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Effect of cassava flour feeding on honey yield and the physicochemical and mineral characteristics of honey

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ABSTRACT

Various studies have shown that honey yield and quality are influenced not only by the bees consumption in their environment, but also by the season. The present study was therefore conducted to evaluate the effects of feeding honeybees with cassava flour on these parameters. Ten honeybee colonies were used, divided into two groups of five replicates each: a control group and an experimental group (150 g of cassava flour per day throughout the study). Honey harvests were carried out in mid-December for the rainy season and mid-May for the dry season to determine yields and physicochemical and mineral characteristics. The results showed that honey yield increased by 26.7% in the rainy season and by 29% in the dry season in colonies fed with cassava flour. Honey from the supplemented colonies exhibited significantly higher pH, electrical conductivity, and water content. Dry matter, organic matter, glucose, and fructose contents were lower than in the control. Concentrations of Ca, Mg, K, Na, P, Mn, Zn, and Fe increased significantly with cassava flour feeding. Cassava flour supplementation improved honey yield and enriched its mineral and protein composition, while remaining compliant with international standards.

Keywords: Honeybees, honey, cassava flour, feed consumption, yield, physicochemical characteristics, mineral characteristics

INTRODUCTION

Adequate nutrition is essential for the growth, development, and productivity of honeybee colonies (DeGrandi-Hoffman et al., 2010; Rashid et al., 2018; Tsuruda et al., 2021). Honey, the main product of the hive, is a natural sweet substance rich in simple carbohydrates (fructose and glucose), amino acids, minerals, vitamins, and bioactive compounds such as phenols, flavonoids, and carotenoids (Küçük et al., 2007; Nayik et al., 2018). These compounds confer antioxidant and therapeutic properties beneficial against various health disorders. However, the physicochemical composition of honey varies according to floral origin, season, beekeeping practices, soil type, and harvesting techniques (Nayik et al., 2018; Bogdanov et al., 2004; Kiran, 2026). In Central Africa, the natural availability of food for bees is limited by fluctuations in floral resources associated with climatic variations (Brodschneider and Crailsheim, 2010; Pirk et al., 2016), which explains the growing interest in alternative feeds. Cassava (*Manihot esculenta*) is a widely cultivated plant in Cameroon, whose leaves and tuber flour are traditionally used for human consumption. This flour is rich in energy, carbohydrates, minerals, vitamins, and phenolic compounds (Chavez and Charles, 2005; Montagnac et al., 2009; Lu et al., 2019). In western Cameroon, cassava flour is widely consumed by humans and is also accessible to bees, which actively consume it. The present study therefore aimed to evaluate the effects of cassava flour feeding on feed consumption by bees, as well as on honey yield, physicochemical quality, and mineral composition, according to season.

MATERIALS AND METHODS

Geo-climatic characteristics of the study area

The study was conducted from August 2023 to May 2024 at the Batseng'la Hope Bee Farm (FAEB), located in the Nkong-Ni district of west Cameroon. Situated between 5°24' and 5°27' N latitude and 10°05' and 10°08' E longitude, the FAEB benefits from a modified equatorial Cameroonian climate due to altitude. The region, strongly oriented toward agriculture and livestock, receives between 1,500 and 2,600 mm of annual rainfall, with average temperatures ranging from a minimum of 10 °C in July–August to a maximum of 30 °C in February, relative humidity of 40–90%, and approximately 1,800 hours of annual sunshine. Its vegetation is rich and diverse, including species from numerous botanical families such as *Calliandra calothyrsus*, *Tithonia diversifolia*, *Helianthus annuus*, *Pennisetum purpureum*, *Sida acuta*, *Imperata cylindrica*, *Cynodon* sp., various fruit trees (*Persea americana*, *Mangifera indica*, *Musa* spp.), stimulant plants (*Coffea arabica*, *Cola anomala*), extensive raffia zones (*Raphia* spp.) in marshy areas, and tubers (*Manihot esculenta*, *Ipomoea batatas*, etc.).

