followed by Duncan's post hoc test, was used to determine the significant differences among the treatment groups. $p<0.05$ was considered statistically significant; all tests were two-sided, and no corrections were applied for multiple significance testing.

3. Results and discussion

3.1. Formula of composite stabilizer

The results shown in Table 1 highlight that the amylose content was the highest in the high-amylose maize starch, followed by the amylose content in the kernels and common corn starch, while the amylose content in the waxy corn starch was the lowest, and its main component was amylopectin. Compared with common corn starch, the lipid and protein content in the corn kernels is higher than that in the common corn starch.

The results shown in Table 1 highlight that the amylose content in the high-amylose maize starch is the highest, followed by the amylose content in the maize kernels and common corn starch, while the amylose content in the waxy corn starch is the lowest, and its main component is amylopectin. Compared with the common corn starch, the lipid and protein content in the maize kernels is higher than that in the common corn starch. During the early stage of the study, based on the response surface optimization experiment, the optimum stabilizer formula of different corn additives and coconut milk was determined.

According to the emulsifier formula (Table 2), the ideal amount of carrageenan that should be added to coconut milk with common corn starch and waxy corn starch is 0.03%, while the amount of carrageenan that should be added to coconut milk with maize kernels is 0.05%. The influencing factor may be that the maize kernels contain up to 70% starch in addition to 4% oil, while carrageenan is a highly charged emulsifier with a negative charge that can form a layer of high charge density interfacial film around oil droplets, protecting the oil droplets and stabilizing the emulsion. Therefore, more carrageenan is needed in corn coconut milk to stabilize the system. Sodium tyrosinate is an amphiphilic surfactant with better thermal stability than other emulsifiers (Z. Long, et al., 2012). The results showed that the maize kernel-coconut milk needed the least amount of surfactant, while the waxy corn starch-coconut milk required the greatest amount, indicating that the maize kernel-coconut milk system was more stable.

The amount of sucrose fatty acid ester in the waxy corn starch coconut milk was 0.06% more than that in the common corn starch coconut milk. We speculated that the sucrose fatty acid ester was a strong hydrophilic emulsifier that could wrap amylopectin maize starch more effectively, which is then not soluble in water (Watanabe, Kawai, & Nonomura, 2017). Furthermore, the content of distearin was higher in the coconut milk system with the maize kernels, common corn starch and high-amylose maize starch, while the content of glyceryl monostearate was the highest in the high-amylose maize starch-coconut milk system. Glyceryl stearate is a polyol type nonionic surfactant that inhibits the aging of starch. Glycerin monostearate easily forms a starch-lipid complex with amylose, which improves the stability of the composite system (Garcia & Franco, 2015). Therefore, the higher the amylose content, the more stearin is required to stabilize the system.

3.2. Steady rheological properties of coconut-corn systems

The apparent viscosity curve of a coconut milk system is determined by setting the shear rate at 0.001-100 s^{-1}. The shear rate is measured by using a groove with a geometric plane to avoid surface slipping. As shown in Figure 1A, under the same preparation, sterilization and measurement conditions, the apparent viscosity of the five samples initially increases and then decreases as the shear rate increases and the rate of decrease slows down.

The maize starch with different amylose concentrations increased the apparent viscosity of the coconut milk, and the difference in the rheological properties was partially due to the solubilization of macromolecular carbohydrates, such as starch. Here, solubilization indicates that the starch macromolecular aggregates are gelatinized and decomposed into colloids. The apparent viscosity of the coconut milk containing the high-amylose maize starch was the highest, which might be due to the gelation of high-amylose starch, increasing the apparent viscosity (Shao, Tseng, Chang, Lin, & Lii, 2007). A similar phenomenon is observed in the corn starch fluid with different amylose ratios of solvent in pure water systems (Xie, et al., 2009). The maize kernel and common corn starch-coconut milk systems have a similar apparent viscosity. Under high-pressure and high-temperature sterilization conditions, the linear amylose molecule might dissolve first, followed by the mild amylopectin molecule, and finally, amylopectin would then dissolve. The short-time high-temperature sterilization resulted in a higher amylose content.

The maize kernel and common corn starch contained a similar content of amylose. Gelatinization of amylose requires a higher temperature, leading to a multiphase transition between starches and an increase in viscosity and shear stress due to the winding of macromolecules between linear polymer chains. The main component of waxy corn starch is amylopectin. The entanglement and interconnection between droplets of stable powder particles are very weak because there is almost no amylose. The three-dimensional network formed by amylose is relatively weak. After high temperature sterilization, amylopectin is mainly composed of short-branched gel spheres that are mainly composed of chains from the same subchain. Compared with amylose, a gel network structure is not easily formed, and the size and length of the chain (only 4-6 glucose) and the molecular entanglement between gel spheres are much smaller than those between linear polymer chains (Han, Campanella, Mix, & Hamaker, 2002; Y. Long & Christie, 2005). Once the mechanical deformation is strengthened, the network undergoes a gradual decomposition into smaller clusters; thus, the apparent viscosity is smaller (Xuanxuan Lu, Wang, Li, & Huang, 2018). In summary, the higher the amylose content in a coconut milk system, the greater the apparent viscosity.

The fluidity of coconut milk is affected by the addition of corn and affects its shear thinning characteristics. As shown in Fig. 1B, the shear stress of the five coconut milk samples increased with the rate of what, indicating that all samples have the characteristics of pseudoplastic fluid with shear thinning. This finding may be explained by the non-Newtonian behavior (shear-induced alignment) of the droplet network or shear continuous phase (Liu & Tang, 2011), which is consistent with the results of the apparent viscosity.

