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# Effects of Ripeness and Blending Speed on the Extraction Yield and Physical Chemical Properties of Low Viscosity Banana Juice

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**Abstract**

Low viscosity banana juice can be extracted from banana by blending and pressing the resulted semi-solid pulp to separate the juice. This juice extraction technology is relatively new and further studies to understand key parameters for juice release is vital for scaling up production and commercialisation. This study, investigated the influence of blending speed and ripeness stage on banana juice yield using two banana cultivars; the East African highland banana (*Mbile*) and the exotic banana (Pisang awak). Types of sugars and organic acids in the juice were analysed using an HPLC. Changes with ripening of fruit firmness, juice pH and soluble solids were also examined. The juice yield increased significantly ($p < 0.05$) with increasing blending speed and ripeness stage for all cultivars. The *Mbile* cultivar from Kagera had the highest juice yield of 82.35%, followed by *Mbile* cultivar from Kilimanjaro with 75.30% and Pisang awak cultivar with juice yield of 62.50%. The highest juice yield for all cultivars was achieved at 3500 rpm blending speed and ripeness stage 5. Fructose and glucose sugars increased significantly ($p < 0.05$) with ripeness, while sucrose showed insignificant changes. Malic and citric acids were observed to increase significantly ($p < 0.05$) during ripening in all banana cultivars.

**Keywords:** East African highland banana, Banana juice extraction, Blending speed, Low viscosity banana juice.

## Introduction

Banana is one of mostly cultivated and consumed fruit crops in the world. It is one of the earliest fruit crops worldwide and originated from South East Asia (Maduwanthi and Marapana 2019). Banana fruit is a good source of nutrients including fibres, proteins, polyphenols, and vitamins with health-promoting properties (Ibarra-Junquera et al. 2014, Pillay and Fungo 2016). Yet, banana is a perishable fruit that should be consumed within a few days after harvest (Kyamuhangire et al. 2002). Banana tissues like other fruits remain alive after harvesting and undergo various biochemical processes, including ripening and respiration (Imsabai et al. 2006, Goulao et al. 2007, Vonali et al. 2009, Hailu et al. 2013). These changes can cause losses in fruit quality and nutritional values that ultimately lead to fruit senescence and postharvest losses. Thus, the processing techniques such as juice extraction, postharvest preservation are required to minimise undesirable changes throughout the postharvest chain to increase the off-seasonal availability of fruits (Surendranathan et al. 2003) and reduce postharvest losses.

Fruit ripening is a complex process triggered by ethylene, a gaseous plant hormone (Imsabai et al. 2006, Hailu et al. 2013). This phenomenon is accompanied by dramatic changes in physiological, molecular,

and biochemical processes leading to biosynthesis of pigments (colour), softening process (firmness), biosynthesis of volatile compounds such as flavour and aroma, starch hydrolysis, sugar accumulation, and disappearance of organic acids that influence taste (Alexander and Grierson 2002, Maduwanthi and Marapana 2019). Knowledge of fruit ripening could enhance the juice production and assist quality control of fruits during postharvest (Kyamuhangire et al. 2002, Majaliwa et al. 2019). Besides, the ripeness changes the physicochemical and sensory properties as the bananas become sweet due to sugar accumulation (Yap et al. 2017). The juice clarity, flavour and aroma may also be influenced by the ripeness stage. The evaluation of the fruit ripeness stage focuses on measuring firmness, colour and total soluble solids.

Low viscosity banana juice has been produced using an indigenous method that involves the use of banana leaves or grasses (*Imperata cylindrica*) to physically crush the ripe banana for about 15–25 min in a saucepan or canoe-like container by using bare hands or feet, respectively, until the juice oozes out (Gensi et al. 1994). This technique has been in use for more than 200 years (Mgenzi et al. 2010). However, this traditional method extracts juice in non-hygienic conditions with low yield, which is unsuitable for commercialisation. New techniques for banana juice extraction that mimic traditional mechanical and or enzymatic methods have been established (Kyamuhangire et al. 2002, Byarugaba-Bazirake 2008). Kibazohi et al. (2017) extracted a low viscosity banana juice from peeled ripe banana using mechanical method and in hygiene conditions involving blending and pressing the semi-solid pulp. The technique was later optimised by Majaliwa et al. (2019) whereby blending speed, extraction time and ripeness stage were identified as important parameters for juice extraction. The authors reported that optimum blending speed is a prerequisite for mechanical disruption of laticifer cells to release tannin compounds. The tannin-protein interaction is highly associated with low viscosity banana juice release from banana (Kyamuhangire et al. 2006). However, Majaliwa et al. (2019) considered only one cultivar, the Pisang awak and physicochemical parameters were also not explored. For a more complete understanding of how those parameters contribute to juice production, further investigation that involved different cultivars of banana at different ripeness stages is required to explore the underlying mechanisms for juice extraction. Besides, the literature contains limited information on how the banana ripeness stage in terms of firmness relates to juice extraction yield. This study, therefore, investigated the effect of blending speed and banana ripeness on juice yield as well as ripeness fruit firmness, juice sugars, organic acids, pH and soluble solids from different banana cultivars.