Cassava flour

The 8034 cassava variety, produced in the Nkong-Ni district, specifically at Batseng'la, was harvested, manually peeled, washed, soaked for 5 days, extracted, and sun-dried (Figure 1). It was then ground using a hammer mill with a capacity of 100 kg/h and sieved through a 150 µm mesh to obtain fine cassava flour. A 100 g sample of this flour was taken and oven-dried to constant weight. This sample was analyzed to determine its chemical and mineral composition (Table 1), according to the methods described by AOAC (2000).

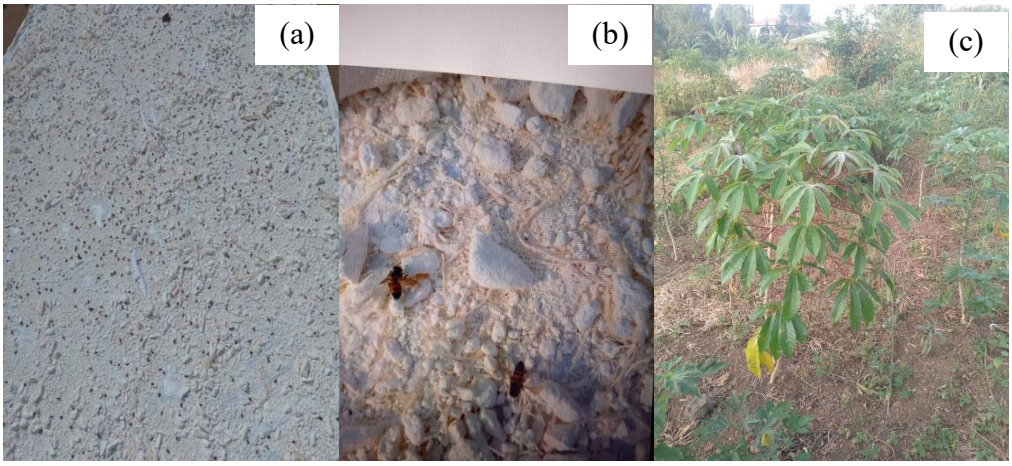


Figure 1. Dried cassava (a), invaded by foraging bees (b) and young cassava production (c)farm

Conduct of the trial

A total of 10 colonies of honeybees (*Apis mellifera*), captured using wax-baited hives, were individually housed in Dadant-type hives (500 × 430 × 300 mm), each equipped with an integrated feeder (Figure 2). The study was conducted using a completely randomized design, with cassava flour and season (dry and rainy) as variation factors. The honeybee colonies were divided into two groups of five replicates each.

Cassava flour consumption

Colonies in the first group (T0) received no supplementation, while those in the second group received 150 g of cassava flour per day throughout the study period. Cassava flour consumption (CFC) was determined by calculating the difference between the amount served (As) and the amount refused (Ar), using the following formula**:** CFC = As – Ar**.**

Table 1. Chemical and mineral composition of cassava flour

Chemical composition (%)	**Cassava flour**
Dry matter	89.9
Organic matter	96.6
Water	10.1
Carbohydrates	91.2
Glucose	0.16
Fructose	0.13
Lipids	0.59
Crude protein	2.08
Ash	3.39
Fiber	2.25
Mineral composition (mg/100g)	
Potassium	210.80
Phosphorus	46.5
Magnesium	29.85
Calcium	41.3
Iron	0.61
Zinc	0.68
Sodium	33.2
Copper	0.15
Manganese	0.42



Figure 2. Colonized hive (a) containing a built-in feeder (b)

Honey yield

At the end of each feeding period (4 months/season), the feeders were removed from the hives, the frames were extracted, and the combs were cut and pressed to separate the honey from the wax. The obtained honey was weighed per hive using an electronic CRANE balance with a capacity of 10 kg

and a precision of 10^{-3} g, then packaged. Honey yield, corresponding to the total quantity of honey produced, was evaluated (Fichtl and Admou, 1994). A 100 ml sample of honey was then taken for analysis of its physicochemical and mineral properties.