At the same shear rate, the shear stress of the coconut milk samples containing the waxy corn starch was always lower than that of the other samples. We inferred that the other four coconut milk samples were more easily shear thinned and had strong pseudoplasticity. The shear stress of the coconut milk containing the high-amylose maize starch and maize kernels was always greater than that of the pure coconut milk. The high yield stress proved that there was a strong network. Studies have shown that potato starch with a high amylose content gelled more easily than potato starch with a low amylose content at a high temperature; thus, the shear stress is stronger (Zhou, et al., 2015). During the process of autoclaving, starch granules burst, and amylose precipitates first (Ji, et al., 2017). However, due to the influence of the spatial structure of starch, amylose has a stronger ability to form hydrogen bonds than amylopectin and solvent molecules, and the structure after binding is more stable, reducing the fluidity of the coconut milk system and increasing the shear stress. Compared with common corn starch, there are more lipids and protein substances in maize kernels, and the fat is easily adsorbed into agglomerates due to the oil-water layer structure; thus, the shear thinning effect of maize kernels is larger than that of common corn starch (Schröder, Berton-Carabin, Venema, & Cornacchia, 2017).

The flow behavior index (n) indicates the degree of the pseudoplasticity of an emulsion as follows: as the pseudoplasticity increases, the n value decreases. Native maize starch and waxy maize starch have more pseudoplasticity because they exhibit a lower flow behavior index. If the amylopectin content is high, the amylopectin solution does not exhibit effective entanglement because there is no entanglement between amylose chains, and the *n* value is higher (Y. Long, et al., 2005). The flow characteristic index of all coconut milk systems is less than 1 (Table 3), and the apparent viscosity decreases as the shear rate increases, reflecting non-Newtonian flow and shear thinning flow behavior (Tanner & Rivlin, 1985). All fluids are pseudoplastic fluids, and the addition of corn kernels or starch does not alter the fluid type of coconut milk. The consistency coefficient (*k*) is an index of the emulsion viscosity. Compared with pure coconut milk, maize starch, common starch and high-amylose maize starch can increase the consistency coefficient of a system, and a higher amylose content leads to a higher *K* value.

3.3. Dynamic rheological properties of coconut-corn systems

The dynamic rheological property (dynamic viscoelasticity) refers to the mechanical response law of the material under the action of alternating stress and is detected by elastic (G') and viscous (G'') moduli as a function of frequency. Coconut milk is a beverage with a higher fat and vegetable protein content; the fat is easily aggregated, and the system is stratified (Jiang, et al., 2016). Once maize starch additives are introduced to the system, the rheological properties of the whole liquid system changes under the action of high-speed shearing and high-temperature processing, thereby affecting the quality. The storage modulus G' can reflect the elasticity of the fluid, the recovery ability of the reaction fluid after deformation, the energy modulus G'', the size of the viscous component and the ability of the fluid to release energy, which reflects the performance of the fluid in resisting the flow

(Barbieri, et al., 2018).

At a scanning range of 0.1-2 Hz, G' and G'' of the coconut milk samples increase as oscillation frequency increases. After adding corn starch additives, G' and G'' both showed a significant increasing trend (Fig. 1D and E), indicating that the dynamic modulus depends on a strong frequency, and the loss modulus exceeds the storage modulus, reflecting fluid-like behavior. Moreover, G' and G'' of the high-amylose maize starch were larger than those of the other samples. The waxy corn starch sample exhibited the smallest G' and G'', and the emulsion had the weakest structure. It's lowest G' value proved this finding and resulted in a WCS with a very high droplet fluidity. The gel network structure formed by amylose increases the elasticity of the liquid system, while amylopectin does not easily form a gel network structure (Yu, Jing, Zhang, & Kopparapu, 2014). Therefore, the higher the amylose content, the greater the dynamic viscoelasticity of a coconut milk system. Studies have shown that the rheological viscoelasticity and viscosity of rice starch are closely related to its amylose content, and the greater the amylose content, the greater the viscoelasticity (Shao, et al., 2007; Takahashi & Fujita, 2017).

In addition, both the complex viscosity η^* and the tangent loss $\tan\delta$ of the sample showed a tendency to decrease as the scanning oscillation frequency increased (Fig. 1C and F), which is consistent with the trend observed in the static rheological research. The tangent loss of all coconut milk systems is related to the scanning frequency, is greater than 1, and gradually approaches 1 as the frequency increases. The tangent loss $\tan\delta=G''/G'$ reflects the relationship between the elastic and viscous characteristics of reactive fluids. If tanδ< 1, the elastic properties of fluids dominate, and if tanδ> 1, the viscous properties of fluids dominate. Following the addition of maize kernels or high-amylose maize starch, coconut milk fluid tends to be rigid in a three-dimensional network, and MS and WCS systems do not exhibit obvious gel properties (Yu, et al., 2014). The decrease in the complex viscosity (η*) may be related to a shrinkage of starch swelling particles, depolymerization of protein or the destruction of protein networks caused by protein thermal coagulation (Vanin, Michon, & Lucas, 2013). In addition, the decrease in energy storage and loss modulus results in a decrease in the hydrogel network strength.