## Materials and Methods

### Banana fruits

Two cultivars of banana *(Musa acuminata)*: the exotic banana (Pisang awak) and High-tannin East African highland banana (locally known as *Mbile*) cultivars were collected from different regions. About 40 kg of Pisang awak bananas from Mbeya region, Southern western Highlands of Tanzania were bought from Urafiki-Mabibo local market in Dar es Salaam region. Two *Mbile* cultivars weighing around 50 kg each were collected from Kagera region, in the north-west of Tanzania and Kilimanjaro region in northern Tanzania. The banana bunches were brought to the Food laboratory at the Department of Chemical and Mining Engineering, University of Dar es Salam and stored at an ambient temperature for ripening before juice extraction.

### Reagents

Methanol (99.9%) analytical reagent (Fisher Scientific, UK) was used as a solvent for preparation of sucrose (BDH, UK), fructose (Carlo Ebra Reagent Group) and glucose (Carlo Ebra reagent Group, UK) standards. A HPLC grade acetonitrile (Fisher Scientific, UK) and HPLC grade deionised water were used to prepare a mobile phase. Citric acid, malic and succinic acids (99.9% purity)

(Sigma-Aldrich, Steinheim, Germany) were used as standards.

**Fruit firmness measurement**

Fruit firmness was measured using a fruit Penetrometer (Yueqing Handpi, Model GY-3, Zhejiang, China) to assess degree of ripeness. A cylindrical plunger having a diameter of 5.2 mm was used to take three measurements of the peeled banana at the top quarter, the middle, and the lower quarter; the trees were averaged to get banana fruit firmness (N $m^{-2}$). For each cultivar, the measurement was performed at different ripeness stages, namely 3, 4 and 5. The selection of ripeness stages was based on colour chart described by Tapre and Jain (2012) whereby fruit colour stage 1 corresponds to all green; stage 2, green with a trace of yellow; stage 3, more green than yellow; stage 4, more yellow than green; stage 5, yellow with a trace of green; stage 6, all yellow, and stage 7, all yellow with brown speckles.

**Juice extraction**

The ripe bananas were plucked from bunches, washed, and hand peeled. About 1.5 kg of the peeled bananas was put into a blender (Blixer 4 V.V, Robot Couple, France), and mashed at different speeds of 1500, 2500 and 3500 rpm. The blending speeds were chosen based on the study by Majaliwa et al. (2019). The semi-solid pulp obtained was then pressed using a mechanical presser to separate the juice from the pulp. The juice samples were stored in a horizontal freezer (Electrolux, ECM30132W) set at -20 °C for further analysis.

**Juice yield, total soluble solids and pH**

For each banana cultivar, juice yield (%) was determined by weighing the juice collected (g) and dividing by the mass of the peeled banana samples. The total soluble solids (°Brix) and pH analyses were carried out, only for the banana juices blended at 2500 rpm as suggested by Majaliwa et al. (2019). Total soluble solids (TSS) and pH of the juice samples were measured following the protocols described by Matabura and Kibazohi (2021). The total soluble solids and pH determinations were performed in triplicates.

**Sugar measurements**

***Standard preparation***

About 25 mL of methanol was poured into a 100 mL conical flask and diluted with 50 mL deionised water. Different sugar quantities were added and the flask filled to the mark with deionised water to obtain concentrations of 5, 40, 80, 120 and 150 g per L of sucrose, fructose, and glucose sugars for calibration analysis according to Medeiros and Simoneit (2007). The prepared standard solutions were degassed in the ultrasonic bath (Wagtech Branson 3210, USA) for 10 min. and filtered using a vacuum pump (Buchi Swetco V-700, UK) before being injected into HPLC.