Physical, chemical, and mineral analyses of honey

Moisture content was determined by refractometry at 20 °C. The pH was measured with a HI 98127 pH meter calibrated with standard solutions (4.0, 7.0, 10.0) in a 10% honey solution, and total acidity by titration with 0.1 N NaOH. Electrical conductivity was measured using a HI86303 conductivity meter. All these parameters were analyzed according to the methods described by Bogdanov (1997). Density was evaluated by the pycnometer method between 15 and 20 °C, while dynamic viscosity was determined according to Stokes' law using a viscometer (Pierron, 2008).

Dry matter and ash content were analyzed by gravimetric drying at 105 °C to constant weight and by calcination of the honey sample at 550 °C (Tosi et al., 2006), respectively. Organic matter was obtained by subtracting ash from dry matter (AOAC, 1990). Protein and lipid contents were determined by the Kjeldahl and Soxhlet methods, respectively (AOAC, 1990). Sugars were determined by HPLC according to the method described by Aljohar et al. (2018). Solutions of fructose (2 g/L), glucose (2 g/L), and sucrose (0.5 g/L) were prepared in distilled water. HPLC analysis was performed by liquid chromatography coupled with a refractive index detector (LC-RID). Separation was carried out on an Aminex HPX-87H carbohydrate column (300 × 7.8 mm).

Mineral analysis of the samples was performed according to the protocols described by Pucholobek et al. (2022). For sample preparation, 1 g of each honey sample was placed in a porcelain crucible and calcined in a Carbolite Eurotherm muffle furnace at 450 °C for 2 hours. The calcined sample was then digested with 10 mL of 1 N nitric acid for 30 minutes, cooled, and filtered through Whatman filter paper into a 50 mL volumetric flask. The volume was brought to the mark with distilled water. Total phosphorus was subsequently analyzed in the extract by UV-visible spectrophotometry using the molybdate-vanadate colored reagent (Bogdanov et al., 2004). Total nitrogen was determined by the Kjeldahl method (AOAC, 1990). Potassium and sodium were quantified by flame emission spectrometry from samples previously calcined and digested with 1 N nitric acid (Kılıç, 2017). Calcium and magnesium contents were determined by complexometry and titrimetry, respectively (Pucholobek et al., 2022). Lead content was measured by titrimetry with potassium iodide (0.025 M). Copper, iron, and zinc were determined by inductively coupled plasma mass spectrometry (ICP-MS) (Alqarni, 2014; Kılıç, 2017).

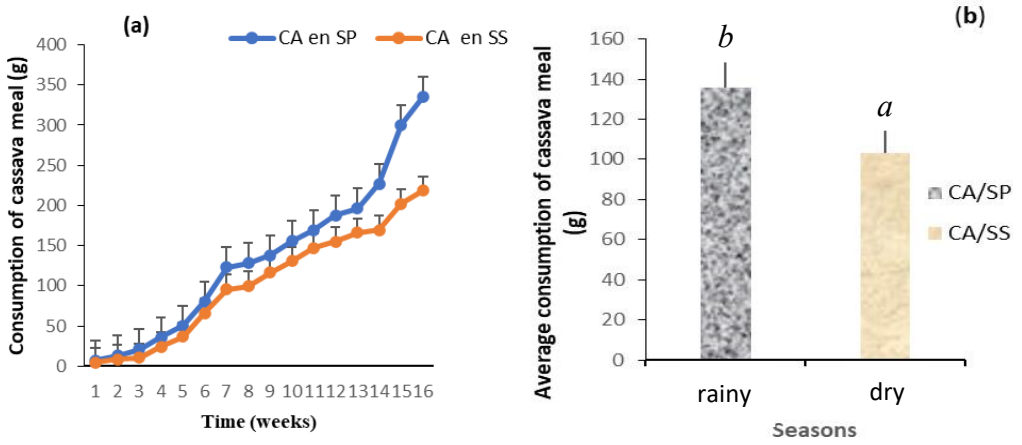
Statistical analysis

Student t-test was used to compare the effects of feeding on the one hand and the effects of season on the other on cassava flour consumption, honey yield, and the physicochemical and mineral properties of honey. All analyses were performed using SPSS software version 26.0.

RESULTS

Cassava flour consumption by bees according to season

Cassava flour consumption increased throughout the study period and was higher during the rainy season (Figure 3a). The overall mean cassava flour consumption was significantly ($p < 0.05$) higher in the rainy season (Figure 3b).