3.4. Changes in the particle size distribution

Figure 2 shows the distribution of the particle size and particle radius of the coconut milk system after the addition of the maize starch supplement. The measurements of the area-based mean particle diameter (D[3,2]) and volume-based mean diameter (D[4,3]) are shown in Table 4. D[4,3] reflects the size of flocculated droplets or solid aggregates. The pure coconut milk system showed three peaks in the particle size distribution, and was mainly concentrated in the range of 0.01-100 μm. A few particles were larger than 100 μm, and the average particle size was 28.6 μm. Coconut milk is mainly composed of proteins and phospholipids, which is similar to most emulsions. Fresh coconut milk is unstable and easy to be stratification. After processing, coconut milk can be divided into cream and whey, which are known as coconut cream and coconut skim milk, respectively. Even after emulsification, coconut milk contains 3 to 4 phases, including an oil phase, cream phase, whey phase and sediment layer. Coconut protein can be used as a natural emulsifier in coconut milk, but following thermal denaturing, coconut protein loses the ability to stabilize emulsion droplets (C. Y. Ng, Mohammad, Ng, & Jahim, 2014; Raghavendra, et al., 2010). The size distribution of pure coconut milk exhibits three peaks at 0.01~1 μm, 4~40 μm, and 40~110 μm, and the second group corresponds to fat globules at a lower particle size (0.01~10 μm). Pure coconut milk emulsion droplets of approximately 100 μm may be white solid particles produced by the condensation of denatured proteins (Nattapol, et al., 2009), while with a high-amylose maize starch and high-amylose maize kernel content, the emulsion particles aggregate in small size directions, indicating that these additions can reduce the denaturation process of the corresponding protein in coconut milk. The addition of both can enhance the heating stability of coconut milk.

After the addition of the maize starch additives to the coconut milk, the D[3,2] and D[4,3] of the system were significantly affected ($p<0.05$). Among these additives, the common corn starch had the most significant impact on the particle size distribution and particle size of the coconut milk ($p<0.05$), and D[4,3] and D[3,2] both sharply increased. However, the high-amylose maize starch and maize kernels had similar effects on the particle size distribution of the coconut milk system. Under the influence of both additives, the peak of the D[3,2] value between 40 and 110 μm disappeared, and the peak between 4 and 40 μm increased, while the peak of D[4,3] obviously increased. The waxy corn starch had no significant effect on the distribution of D[4,3] in the coconut milk system ($p>0.05$), but the distribution of D[3,2] became more uniform and concentrated.

Studies have shown that D[3,2] is more susceptible to small molecular particles, while D[4,3] is more susceptible to macromolecular particles (Ped, Ibarz, & Cristianini, 2013). The grain size of common corn starch is significantly larger than that of high-amylose maize starch (L. Lin, et al., 2016), and the grain size of waxy corn starch is 16.4 μm(J. H. Lin, Kao, Tsai, & Chang, 2013), which is less than the average particle size of coconut milk. Therefore, once maize grain or maize starch is added to a coconut milk system, the average particle size of the system is affected to varying degrees. Among these additives, common corn starch increases the size of the system particles. The larger the particle size, the higher the number of starch granules required to cover the same interface area probably because more starch granules are required to stabilize a larger interface area. As the surface coverage of the droplets increased, and the starch granules showed monolayer compact accumulation after gelatinization. The dense accumulation of starch particles at the interface can enhance the coalescence stability of adjacent droplets by forming a strong spatial barrier (Li, Li, Sun, & Yang, 2013). Waxy corn starch can reduce the size of coconut milk particles, resulting in a larger specific surface area, and as the average distance between the particles decreased, the better the dispersion of the smaller particles in the coconut milk . In addition, the surface active component adsorbed on the oil droplets easily generates a noncovalent interaction with the hydrophobicity and corn bonding between the waxy corn starch molecules, leading to a stronger interparticle interaction, and the formed emulsion exhibited good anti-coalescence stability during storage (Bi, Hemar, Balaban, & Liao, 2015; B. Wang, Wang, Li, Adhikari, & Shi, 2011; Yusoff & Murray, 2011).

3.5. Changes in color, surface tension and ζ-potential

The L^* value of the coconut milk system decreased after the addition of the maize supplement, while the a^* value showed the opposite result (Table 5). The deepening of the color caused by the addition of maize kernels may be attributed to the migration of pigments from the maize kernels, the oxidation of carotenoids and the increase in free phenolics during processing,causing coconut milk nonenzymatic browning of the Maillard type (Rochavillarreal, Hoffmann, Vanier, Sernasaldivar, & Garcíalara, 2018). In addition, the waxy corn starch significantly increased the a^* value of the system ($p<0.05$), while the high-amylose maize starch and maize kernels had a negligible effect on the a^* value of the system. Most likely, this result is due to the large number of Maillard reactions between the added reducing sugars and the amino groups in the protein that occur under high temperature sterilization (Rodsamran & Sothornvit, 2018). Amylopectin caused the loss of the luminosity of the system and increased the red color intensity of the system, while the high-amylose content had less of an effect on the red color of the system. Most likely, due to the large particle size of the amylopectin particles, the macromolecular particles in coconut milk are easily susceptible to precipitation, affecting the depth of the system. In addition, the ΔE value of the corn supplement system significantly increased compared to that of the pure coconut milk system.

