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RESEARCH ARTICLE

Influence of Temperature on the Rheological Properties of Selected Mango Products with 'Saba' Banana (*Musa acuminata* x *Musa balbisiana* BBB Group) Peel Pectin

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Abstract Saba banana peel pectin (BPP) was applied to mango jelly and mango juice. The rheological characteristics (flow curve, viscosity curve) of mango products at different temperatures (15°C, 25°C, 35°C, 45°C and 55°C) were then evaluated. The rheological data were fitted using the Hershel-Buckley model and the yield stress, consistency index, and flow behavior were identified. Values obtained from BPP mango products were compared to those with commercial low methoxyl pectin (LMP) and high methoxyl pectin (HMP). Results showed that all types of pectin resulted in non-Newtonian mango jelly and mango juice at all temperatures. For both mango jelly and mango juice, the yield stress contributed by BPP was similar to that of HMP. For the consistency, BPP and LMP had same effects on mango jelly while BPP and HMP had the same effects on mango juice at lower temperatures. For the flow behavior, BPP and HMP showed shear thinning effects for most of the temperatures tested.

Keywords: Banana peel pectin, Rheology, Flow curve, Mango jelly, Mango juice.

Introduction

Pectin, a high-value food ingredient, can be extracted from fruit peels and other plant parts. It is used as a gelling agent and a stabilizer in emulsion systems and thus has wide application prospects in the food industry. It is also used as a food additive and a component of edible films [1,2]. It has been used to maintain qualitative characteristics such as extending the shelf-life of fruits and vegetables [3]. Pectin also reduces the cooking time, improves the texture and color, and increases the shelf-life of fruit and fruit products [4].

Commercially, pectin can be used as a gelling agent, giving fruit products such as jams and jellies their desired structure and characteristics. For these types of products, high-methoxyl pectin (HMP, 8%–11% methoxyl content) is generally applied, as it facilitates the formation of a gel when combined with sugar and acid. HMP leads to fast gel formation and can form gels with a high sugar content (>65% sugar) and acidic pH (2.20–2.80). The low pH reduces the electrostatic repulsion and the sugar helps to bring the chains closer together, thereby establishing strong hydrogen bonds because of reduced water activity.

Low-methoxyl pectin (LMP, <7% methoxyl content) may also act as a gelling agent but with a different mechanism. It forms a gel by strongly binding divalent ions. For LMP, the pH of the medium should be higher than the pectin's isoelectric pH. A junction zone will then be created between unbranched non-esterified galacturonan blocks that are covalently bound together by coordinated calcium ions [5]. LMP can form gels at a lower sugar content than HMP so it has more applications. The gel network created by pectin traps water and provides the desired thickness and consistency. Pectin also helps maintain

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the stability and consistency of a product. Jelly without pectin has a weak gel structure, which may break down, resulting in the separation of liquid and solid components.

For fruit juices, pectin acts as a thickener. As sugar is added to a fruit juice with pectin, the pectin–water equilibrium breaks down, and a fibrous network capable of supporting liquids is established [6]. The fiber network, just like in gelling, is formed and that makes the juices thick and stable.

Pectin can be extracted from ‘saba’ banana peels [7][8]. In 2023, out of the banana varieties produced in the Philippines, ‘saba’ banana was produced at the second greatest volume [9]. Since only the flesh of the saba banana fruit is eaten, its peel is often discarded as waste [10]. The extraction and application of ‘saba’ banana peel pectin (BPP) to food products provide a basis for promoting the valorization of agricultural and food processing wastes.

Rheological properties of food products provide data on the microstructure of food. They indicate the rate and nature of deformation that occurs in a product when it is subjected to stress. The data obtained from rheological testing are vital in predicting the behavior of fluid and in determining the energy required to transport samples within the processing plant [11]. Rheology parameters are also used to define quality attributes of food – which are especially important in identifying possible ways to improve the overall sensory qualities of food products.

In this study, ultrasound-assisted extracted saba banana peel pectin was applied in mango jam and mango jelly. Then, its rheological properties were measured and compared to that of commercial low methoxyl citrus pectin and high methoxyl citrus pectin. Moreover, since temperature changes can alter the physical and chemical properties of food components and thus influence the overall product quality, the influence of temperature on the properties of mango jelly and juice was investigated.