SP: rainy season; SS: dry season; (a): Consumption of cassava meal (g) over time; (b): Average consumption of cassava meal (g)

Figure 3. Consumption of cassava meal by bees according to season

Effects of cassava flour feeding on honey yield according to season

Colonies fed with cassava flour showed a significantly ($p < 0.05$) higher mean honey yield regardless of season (Table 2). However, honey yield from colonies fed cassava flour during the dry season was statistically comparable ($p > 0.05$) to that obtained during the rainy season. Cassava flour feeding resulted in an increase in yield of approximately 26.7% during the rainy season and 29.1% during the dry season.

Table 2. Effect of cassava meal feeding on honey yield according to season

Seasons	Honey yield (kg)		*p*
	T0 (n=5)	T1 (n=5)	
Dry	4.01±1.35[a]	5.18±0.41[b]	0.020
Rainy	3.85±1.44[a]	4.88±0.61[b]	0.004
p_1	0.68	0.47	

a, b: means with the same letter on the same line are not significantly different at the 5% level. *p*: probability; T0: control; T1: cassava meal treatment; n=number of replicates, p_1: inter seasonal comparison in the same group.

Effects of cassava flour feeding on the physical properties of honey according to season

Honey produced by colonies fed with cassava flour exhibited significantly ($p < 0.05$) higher pH, electrical conductivity, and water content, while acidity and viscosity were significantly ($p < 0.05$) lower regardless of season (Table 3).

Table 3. Effect of cassava meal feeding on the physical properties of honey according to season

Physical properties of honey	Seasons	Treatments		*p*
		T0 (n=5)	T1 (n=5)	
pH	Dry	3.02±0.07[a]	3.12±0.01[b]	0.001
	Rainy	3.28±0.02[a]	3.65±0.35[b]	0.026
p_1		0.22	0.06	
Acidity level (%)	Dry	0.14±0.01[b]	0.13±0.01[a]	0.013
	Rainy	0.16±0.00[b]	0.15±0.01[a]	0.001
p_1		0.32	0.97	
Conductivity (µs/cm)	Dry	2.70±0.03[a]	2.88±0.05[b]	0.010
	Rainy	2.79±0.01[a]	2.84±0.01[b]	0.001
p_1		0.35	0.24	
Density (g/cm^3)	Dry	1.50±0.06[b]	1.45±0.00[a]	0.010
	Rainy	1.37±0.01[b]	1.35±0.03[a]	0.001
p_1		0.13	0.14	
Viscosity	Dry	3188.59±100.00[bA]	2872.94±25.00[aA]	0.001
	Rainy	2634.35±250.80[bB]	2420.79±62.90[aB]	0.001
p_1		0.02	0.04	
Water content (%)	Dry	15.00±0.10[a]	15.20±0.00[bB]	0.001
	Rainy	15.62±0.02[a]	16.15±0.05[bA]	0.001
p_1		0.21	0.01	

a, b: means with the same letter in the same row are not significantly different at the 5% level.
A, B: means with the same letter in the same column are not significantly different at the 5% level.
p: probability; T0: control; T1: cassava meal treatment; n=number of replicates; p_1: inter seasonal comparison in the same group.

However, cassava flour feeding led to a significant ($p < 0.05$) increase in honey density during the rainy season. Water content was significantly ($p <$

0.05) higher during the rainy season with cassava flour feeding, and viscosity showed the opposite effect. Furthermore, season had no significant effect ($p > 0.05$) on pH, acidity, conductivity, or density of honey, regardless of the level of cassava flour feeding.

Effects of cassava flour feeding on the chemical composition of honey according to season

Cassava flour feeding significantly ($p < 0.05$) reduced dry matter, organic matter, and organic carbon content of honey regardless of season (Table 4).