One of the most important parameters of the stability of food emulsions is the droplet size because emulsion coalescence with larger droplets is faster, and a smaller particle size is more stable. The coalescence rate constant is inversely proportional to the ζ-potential, and the ζ-potential is related to the surface charge of the emulsion droplet. The larger the net surface charge, the less coalescence (Das & Kinsella, 1990). After the different corn starch additives were added to the system, the ζ-potential of the pure coconut milk became less negative and even became positive (Table 5). The ζ-potential refers to the mutual exclusion or attraction between particles. The smaller the dispersed particles, the larger the ζ-potential absolute value and the more stable the system. The smaller the ζ-potential absolute value, the easier the condensation or agglomeration. The maize kernels and high-amylose maize kernels reduced the ζ-potential of the coconut milk to -7.93 mV and -0.7 mV, respectively, suggesting that the system began to appear unstable, and the attraction between the particles exceeded the rejection. After the common corn starch and waxy corn starch were added, the ζ-potential of the system became positive at 1.38 mV and 1.39 mV, respectively; thus, a part of the system produced condensation or agglomeration phenomenon, which may have affected the stability of the system. The increase in the ζ-potential of the coconut milk after the addition of the maize kernels and maize starch may be due to (1) the potential change in the starch granule surface protein from hydrophilicity to hydrophobicity after heating, and the hydrophobicity of starch is also improved (Li, et al., 2013). (2) In addition, electrostatic interactions between adsorbed and unsorbed proteins and polysaccharides in the coconut milk could also be induced (Evans, Ratcliffe, & Williams, 2013). (3) Once a surfactant is added to a coconut milk emulsion before emulsification, the small molecule surfactant completely replaces the coconut protein adsorbed onto the newly created interface, resulting in a decrease in negative charge on the surface protein and a change in the ζ-potential of the emulsion droplet. The addition of a nonionic surfactant can provide space stability and eliminate the electrostatic effects of the protein. If the protein on the emulsion droplets is completely replaced, the nature of the emulsion should be the same as that of the surfactant being replaced (Mcclements, 2005).

Many products with oil-in-water (O/W) or water-in-oil (W/O) emulsions contain emulsifiers or stabilizers to reduce the interfacial tension between the oil and water phases, thereby increasing the stability of the system. Surface tension plays an important role in determining the ability to form and stabilize an emulsion. The surface tension of water is 72 mN/m, and corn oil has a surface tension value of 30.96 mN/m at 25 °C (Nitschke, et al., 2010). Compared with natural proteins, the partial denaturation of proteins in pure coconut milk and the interaction between protein molecules can cause the formation of protein aggregates. When such autoclaving aggregation occurs at a sufficiently high protein concentration, oil can be embedded in the three-dimensional matrix of the aggregates. Moreover, heat-treated proteins exhibit a lower surface tension due to protein denaturation and the increase in surface hydrophobicity (J. Wang, et al., 2012). The surface tension and interfacial elasticity of the emulsion protein film were decreased by the addition of the surfactants of glyceryl monostearate, distearin, sucrose fatty acid ester and sodium caseinate corresponding to the ratio of surfactant to protein. Thus, the addition of maize kernels and starch increased the surface tension of the system. There was no significant difference in the surface tension between the maize kernels and coconut milk with different amylose contents (p>0.05). Starch polysaccharides have no surface activity, but they bind surfactants, and their binding capacity is independent of the type of starch. The combination of surfactant and amylose is synergistic, while the combination of surfactant and amylopectin is a Langmuir type (Lundqvist, Eliasson, & Olofsson, 2002).

3.6. Changes in thermal properties

The endothermic conversion of pure coconut milk systems occurs between 58 and 71°C. The endothermic enthalpy produced by the initial gelatinization temperature may be related to the denaturation temperature of some globulins in coconut milk. Reheating after high pressure sterilization may cause the inner part of the protein to continue denaturing (Nattapol, et al., 2009).The addition of corn starch additives changed the endothermic conversion of the system to different degrees. HAMS significantly increased the T_0 of the system (p<0.05), followed by maize kernels, and common corn starch and waxy corn starch slightly increased the T_0. HAMS and MK increased the T_p of the system, whereas the common corn starch and waxy corn starch slightly decreased the T_p (Table 6).In addition, the T_e value of the system increased following the addition of maize starch, and the order was HAMS>MK>WCS>MS. Compared with the pure coconut milk system, the $\triangle H$ of HAMS and MK increased by 6.8/J·g^{-1} and 6.56/J·g^{-1}, respectively. Granules of high amylose maize starch, especially small size granules, still retain some Maltese cross characteristics when heated at 120°C(Xu, et al., 2017).Therefore, a wide range of endothermic gelation temperatures of high amylose is still obtained in the temperature range of 65 to 125°C (Haralampu, 2000), and the wider peak value is attributed to the overlapping of transitions, which is related to starch gelatinization and the denaturation of some proteins.The superfluous endothermic enthalpy of coconut milk with corn kernel, maize starch and high-amylose maize starch may represent the phase transition of the amylose-lipid complex. The type I composite is formed at or below 60°C and results in the formation of a single spiral segment with a random orientation.However, the complex formed at 70°C may be a mixture of type I and type II crystals.Reaching 90°C results in the formation of a starch-CLA complex mainly composed of type II crystals. The detection of a higher temperature in starch rich in amylose can be used to explain its higher viscosity and reduced Newtonian behavior.Regarding MS and WCS, there is no significant impact on the $\triangle H$ of the system (p>0.05). The gel spheres formed by amylopectin require less energy to move than long straight chains, showing increased Newtonian behavior (Karkalas, Ma, Morrison, & Pethrick, 1995).

The effect of the system's T_e-T_0 on the maize starch additives decreased, except when waxy corn starch was used. The results show that the heat treatment increased the temperature of the endothermic conversion and narrowed the temperature range of the starch. Higher crystallinity and a more orderly crystalline structure increase the temperature of endothermic conversion. However, the relative crystallinity of heat-treated (annealed) starch does not increase; thus, the increase in the thermal transition temperature and the decrease in the temperature range are attributed to an increase in the crystallization order.The improvement of order is related to the agglomeration of amylopectin caused by amylose recombination. The waxy corn starch-coconut milk system exhibited the least variation due to the lack of amylose molecules in the system.There was no significant difference in $\triangle H$ between the waxy corn starch and common corn starch (p>0.05) mainly because the starch granules had no crystal or double helix structures. Therefore, the amylose composition of the system has an important influence on the endothermic conversion and temperature transformation range of the system.