***HPLC for sugar analysis***

High-Performance Liquid Chromatography (Shimadzu-HPLC, LC-20AT**,** Japan) was used to identify and quantify sugars in the banana juice using UV-detector at 250 nm wavelength. The chromatography separation was achieved in a Nucleosil carbohydrate column, EC 250/4 at 30 °C, under the acetonitrile-water mix of 80: 20 (v/v) as the mobile phase. Juice samples were mixed with deionised water at a ratio of 1: 2 (v/v) and then vortexed before injection. The injection volume of the sample was 10 µL and the mobile-phase flow rate was 1.3 mL per min. Both data acquisition and analysis were performed using Lab Solution (LC Solutions) software.

**Organic acid measurements**

***Standard preparation***

Five standard solutions of each citric acid, malic and succinic acids ranging from 2 to 17 g per L were prepared for analysis of acids in the banana juice. The stock solutions and dilutions were stored in darkness in a refrigerator set at 4 °C. The prepared standard solutions were degassed in the ultrasonic bath (Wagtech Branson 3210, USA) for 10 min to remove bubbles and filtered using a vacuum pump (Buchi Swetco V-700, UK) before being injected into HPLC.

***HPLC for acids quantification***

Acids in the banana juice were measured using High-Performance Liquid Chromatography (Shimadzu-HPLC, LC-20AT**,** Japan) using UV-detector at 250 nm wavelength. The separation procedure was performed on a Hypersil Gold Thermo Scientific column 250 mm at 10 °C. The mobile phase was prepared using acetonitrile, potassium dihydrogen orthophosphate together with phosphoric acid, from which 6.82 g of potassium phosphate was dissolved in 200 mL deionised water (Shui and Leong 2002). Phosphoric acid (0.1 M) was added dropwise to the buffer to adjust the pH of the solution to 2.8. Deionised water was added to make-up the solution of 1 L then filtered using a vacuum filter with 0.25 μm pore membrane. Juice samples were mixed with deionised water at a ratio of 1: 2 (v/v), and then vortexed before injection at the injection volume of 5 μL, whereas the flow rate for the mobile-phase was 0.7 mL per min. Both data acquisition and analysis were performed using Lab Solution (LC Solutions) software.

**Statistical analysis**

The resulting experimental datasets were statistically analysed using a factorial ANOVA with replications. The Tukey Kramer test for multiple range comparisons ($p < 0.05$) was carried out for statistical comparison among the measured mean values expressed as mean and standard deviation ($\bar{x} \pm$ SD).

**Results and Discussion**

**Fruits firmness and juice yields**

The different banana cultivars showed significant differences in fruit firmness during ripening as shown in Figure 1. The Pisang awak banana had the highest firmness value of $1.28 \pm 0.05 \times 10^{-5}$ N $m^{-2}$ at ripeness stage 3, but the firmness decreased to $0.79 \pm 0.08 \times 10^{-5}$ N $m^{-2}$ at stage 5 of ripeness. On the other hand, *Mbile* banana from Kagera was softer than the Pisang awak banana with firmness of $0.98 \pm 0.03\ 10^{-5}$ N $m^{-2}$ at ripeness stage 3 and decreased to $0.49 \pm 0.05 \times 10^{-5}$ N $m^{-2}$ at ripeness stage 5. The *Mbile* from Kilimanjaro had the lowest firmness of $0.59 \pm 0.04 \times 10^{-5}$ N $m^{-2}$ at ripeness stage 3 and decreased to $0.24 \pm 0.03 \times 10^{-5}$ N $m^{-2}$ at ripeness stage 5. These findings agree with previous data reported by several studies (Kibazohi et al. 2017, Majaliwa et al. 2019). Kibazohi et al. (2017) reported that the firmness of banana fruit decreased from (3.60 to 0.94) $\times 10^{-5}$ N $m^{-2}$ from ripeness stages 1 to 5. The softening of banana fruit during ripening has been suggested to be mainly due to pectin breakdown by different cell wall degrading enzymes, which are triggered by ethylene gas (Imsabai et al. 2006, Hailu et al. 2013). Juice yields increased as the banana fruits became soft in all the banana cultivars, as illustrated in Figure 1. Similar findings on increase of banana juice yields was reported by Kibazohi et al. (2017). Several studies suggested that the increase in banana juice yield is due to the increase in starch conversion to sugars with ripening, in the presence of high concentrations of soluble tannins, the compounds responsible for low viscosity juice release (Kyamuhangire et al. 2006, Tapre and Jain 2012, Seymour et al. 2013, Kibazohi et al. 2017).