Materials and Methods

Raw Material

BPP is an ultrasound-extracted pectin from ‘saba’ banana peel waste. It was obtained from the Institute of Food Science and Technology, University of the Philippines Los Baños (IFST-UPLB), Laguna, 4031, Philippines. HMP and LMP were obtained from a local pectin supplier. The fruits used to produce the mango jelly and juice were obtained from Bay, Laguna, Philippines. All other chemicals and reagents used were analytical grade, unless otherwise stated.

Mango Jelly and Juice

For mango jelly and juice, the mango extract was prepared first by mixing 50 parts of mango puree with 50 parts of distilled water. The mixture was boiled for 15 minutes and filtered with a clean cheesecloth afterward.

For mango jelly, the established protocol of the IFST-UPLB was used with some modifications. The mango extract was combined with sugar following a 45:55 ratio (extract to sugar). The mixture was heated slowly and then added with 1% pectin (BPP, HMP, and LMP) and calcium citrate (1% w/w). Moreover, glucono-delta lactone was added at a 0.5% w/w concentration. The mixture was heated until the total soluble solids (TSS) reached 65 to 68°Brix. The mixture was then poured into pre-sterilized cans, sealed, and stored at room temperature. A control sample without pectin was also prepared.

For juice processing, 25 parts of the mango extract were combined with 75 parts of distilled water. The solution was added with 16% (w/v) sugar (w/v), 0.5% (w/v) food-grade citric acid (the pH should be <4.5), and 1% pectin (BPP, HMP, and LMP). The sample was then heated to 80°C for 5 min. After heating, the juice was hot-filled in polyethylene terephthalate bottles and stored at 4°C prior to analysis. A control sample without pectin was prepared.

Rheological Testing

Measurement of rheological properties was conducted using a cone-plate rheometer (RM 200 CP4000 Plus) using an increasing shear rate from 2 to 200 s^{-1} [8] at variable temperatures (15°C, 25°C, 35°C, 45°C and 55°C). Flow curves (shear stress in Pa versus shear rate in s^{-1}) and viscosity curves (viscosity in P vs. shear rate in s^{-1}) were obtained, and a suitable regression model was selected. Yield stress was determined using the appropriate model. Moreover, the relationship between shear stress and shear rate was used to determine the thixotropic effect.

Results and Discussion

Mango Jelly

The flow curves (Figure 1) of mango jelly indicated that shear stress increased with increasing shear rate, whereas the viscosity curve (Figure 2) showed decreased viscosity. This finding confirms that all mango jelly samples exhibited shear thinning with yield stress behavior, which is common in suspension foods derived from fruits [12].

Rheological data were fitted using the Herschel–Bulkley model to determine the of yield stress, consistency index, and flow behavior of the non-Newtonian mango jelly. The Herschel-Bulkley model is an empirical rheological model that extends the power-law relationship to include yield stress in addition to the shear-thinning behavior observed in pseudoplastic fluids. As shown in Table 1, BPP and HMP resulted in mango jellies with yield stresses that are not significantly different ($p<0.05$) at all temperatures. Mango jelly added with LMP, however, had the highest yield stress. Yield stress is the minimum shear stress applied to a material to initiate flow. It is regarded as a transition stress, where a material exhibits a viscoelastic behavior, that is, it behaves like an elastic solid or viscous liquid. In food, yield stress is a measure of the spreadability of semi-solid food products, such as jelly. It is associated with the quality and consumer acceptance of spreadable foods and is an important parameter in quality control in manufacturing [13]. Yield stress is correlated with sensory attributes, such as spreadability and mouthfeel, and a low yield stress value indicates a good spreadability of a food product [14]. These findings provide an understanding of the initial flow behavior of mango jelly samples added with different types of pectin at different temperatures.