3.7. Effects of maize starch additives on CM stability

Fig. 3 shows a typical Lumifuge diagram of the transmission light evolution during the centrifugation of the coconut milk after high temperature sterilization. If the oil droplet density is small and the sample solution is clarified, the light intensity of the detection curve is strong. The light intensity on the right side of the X-axis is at the bottom of the sample colorimetric dish, and the light intensity on the left side of the X-axis is on the left side of the sample colorimetric dish. The initial transmission distribution (red line) shows the movement of the particles, and the final transmission distribution (green line at the top of the picture) represents the emulsion layer of the oil droplets.Colloidal instability appears as emulsification or precipitation (Lerche & Sobisch, 2011). After centrifugation, colloidal instability can be observed in the tube and the transmission profile. The high-density red line in the profile indicates a slower separation and higher stability, which can be observed in the emulsions with the different amylose contents of maize starch (Fig. 3C, D, E). The profile of the pure coconut milk and coconut milk with added maize kernels showed progressive movement, rapid particle separation and a fat layer (Fig. 3A, B).According to the transmission curve, compared with the coconut milk with the added starch, the thickness of the emulsified layer in the pure coconut milk and the stable emulsion with the added maize kernels was reduced. The larger gap between the red lines represents slow emulsification. Compared with the starch coconut milk, the clarification rate of the pure coconut milk and coconut milk with the added maize kernels was higher. Gravity often affects the movement of liquid droplets, causing precipitation and coagulation and resulting in a higher clarification rate (Piorkowski & Mcclements, 2014).During the whole centrifugation process, the destruction of condensed large liquid particles led to the destruction of the emulsion structure, but the transmission distribution of all coconut milk samples clearly showed that there was no phase separation phenomenon.

This study uses the creaming index (*CI*) (%/hr) to describe the rotational rate of light intensity, and the *CI* is calculated by integrating the slope of the curve of transmitted light over time (Mao, Boiteux, Roos, & Miao, 2014).As shown in Table 5, the coconut milk without the maize starch additives had the highest *CI* value, indicating that the system was the most unstable and a few layers existed. In the coconut milk emulsion, due to the presence of phospholipids, proteins and other components, even though the sample was homogenized, there were different phases; thus, the emulsion state is unstable (Jiang, et al., 2016).The combination of the four kinds of starch additives reduced the *CI* value of the mixed system; thus, maize starch can effectively improve the stability of the system. Among the systems, the *CI* value of the corn additive system slightly decreased, while the other three types of maize starches significantly reduced the system *CI* value ($p<0.05$).Banana starch is also often used as an emulsion stabilizer through a hydrophilic interaction with the oil phase (Bellopérez, Belloflores, Nuñezsantiago, Coronelaguilera, & Alvarezramirez, 2015). However, maize kernels also contain complex components, such as fats and proteins. During the process of high pressure sterilization, the starch granules in maize kernels swell and cause some mechanical damage to corn granules, leading to the leaching of amylose from starch granules. The leached amylose can enhance the viscosity and stability of the emulsion by forming a three-dimensional network in the system (Lii, Tsai, & Tseng, 1996). Such cell disruption and further fragmentation results in the release of cell wall components (e.g., starch and protein) into the coconut milk, which can enhance particle-particle and particle-emulsion interactions through Van der Waals forces, electrostatic forces, and/or water forces (Ped, et al., 2013). The MS, with the added large particles, may be adsorbed onto the surface of the oil droplet and form a strong network due to its flocculation. The network acts as a mechanical barrier to prevent droplet coalescence, which is the result of stronger network formation; thus, the emulsion remains stable. HAMS and networks with a high viscosity move at slower speeds and inhibit extensive coalescence, resulting in better emulsion stability.Proteins can improve the stability of the emulsion by reducing the interfacial tension and forming a protective film around the fat droplets. Polysaccharides can act as emulsion stabilizers by increasing the viscosity or gel strength of the continuous phase and inducing flocculation of emulsion droplets through bridging or consumption mechanisms depending on the adsorption properties of polysaccharides (Eric, 2009). In accordance with Stokes' law, the apparent viscosity and yield stress of coconut milk with maize kernels or amylose starch increased, while the droplets in the coconut milk with the waxy corn starch probably have a smaller particle size and specific surface area due to the more dependent surfactants (more sodium caseinate and sucrose fatty acid esters), both of which contribute to improving the stability of pure coconut milk.

4. Conclusion

The purpose of this study was to obtain an understanding of the effect of maize starch with different amylose contents on the stability of coconut milk emulsions. Maize grains and maize starch additives do not change the type of fluids in coconut milk. Due to the higher the amylase content the greater the dynamic viscoelasticity. The addition of maize grain can reduce the average particle size of the system, making it difficult for the composite system to coagulate or precipitate.The addition of maize kernels and starch resulted in a significant decrease in the white value of the coconut milk system, and the ζ-potential and surface tension significantly increased (p<0.05).The high-amylose maize starch significantly improved the system's T_0, T_e, T_p and $\triangle H$ (p<0.05) but shortened the temperature range of the system and enhanced the thermal stability of the coconut milk.Maize kernels and maize starch increased the viscosity of the emulsion, waxy maize starch improves the stability of coconut milk emulsions by the action of the surfactant. The stability of the formed system of maize kernelsis similar to that of coconut milk formed by the addition of high-amylose maize starch in terms of the fluid properties. The results obtained in this study can provide a useful insight into the addition of maize or maize flour as stabilizers or nutritional enhancers to foods containing emulsions, such as flavoring agents, condiments and beverages.