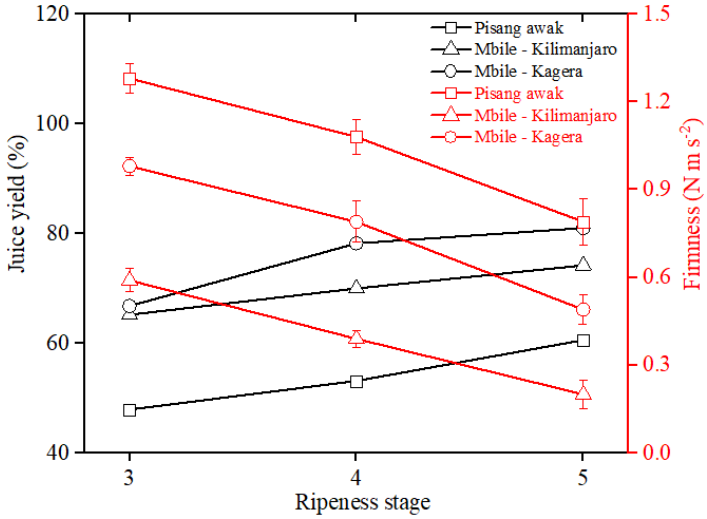


**Figure 1:** Relationship between firmness (N $m^{-2}$) and banana juice yield in different cultivars during ripening.

**Blending speed and juice yields**

Figure 2 highlights the variations of banana juice yields with ripeness stages and blending speed. *Mbile* cultivar from Kagera had the highest juice yield, which increased significantly ($p < 0.05$) with the increasing blending speed and ripeness stage. In this way, the juice yields of 66.80 ± 1.71, 72.60 ± 2.15, and 77.40 ± 3.11% were observed at ripeness stage 3 when blended at 1500, 2500, and 3500 rpm, respectively (Figure 2), while at ripeness stage 5, the juice yields increased to 81.10 ± 2.50, 81.50 ± 2.20, and 82.40 ± 3.10% at a blending speed of 1500, 2500, and 3500 rpm, respectively (Figure 2 stage 5). In the case of the Pisang awak cultivar from Mbeya and *Mbile* cultivar from Kilimanjaro, their juice yields were not significantly ($p > 0.05$) affected by blending speed for each ripeness stage. The juice yield for *Mbile* cultivar from Kilimanjaro ranged between 65.20 and 66.40% at a ripeness stage 3 and then increased to the mean value ranging between 74.20 and 75.30% at ripeness stage 5 for all three blending speeds. Pisang awak cultivar from Mbeya showed the lowest juice yield of about 47.90 to 48.20 at ripeness stage 3 for all blending speeds used. At ripeness stage 5, the juice yields increased to the mean values of 60.70–62.50% for all three blending speeds (Figure 2). These findings concur with the previous studies that reported the increase in juice yields during ripening (Kibazohi et al. 2017, Majaliwa et al. 2019). The increasing trend in juice yields at stage 5 of ripeness could be ascribed by the increase in soluble pectin and conversion of starch to sugars (Seymour et al. 2013).

**Total soluble solids and pH**

Figures 3 and 4 show the mean values of pH and total soluble solids in the banana juice, respectively. The banana juice from Pisang awak from Mbeya had 4.16 ± 0.15 pH (Figure 3) and total soluble solids of 27.20 ± 0.72 °Brix (Figure 4) at ripeness stage 3 and no significant ($p > 0.05$) changes were observed at ripeness stage 5. In the case of the juice from *Mbile* cultivar from Kilimanjaro, a pH of 4.20 ± 0.12 and TSS of 20.70 ± 0.31 °Brix were observed at ripeness stage 3 and evolved to 4.15 ± 0.04 pH and 20.06 ± 0.06 °Brix at ripeness stage 5 as displayed in Figure 3 and 4, respectively. On the other hand, *Mbile* banana from Kagera had a pH of 4.06 ± 0.17 (Figure 3) and TSS of 19.40 ± 0.30 °Brix (Figure 4) at ripeness stage 3. A significant increase ($p < 0.05$) in pH = 4.28 ± 0.11 and TSS = 23.10 ± 0.08 °Brix was observed at a ripeness stage 5 as illustrated in Figures 3 and 4, respectively. The increases of pH and TSS during ripening are related to the evolution of