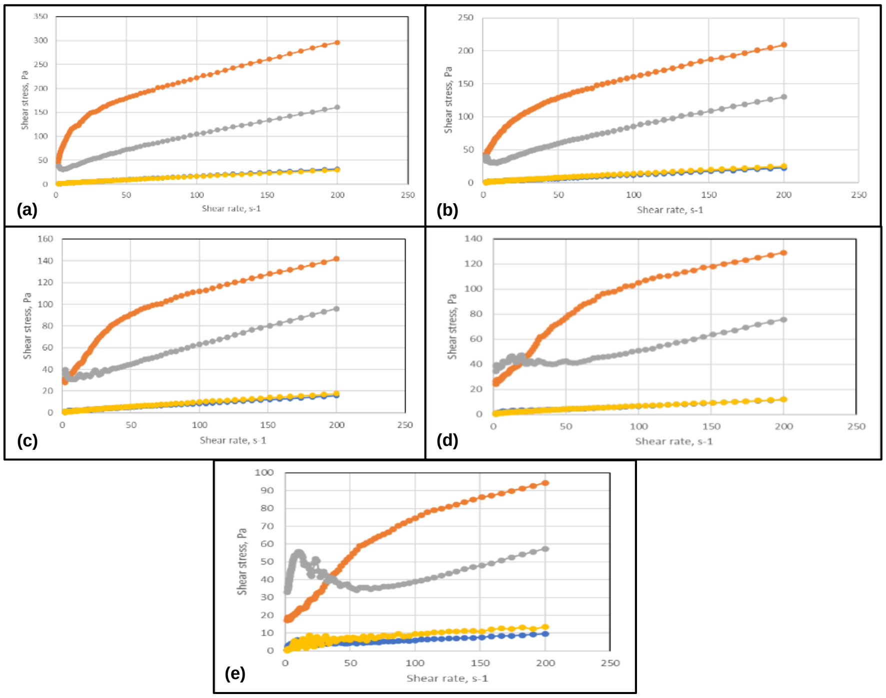

Figure 1. Flow curves of mango jelly at different temperatures. (a - 15°C, b - 25°C, c - 35°C, d - 45°C, and 55°C; blue dotted line - control, orange dotted line - HMP, gray dotted line - LMP, yellow dotted line - BPP)

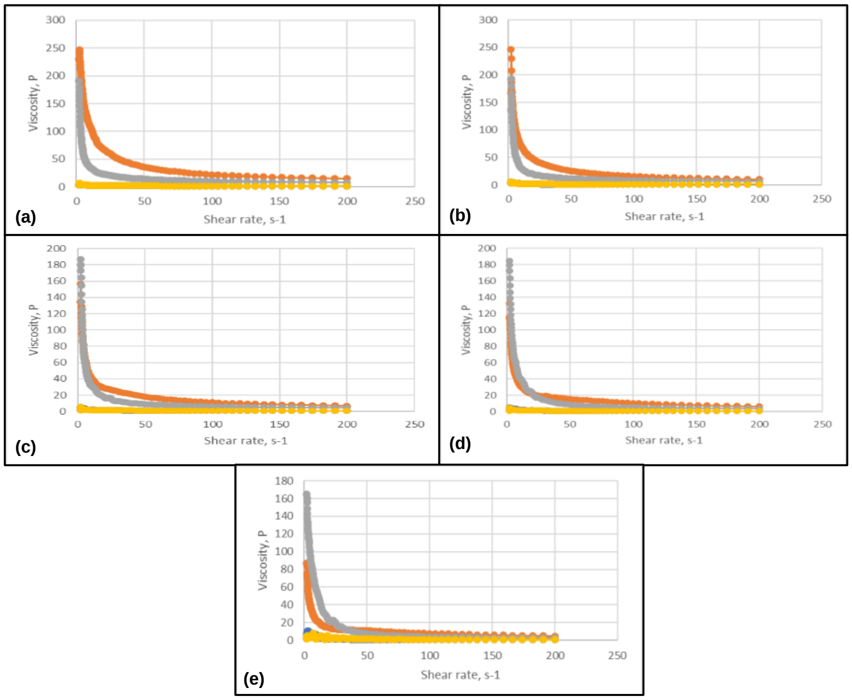

Figure 2. Viscosity curves of mango jelly at different temperatures. (a - 15°C, b - 25°C, c - 35°C, d - 45°C, and 55°C; blue dotted line - control, orange dotted line - HMP, gray dotted line - LMP, yellow dotted line - BPP)

On the effect of pectin on mango jelly's consistency index, results (Table 1) showed that BPP and LMP produced similar consistency ($p<0.05$) in all temperatures evaluated. It was also observed that increasing the temperature generally reduced the consistency of mango jellies fortified with BPP and HMP. The consistency index decreased with increasing temperature, conforming to the general trend that viscosity decreases with temperature. Consistency index measures the flowability of a fluid or powder material and is calculated using physical parameters, such as viscosity. It does not depend on the size or shape of particles in the material but indicates the relationship between viscosity and temperature [15].