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Conflict of interest

All co-authors declare no conflict of interest.

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Figure captions

Figure 1. Rheology properties of coconut milk. (A) Influence of the shear rate on the apparent viscosity curve (B) and flow curve. (C) Strain dependence of the storage modulus *G'* (D), loss modulus *G''* (E) and loss tangent (tanδ) as a function of frequency.

Figure 2. Particle size distribution and particle diameters of coconut milk supplemented with maize kernels and starch.

Figure 3. Evolution of transmission light signals of coconut milk measured by a Lumifuge. The bottom red line represents the first scanning profile, and the top green line represents the final scanning profile. A: CM; B: MK; C: MS; D: HAMS; E: WCS.

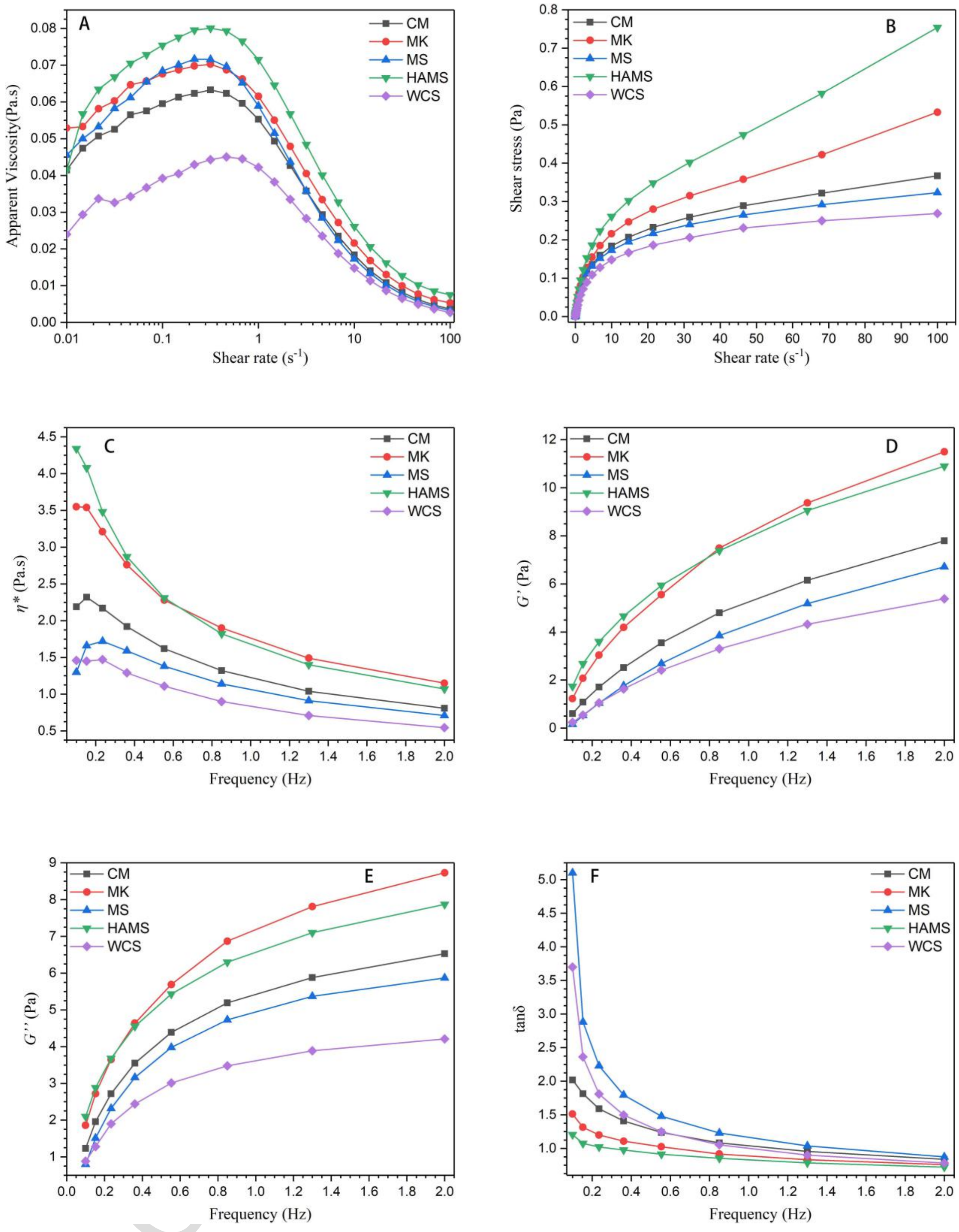
A
B
C
D
E
F
CM
MK
MS
HAMS
WCS
Apparent Viscosity(Pa.s)
Shear rate (s-1)
Shear stress (Pa)
η* (Pa.s)
G' (Pa)
G'' (Pa)
tanδ
Frequency (Hz)