organic acids in the fruits (Imsabai et al. 2006, Hailu et al. 2013). Besides, the increase in TSS observed is likely due to the sugar accumulation coupled with increases in flavour and volatiles during the ripening process (Imsabai et al. 2006, Kyamuhangire et al. 2006, Kibazohi et al. 2017). In contrast, Adi et al. (2019) reported a decreasing trend of pH with ripening in plantain banana (*Musa* ABB).

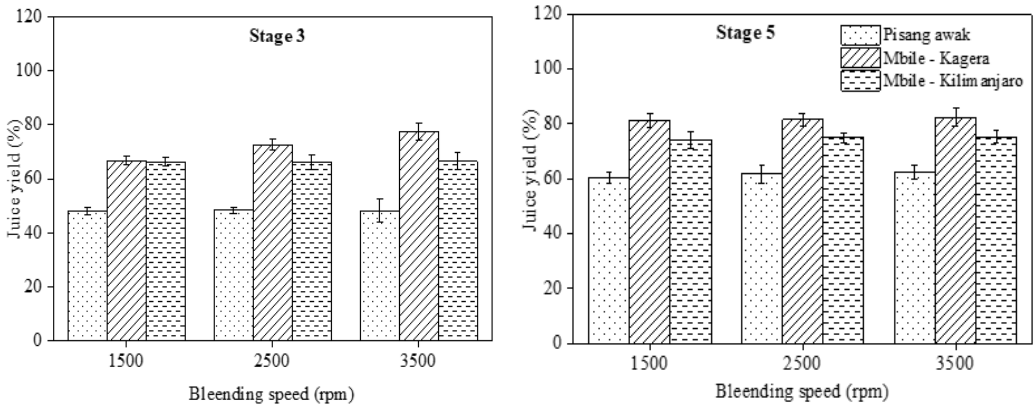


**Figure 2:** Effect of blending speed on banana juice yields extracted from different cultivars: Pisang awak, *Mbile* - Kagera, and *Mbile* - Kilimanjaro during ripeness stages 3 and 5.

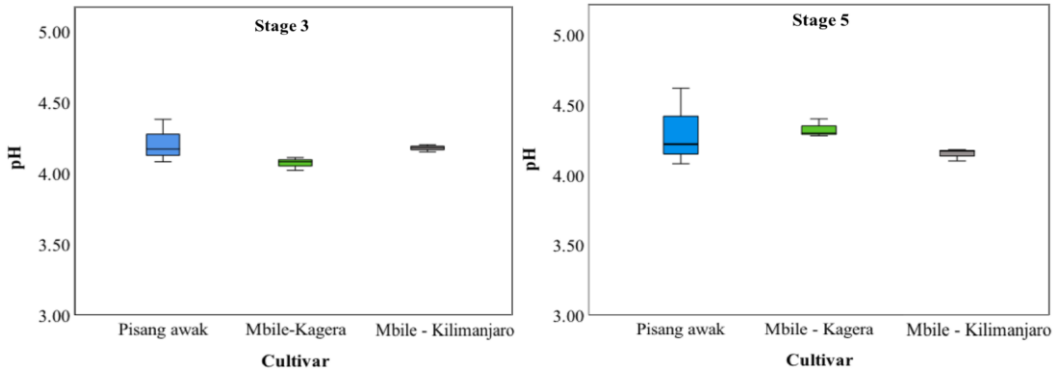


**Figure 3:** Mean values, together with the standard deviations (SD) for the pH in each banana juice cultivar at ripeness stages 3 and 5.