In terms of flow behavior index, all pectin samples resulted in shear-thinning mango jellies at 15ºC and 25ºC. At 35ºC and 45ºC, both BPP and HMP maintained the jellies' thinning behavior while LMP resulted in a shear-thickening jelly. The flow behavior index measures the degree of shear thinning or thickening characteristic and provides information on flow phenomena for single-phase flow or flow-carrying suspended particles. In BPP and HMP, it increases with increasing temperature, indicating that the behavior of jelly becomes less shear thinning.

Table 1. Yield stress, consistency index, and flow behavior of mango jelly with different pectin types at various temperatures

Temperature (°C)	Pectin Type	Yield Stress (x10^{-3}), τ (Pa)	Consistency Index, K (Pa-s^{n})	Flow Behavior, n
15	CTRL	0.47±0.3^{bAB}	0.30±0.03^{bB}	0.87±0.1^{aA}
15	HMP	2.00×10^{-5}±1.0×10^{-5bC}	44.28±6.8^{aA}	0.36±0.1^{bC}
15	LMP	28.10±3.4^{aA}	1.19±0.5^{bA}	0.91±0.1^{aAB}
15	BPP	0.34±0.4^{bAB}	0.37±0.1^{bA}	0.79±0.1^{aB}
25	CTRL	0.58±0.3^{bA}	0.28±0.1^{bB}	0.82±0.1^{aA}
25	HMP	0.57±1.1^{bC}	28.15±6.4^{aB}	0.39±0.1^{bC}
25	LMP	26.75±5.8^{aA}	1.17±1.5^{bA}	0.96±0.2^{aAB}
25	BPP	0.50±0.1^{bAB}	0.28±0.1^{bA}	0.85±0.1^{aB}
35	CTRL	0.04±0.1^{cBC}	0.45±0.2^{bB}	0.66±0.1^{bB}
35	HMP	13.83±2.1^{bAB}	9.33±0.8^{aC}	0.51±1.7×10^{-2cB}

Temperature (°C)	Pectin Type	Yield Stress (x10^{-3}), τ (Pa)	Consistency Index, K (Pa-s^{n})	Flow Behavior, n
35	LMP	32.05±1.6^{aA}	0.09±0.1^{bA}	1.27±0.1^{aAB}
35	BPP	0.16±0.2c^{AB}	0.29±0.1^{bA}	0.76±4.6×10^{-2bB}
45	CTRL	3.00×10^{-5}±1×10^{-5cC}	0.50±0.1^{bB}	0.57±3.8×10^{-2bB}
45	HMP	17.42±2.9^{bA}	3.89±0.9^{aC}	0.67±0.1^{bA}
45	LMP	39.71±4.1^{aA}	4.00×10^{3}±5.4×10^{3bA}	1.96±0.4^{aA}
45	BPP	0.05±0.1^{cB}	0.28±0.1^{bA}	0.71±3.1×10^{-2bB}
55	CTRL	2.00×10^{-5}±1.0×10^{-5bC}	1.00±0.3^{aA}	0.41±0.1^{aC}
55	HMP	12.95±1.3^{abB}	1.82±0.1^{aC}	0.75±1.1×10^{-2aA}
55	LMP	30.70±20.6^{aA}	9.95±19.8^{aA}	0.63±1.2^{aB}
55	BPP	0.66±0.4^{bA}	0.03±0.1^{aB}	1.50±0.4^{aA}

Results are mean ± SD of four replicate measurements ($p<0.05$).
Values with same lower-case letters are statistically equal across pectin types within the same temperature.
Values with same upper-case letters are statistically equal across different temperatures within the same pectin type.