Fig.1

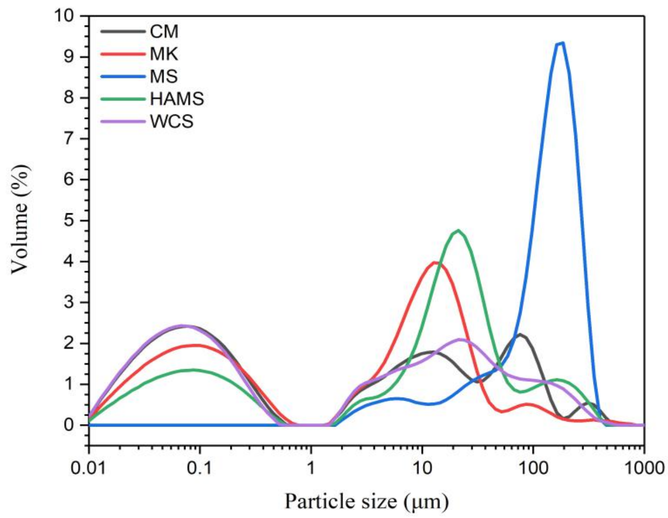
CM
MK
MS
HAMS
WCS
Volume (%)
Particle size (μm)
0
1
2
3
4
5
6
7
8
9
10
0.01
0.1
1
10
100
1000

Fig.2

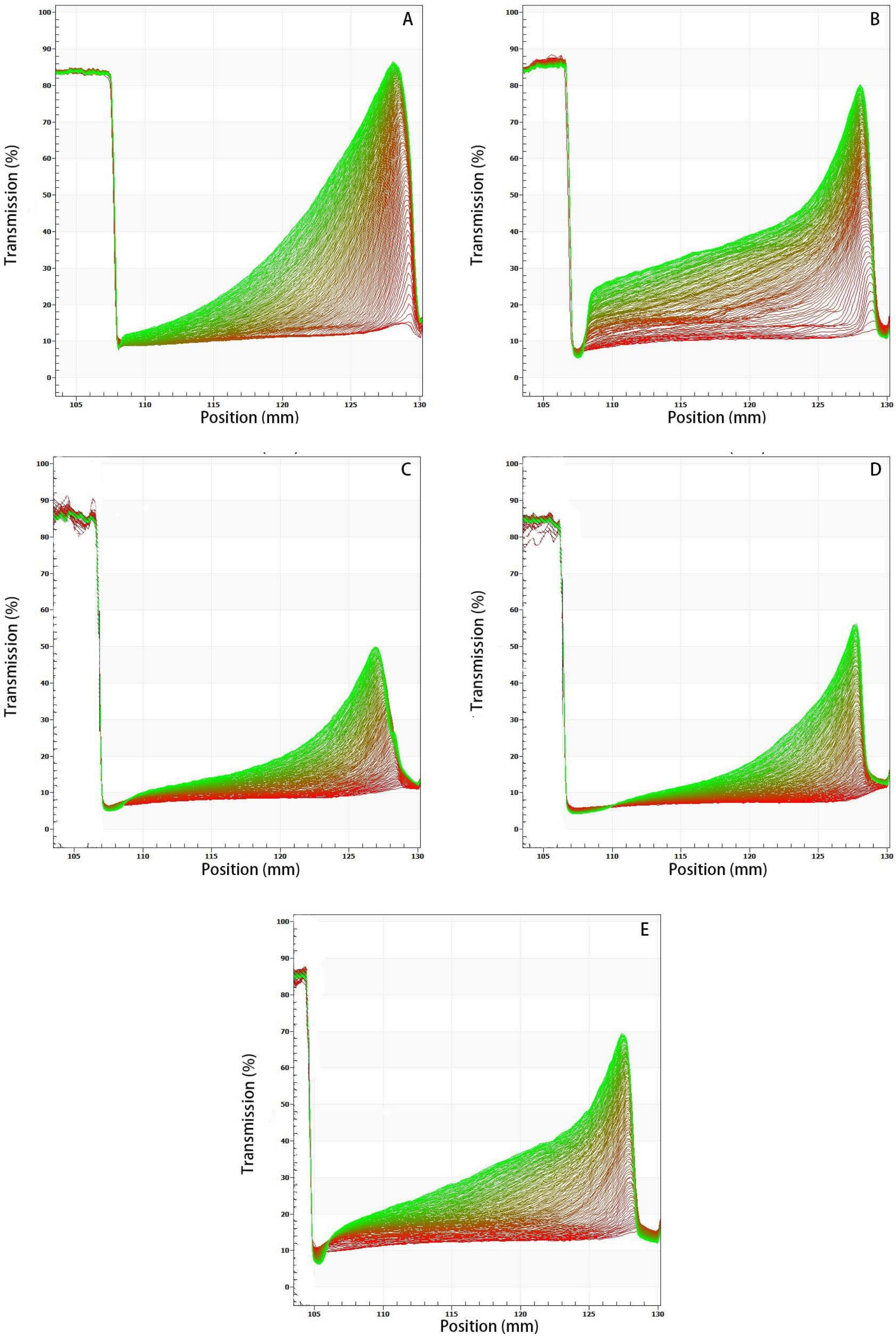
A
B
C
D
E
Transmission (%)
Position (mm)
0
10
20
30
40
50
60
70
80
90
100
105
110
115
120
125
130

Fig.3

Highlights

- The amylose content increased the viscosity and yield stress of coconut milk.
- The coconut milk fluid of the maize kernel is similar to high-amylose maize starch.
- The addition of corn improves the stability of coconut milk.