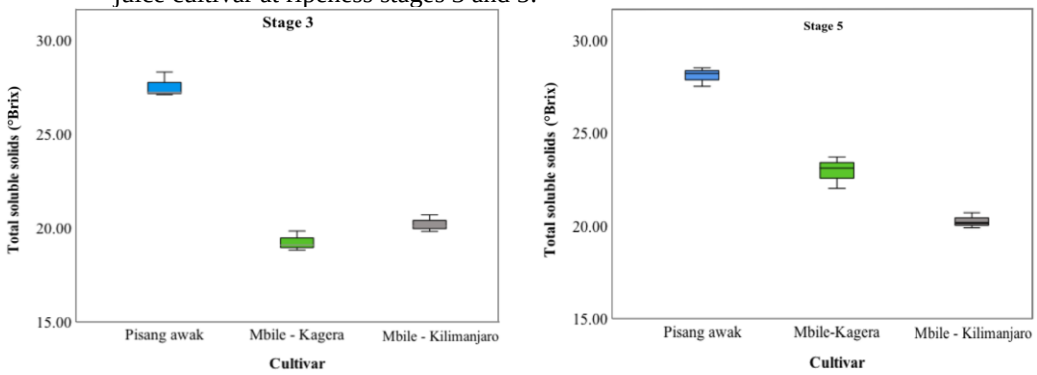


**Figure 4:** Mean values, together with the standard deviations (SD) for the total soluble solids (°Brix) in each banana juice cultivar at ripeness stages 3 and 5.

**Sugar contents**

Table 1 shows concentrations (g per L) of glucose, fructose and sucrose sugars in banana juice. Fructose and glucose increased significantly ($p < 0.05$) with ripening. Values of fructose and glucose in Pisang awak banana juice at stage 3 of ripeness were 46.7 ± 0.28 and 48.0 ± 1.50 g per L, respectively; the values significantly increased to 123.3 ± 4.32 g per L fructose and 117.0 117 ± 3.67 g per L glucose at stage 5 of ripeness. Similarly, fructose and glucose concentrations in the juice of *Mbile* from Kagera at stage 3 of ripeness were 67.0 ± 2.54 and 61.1 ± 2.02 g per L, respectively; the values increased to 155.2 ± 5.11 and 145.8 ± 4.84 g per L, respectively at ripeness stage 5, and fructose and glucose concentrations in the juice of *Mbile* from Kilimanjaro at stage 3 of ripeness were 55.2 ± 3.01 and 54.2 ± 2.01 g per L, the values increased to 86.8 ± 2.36 and 83.6 ± 4.90 g per L, respectively at ripeness stage 5. On the other hand, sucrose did not change significantly with ripeness. Pisang awak had the highest concentration of sucrose of 109.6 ± 4.10 g per L at the ripeness stage 3 and 106.1 ± 1.08 g per L at ripeness stage 5, while *Mbile* from Kagera had sucrose concentrations of 55.4 ± 2. 23 g per L and 53.9 ± 2. 01 at ripeness stages 3 and 5, respectively, and *Mbile* from Kilimanjaro had sucrose concentrations of 52.3 ± 1.44 g per L and 50.4 ± 1.52 at ripeness stages 3 and 5, respectively. Fructose was comparable to glucose suggesting they were formed from hydrolysis of starch during ripening. The differences in the fructose, glucose and sucrose concentrations may be attributable to the banana plants and varietal differences.

These observations were similar to those of Kyamuhangire et al. (2002) and Yap et al. (2017) who reported increasing trends of fructose and glucose sugars in banana during ripening as the sucrose concentration remains unchanged. Hakim et al. (2012) suggested that the increase of fructose and glucose in banana juice could be due to the enzymatic activities of amylase and maltase that breakdown starch into reduced sugars during ripening. The breakdown of starch into sugars gradually decreases starch content as the banana ripens. Fernandes et al. (1979) stated changes of physicochemical properties in silver banana during ripening and presented increase of fructose and glucose sugars as the sucrose decreases. Ssamula et al. (2015) reported similar observations of high sucrose content in Pisang awak relative to those reported in *Mbile* cultivar.

**Organic acids**

Different concentrations of malic, citric and succinic acids (g per L) in the banana juices are presented in Figure 5. The malic and citric acid concentrations significantly ($p < 0.05$) increased from 19.06 ± 1.06 to 36.67 ± 2.32 g per L and from 5.5 ± 1.02 to 10.02 ± 1.44 g per L, respectively, whereas succinic acid decreased significantly ($p < 0.05$) from 9.95 ± 1.15 to 6.67 ± 1.81g per L as Pisang awak bananas ripened from stage 3 to 5. Pisang awak showed the highest concentrations of malic acid at both ripeness stages (Figure 5). This increasing trend of malic and citric acids as the succinic acid decreased was also observed for *Mbile* bananas from Kagera. On the other hand, *Mbile* bananas from Kilimanjaro showed the highest succinic acid concentrations of 22.98 ± 1.92 g per L at stage 3 and slightly lower value of 19.42 ± 1.08 g per L at the ripeness stage 5. This increasing trend in malic acid during ripening of banana fruit has been previously reported (Wyman and Palmer 1964). In principle, malic and citric acids are the organic acids responsible for tartness flavour in the unripe banana fruit (Seymour et al. 1987).