Mango Juice

Similar to mango jelly, the rheological data obtained from the mango juice supplemented with different types of pectin were fitted in Herschel–Bulkley model. As expected, the samples exhibited a non-Newtonian fluid behavior as evidently shown in their flow (Figure 3) and viscosity (Figure 4) curves. As the shear stress increased, the shear rate also increased with a concomitant decrease in apparent viscosity. This observation is parallel with the rheological behavior of a ready-to-drink (RTD) mango juice [16] and other fruit juices [17].

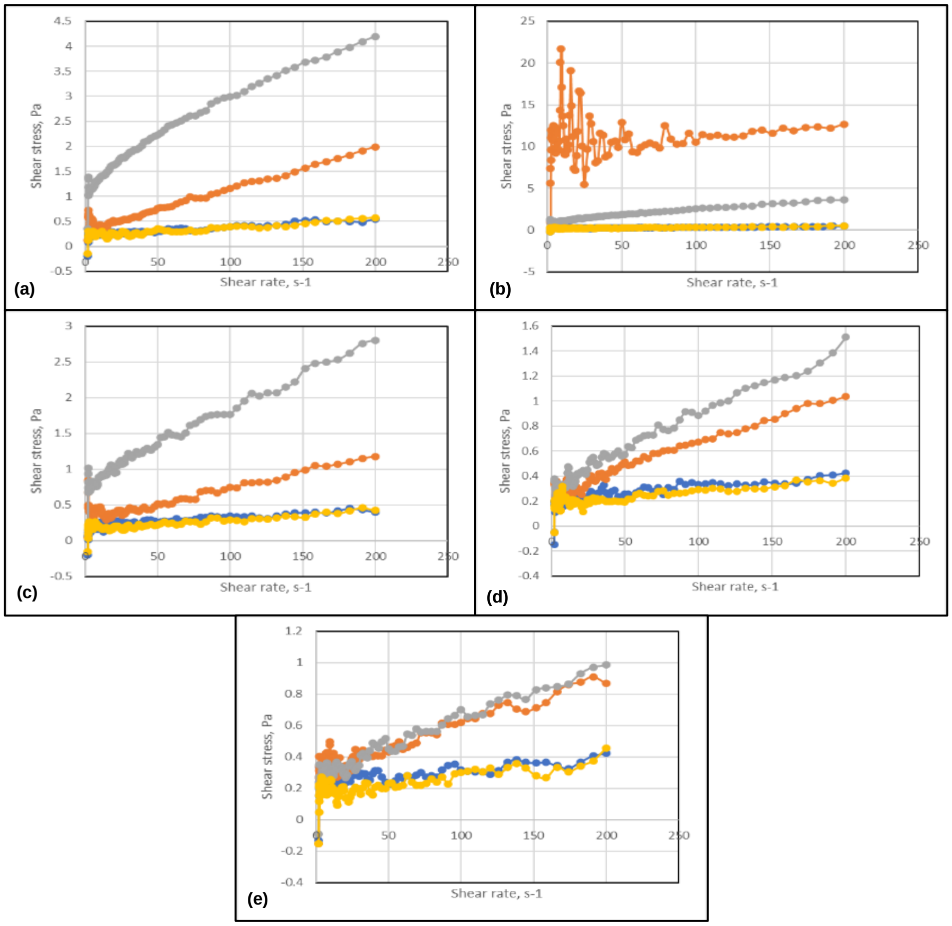

Figure 3. Flow curves of mango juice at different temperatures. (a - 15°C, b - 25°C, c - 35°C, d - 45°C, and 55°C; blue dotted line - control, orange dotted line - HMP, gray dotted line - LMP, yellow dotted line - BPP)

In addition, the yield stresses of mango juice, regardless of pectin types and temperatures, were not significantly different ($p<0.05$). Moreover, the yield stress obtained for mango juice was lower than that of mango jelly. Hence, mango juice did not require much shear stress to initiate flow. In addition, BPP behaved like HMP at temperatures 15ºC, 25ºC, and 35ºC (Table 2). At higher temperatures, the consistency indices of the samples were not significantly different ($p<0.05$). For the flow behavior, BPP showed no significant difference ($p<0.05$) with other types of pectin at all temperatures.