Table 1 Nutrient composition of maize starch used in this study (%)

Sample	Amyose[a]	Water[b]	Lipid[c]	Protein[d]	Ash[e]
maize kernels	25.63%±0.26	13.49%±0.40	4.43%±0.03	8.76%±0.17	1.45%±0.06
maize starch	26.89%±0.04	9.46%±0.37	0.04%±0.03	0.21%±0.05	0.17%±0.02
high-amylose maize starch	89.06%±0.18	11.29%±0.35	0.13%±0.01	0.39%±0.32	0.08%±0.02
waxy corn starch	0.86%±0.14	10.03%±0.27	0.19%±0.04	0.15%±0.03	0.04%±0.01

Test methods: [a] amylose / amylopectin assay kit (Megazyme Int, Ireland), [b] AACC International Method 44-15.02 (1999), [C] AACC International Method 30-10.01 (1999), [d] AACC International Method 46-16.01 (1999), [e] AACC International Method 08-17.01 (1999).

Table 2 Formulation of composite stabilizers and additives under optimal stability in each group of coconut milk

Sample	Carrageenan (g/L)	Distearin (g/L)	Sodium caseinate (g/L)	Sucrose fatty acid ester (g/L)	Glyceryl monostearate (g/L)	Corn kernels and starch content (g/L)	Creaming rate (mm/d)
CM	0.5	0.5	1	1.5	10	0	0.0184
MK	0.5	0.7	0.8	1.1	10	100	0.0142
MS	0.3	0.7	1.2	1.5	10	3.956	0.0079
HAMS	0.3	0.8	1	1.3	12	3.956	0.0083
WCS	0.3	0.5	1.6	1.7	10	3.956	0.0133

Note: The velocities of the separation of individual particles (mm/d) are used as an indicator; the slower the particle separation rate is, the more stable the system.

Table 3 Modeling of the flow curve between 0.01 and 100 s^{-1} of the shear rate of the coconut milk containing maize kernels and starch using the Herschel-Bulkley model

Sample	τ_0/Pa	K/(Pa•S^n)	n	R^2
CM	-0.0448	0.0951	0.2900	0.9963
MK	-0.0301	0.1184	0.3700	0.9973
MS	-0.0500	0.1104	0.2600	0.9960
HAMS	-0.0228	0.1219	0.3500	0.9984
WCS	-0.0421	0.0987	0.2700	0.9935

Table 4 D[4,3], D[3,2] and the specific surface area of coconut milk supplemented with maize kernels and starch; D[3,2]: surface-area-based mean diameter; D[4,3]: volume-based mean diameter

Sample	D[4,3] (μm)	D[3,2] (μm)	Specific surface area (m^2/kg)
CM	28.64±1.1^{a}	0.11± 0.00^{a}	35730± 1589.12^{a}
MK	16.12±0.32^{b}	0.13± 0.01^{b}	28000± 1242.51^{b}
MS	150.35±6.71^{c}	40.97± 0.32^{c}	91.63± 1.00^{c}
HAMS	35.71±1.52^{d}	0.19± 0.01^{d}	19370± 561.15^{d}
WCS	27.44±0.91^{a}	0.11± 0.01^{a}	36160± 798.89^{a}

^{abc} Means in the same column without the same letter are significantly different ($p < 0.05$) according to a Duncan multiple range test.

Table 5 Changes in the color, surface tension, zeta-potential and creaming index of coconut milk stabled by the five tested samples (CM, MK, MS, HAMS, and WCS)

Sample	L^*	a^*	b^*	$\triangle E$	Zeta potential (mv)	Surface tension (mN/m)	Creaming index (%/h)
CM	78.12±0.81[a]	-2.98±0.02[a]	-2.89±0.01[a]	0[a]	-25.54±2.12[a]	19.18±0.34[a]	4.12±0.23[a]
MK	72.73±0.19[b]	-3.14±0.05[b]	-3.29±0.03[b]	5.4±0.38[b]	-7.93±0.34[b]	20.58±0.45[b]	3.69±0.11[b]
MS	74.48±0.91[c]	-4.49±0.06[c]	-5.35±0.07[c]	4.64±0.33[c]	1.38±0.57[c]	20.46±0.51[b]	2.47±0.04[c]
HAMS	75.87±0.48[c]	-3.32±0.03[d]	-3.88±0.06[d]	2.46±0.16[d]	-0.7±0.35[d]	20.58±0.38[b]	2.94±0.09[d]
WCS	74.76±1.01[c]	-5.32±0.03[e]	-6.25±0.01[e]	5.29±0.29[b]	1.39±0.99[c]	20.12±0.21[b]	2.76±0.06[e]

[abc] Means in the same column without the same letter are significantly different ($p < 0.05$) according to a Duncan multiple range test.

Table 6 DSC scans of coconut milk stabilized by the five tested samples (CM, MK, MS, HAMS, and WCS)

Sample	T_0 Initial gelatinization temperature /°C	T_p Peak of gelatinization temperature /°C	T_e Termination of gelatinization temperature /°C	$\triangle H$ Thermal enthalpy /J·g^{-1}
CM	58.23±0.23^{a}	65.10±0.31^{a}	71.91±0.24^{a}	44.23±0.61^{a}
MK	64.99±0.17^{b}	70.60±0.29^{b}	76.88±0.16^{b}	50.79±0.63^{b}
MS	60.96±0.21^{c}	64.90±0.22^{a}	73.78±0.26^{c}	47.73±0.47^{c}
HAMS	67.21±0.45^{d}	71.9±0.31^{c}	79.12±0.36^{d}	51.03±0.24^{b}
WCS	60.13±0.19^{c}	63.70±0.34^{d}	76.21±0.26^{b}	45.88±0.58^{d}

^{abc} Means in the same column without the same letter are significantly different ($p < 0.05$) according to a Duncan multiple range test.