**Table 1:** Mean values, together with their standard deviations (SD) of sugar concentrations (fructose, glucose, and sucrose) analysed in banana juices using HPLC. The mean values with different superscripts for each sugar and banana cultivar indicate that the means are significantly different at ($p < 0.05$)

| | Cultivar | Pisang awak | *Mbile* - Kagera | *Mbile* - Kilimanjaro |
|---|---|---|---|---|
| Fructose | Stage 3 | $46.7 \pm 0.28^a$ | $67.0 \pm 2.54^a$ | $55.2 \pm 3.01^a$ |
| (g per L) | Stage 5 | $123.3 \pm 4.32^b$ | $155.2 \pm 5.11^b$ | $86.8 \pm 2.36^b$ |
| Glucose | Stage 3 | $48.0 \pm 1.50^a$ | $61.1 \pm 2.02^a$ | $54.2 \pm 2.01^a$ |
| (g per L) | Stage 5 | $117 \pm 3.67^b$ | $145.8 \pm 4.84^b$ | $83.6 \pm 4.90^b$ |
| Sucrose | Stage 3 | $109.6 \pm 4.10^a$ | $55.4 \pm 2.23^a$ | $52.3 \pm 1.44^a$ |
| (g per L) | Stage 5 | $106.1 \pm 1.08^a$ | $53.9 \pm 2.01^a$ | $50.4 \pm 1.52^a$ |

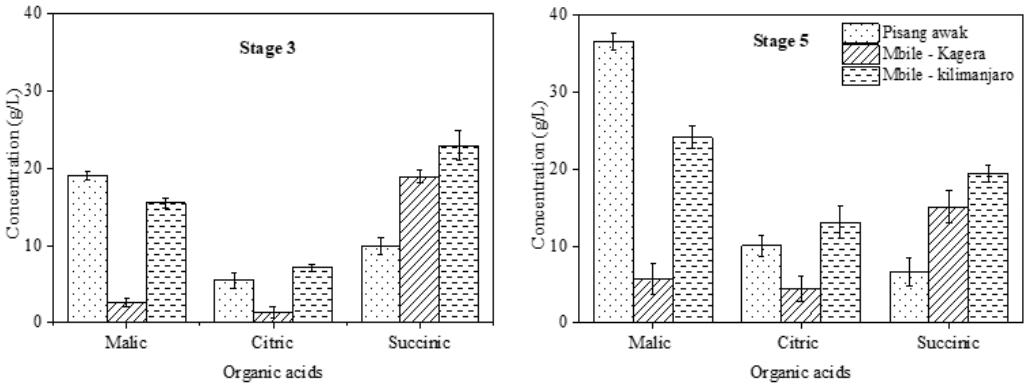


**Figure 5:** Representation of organic acid concentrations (g per L) measured in banana juices extracted from Pasang awak and *Mbile* cultivars at ripeness stages 3 and 5.

## Conclusions

In this study, the influences of blending speed and ripeness stage on banana juice production yields were examined. The results indicated increasing trends of juice yields with increasing in ripeness stages for all banana cultivars. Highest juice yield was observed for *Mbile* cultivar from Kagera. The juice yield increased with blending speed in all banana cultivars at ripeness stage 3. There were significant ($p < 0.05$) increases in fructose and glucose concentrations with ripening, while sucrose contents showed no significant changes in all banana juices from different cultivars. Malic and citric contents increased significantly ($p < 0.05$), while succinic acid decreased ($p < 0.05$) with ripening. The results presented in this work suggest that the blending speed of 3500 rpm and stage 5 of ripeness are suitable extraction conditions for high banana juice yield. The findings are key parameters for extraction of low viscosity banana juice for future commercialisation of the juice extraction by the new mechanical method for potential reduction of postharvest losses of banana.

## Declaration of Competing Interest

The authors declare that they have no competing interests to disclose.

## Availability of Data

The full datasets generated and used by this study are available from the authors upon reasonable request.

## Acknowledgement

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