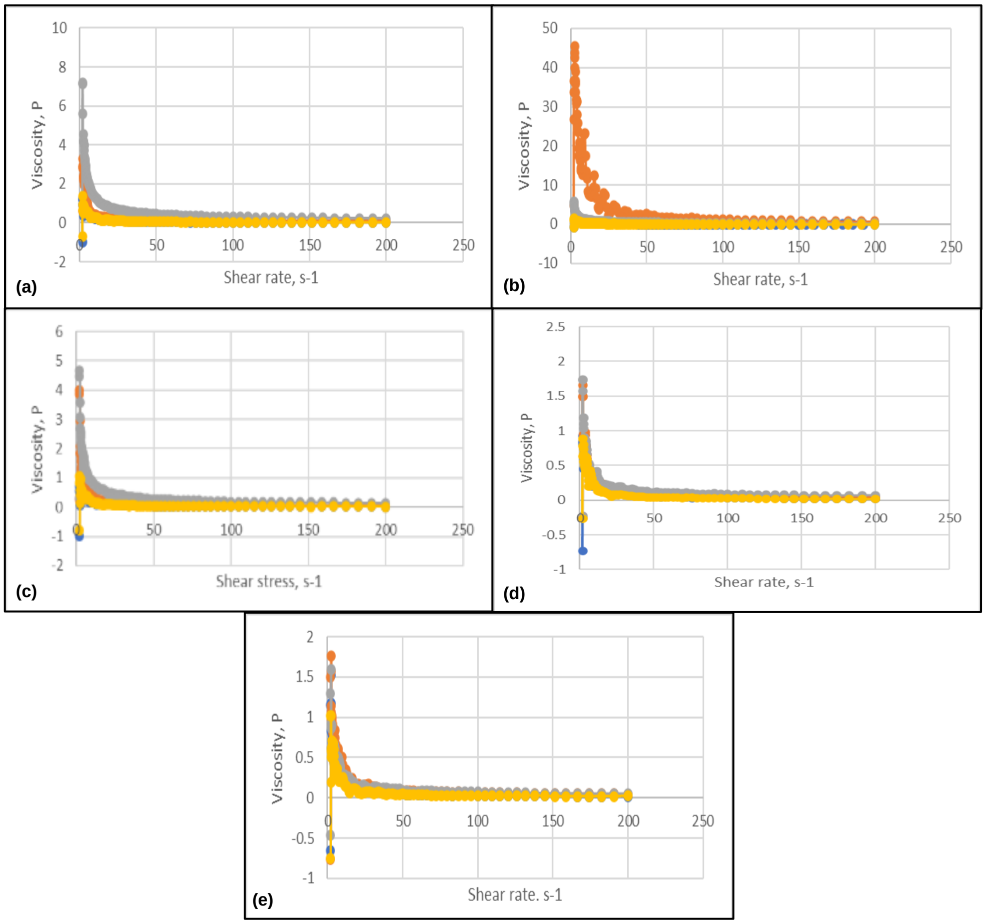

Figure 4. Viscosity curves of mango juice at different temperatures. (a - 15°C, b - 25°C, c - 35°C, d - 45°C, and 55°C; blue dotted line - control, orange dotted line - HMP, gray dotted line - LMP, yellow dotted line - BPP)

The influence of temperature on the rheological behavior of juices has been previously demonstrated by different studies. In beetroot juice, increasing temperature resulted in lower values of yield stress, consistency index, and flow behavior [18]. Similarly, tomato juice had resulted in a decrease in such parameters when subjected to temperatures between 0-80°C [19]. However, this was not observed in the current study. This may be due to the level of pectin or solids in the developed mango juice. Concentration of solids in juices has been identified to significantly influence the dependence of viscosity on temperature. Juices with higher amounts of soluble solids are more likely to be affected by changes in temperature [20]. Hence, increasing the levels of BPP on mango juice as well as the amount of sugar in the formulation can be further explored to fully understand the changes in the rheological behavior of such a beverage as influenced by temperature.

Table 2. Yield stress, consistency index, and flow behavior of mango juice with different pectin types at various temperatures

Temperature (°C)	Pectin Type	Yield Stress ($x10^{-3}$), τ (Pa)	Consistency Index, K ($Pa\text{-}s^n$)	Flow Behavior, n
15	CTRL	0.09 ± 0.1^{aA}	$0.02 \pm 3.9 \times 10^{-2bA}$	0.81 ± 0.3^{aA}
15	HMP	0.28 ± 0.2^{aA}	$0.01 \pm 1.6 \times 10^{-2bB}$	1.10 ± 0.4^{aA}
15	LMP	$4.00 \times 10^{-4} \pm 8.0 \times 10^{-4aA}$	0.48 ± 0.20^{aA}	0.42 ± 0.1^{aB}
15	BPP	0.10 ± 0.1^{aA}	$0.03 \pm 3.7 \times 10^{-2bA}$	0.80 ± 0.5^{aA}
25	CTRL	0.09 ± 0.1^{aA}	$0.02 \pm 2.9 \times 10^{-2bA}$	0.85 ± 0.4^{aA}
25	HMP	0.59 ± 1.2^{aA}	1.82 ± 1.2^{aA}	0.47 ± 0.3^{aA}
25	LMP	0.39 ± 0.4^{aA}	0.17 ± 0.1^{bAB}	0.63 ± 0.2^{aAB}
25	BPP	0.04 ± 0.1^{aA}	$0.01 \pm 1.5 \times 10^{-2bA}$	0.82 ± 0.2^{aA}
35	CTRL	$0.01 \pm 2.1 \times 10^{-2aA}$	$0.03 \pm 1.0 \times 10^{-2aA}$	0.54 ± 0.1^{bA}
35	HMP	0.29 ± 0.2^{aA}	$0.01 \pm 2.8 \times 10^{-2aB}$	1.29 ± 0.5^{aA}
35	LMP	0.26 ± 0.3^{aA}	0.17 ± 0.2^{aAB}	0.64 ± 0.3^{abAB}
35	BPP	0.04 ± 0.1^{aA}	$0.01 \pm 8.8 \times 10^{3aA}$	0.81 ± 0.3^{abA}
45	CTRL	0.09 ± 0.1^{aA}	$0.02 \pm 2.1 \times 10^{-2aA}$	0.91 ± 0.6^{aA}
45	HMP	0.13 ± 0.1^{aA}	$0.03 \pm 3.1 \times 10^{-2aB}$	0.74 ± 0.2^{aA}
45	LMP	0.19 ± 0.1^{aA}	$0.03 \pm 3.3 \times 10^{-2aB}$	0.76 ± 0.1^{aAB}
45	BPP	0.08 ± 0.1^{aA}	$5.27 \times 10^{-3} \pm 9.7 \times 10^{-3aA}$	1.16 ± 0.4^{aA}
55	CTRL	0.09 ± 0.1^{aA}	$0.02 \pm 3.0 \times 10^{-2aA}$	0.76 ± 0.4^{aA}
55	HMP	0.24 ± 0.2^{aA}	$0.01 \pm 1.8 \times 10^{-2aB}$	1.05 ± 0.5^{aA}
55	LMP	0.13 ± 0.2^{aA}	$0.06 \pm 2.6 \times 10^{-2aB}$	0.95 ± 0.3^{aA}
55	BPP	0.06 ± 0.1^{aA}	$6.0 \times 10^{-4} \pm 9.0 \times 10^{-4aA}$	0.99 ± 0.7^{aA}

Results are mean ± SD of four replicate measurements ($p<0.05$).
Values with same lower-case letters are statistically equal across pectin types within the same temperature.
Values with same upper-case letters are statistically equal across different temperatures within the same pectin type.

Conclusions

Mango jelly and mango juice were produced using ‘saba’ banana peel pectin, and these products were compared to those made with high-methoxyl pectin (HMP) and commercial low-methoxyl pectin (LMP). Upon examining the rheological properties, findings revealed that all pectin types led to the development of non-Newtonian characteristics in both mango jelly and mango juice across all temperatures. In terms of yield stress, BPP exhibited similar effects to HMP in both mango jelly and mango juice. Consistency was comparable between BPP and LMP for mango jelly, while BPP and HMP showed similar impacts on mango juice at lower temperatures. Regarding flow behavior, BPP and HMP displayed shear-thinning effects for most of the tested temperatures in both mango jelly and mango juice. Collectively, these results serve as an initial attempt to understand the effects of BPP in modifying the rheological properties of mango jelly and mango juice.

Conflicts of interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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