Table 4. Effect of cassava meal feeding on the chemical composition of honey according to season

Chemical composition of honey (%)	**Seasons**	**Treatments**		***p***
		T0 (n=5)	**T1 (n=5)**	
Dry matter	Dry	86.10±0.00^{b}	85.30±0.50^{a}	0.001
	Rainy	84.90±0.50^{b}	83.85±0.03^{a}	0.001
p_1		0.11	0.14	
Ash	Dry	0.46±0.00^{a}	0.62±0.01^{b}	0.001
	Rainy	0.21±0.01^{a}	0.50±0.00^{b}	0.001
p_1		0.42	0.11	
Organic matter	Dry	99.7±0.01^{b}	99.5±0.02^{a}	0.001
	Rainy	99.84±0.04^{b}	99.50±0.1^{a}	0.001
p_1		0.11	0.08	
Organic carbon	Dry	49.85±0.01^{b}	49.74±0.01^{a}	0.010
	Rainy	49.92±0.01^{b}	49.75±0.00^{a}	0.001
p_1		0.11	0.08	
Total nitrogen	Dry	0.09±0.00^{a}	0.20 ±0.01^{bA}	0.001
	Rainy	0.08±0.01^{a}	0.18±0.00^{bB}	0.001
p_1		0.11	0.01	
Protein	Dry	0,65±0,00^{a}	1.35±0.10^{b}	0.001
	Rainy	0,55±0,01^{a}	1.21±0.03^{b}	0.001
p_1		0,34	0.15	
Fiber	Dry	0.09±0.00^{a}	0.16±0.05^{b}	0.020
	Rainy	0.11±0.01^{a}	0.15±0.06^{b}	0.011
p_1		0.27	0.90	
Lipid	Dry	0.32±0.01^{a}	0.38±0.01^{b}	0.001
	Rainy	0.28±0.00^{a}	0.36±0.02^{b}	0.010
p_1		0.11	0.07	

a, b: means with the same letter in the same row are not significantly different at the 5% level.
A, B: means with the same letter in the same column are not significantly different at the 5% level.
p: probability; T0: control; T1: cassava meal treatment; n=number of replicates; p_1: inter seasonal comparison in the same group.

In contrast, ash, total nitrogen, protein, fiber, and lipid contents significantly increased ($p < 0.05$) with cassava flour feeding regardless of season. Total nitrogen content was significantly higher ($p < 0.05$) in the dry season when colonies were fed cassava flour.

Effects of cassava flour feeding on sugar content of honey according to season

Feeding colonies with cassava flour significantly ($p < 0.05$) reduced carbohydrate, glucose, and fructose contents of honey regardless of season (Table 5).

Table 5. Effect of cassava meal feeding on honey sugar content according to season

Honey sugars (%)	**Seasons**	**Treatments**		***p***
		T0 (n=5)	**T1 (n=5)**	
Carbohydrates	Dry	85.74±0.50^{b}	84.09±0.50^{a}	0.001
	Rainy	83.74±0.50^{b}	81.59±0.43^{a}	0.001
p_1		0.38	0.11	
Glucose	Dry	28.47±0.50^{b}	27.62±0.04^{aA}	0.026
	Rainy	25.47±0.50^{b}	24.57±0.09^{aB}	0.001
p_1		1.00	0.01	
Fructose	Dry	36.29±0.01^{b}	35.91±0.36^{a}	0.001
	Rainy	33.29±0.03^{b}	32.82±0.39^{a}	0.001
p_1		0.11	0.69	
Sucrose	Dry	1.71±0.05^{a}	2.63±0.01^{bA}	0.001
	Rainy	1.61±0.05^{a}	1.63±0.10^{bB}	0.001
p_1		0.99	0.02	

a, b: means with the same letter in the same row are not significantly different at the 5% level.
A, B: means with the same letter in the same column are not significantly different at the 5% level.
p: probability; T0: control; T1: cassava meal treatment; n=number of replicates; p_1: inter seasonal comparison in the same group.

However, the opposite effect was observed for sucrose content. Season had no significant effect ($p > 0.05$) on carbohydrate and fructose contents. However, glucose and sucrose contents were significantly higher ($p < 0.05$) in the dry season when colonies were fed cassava flour.

Effects of cassava flour feeding on the mineral content of honey according to season

Cassava flour feeding significantly ($p < 0.05$) increased calcium, magnesium, potassium, sodium, zinc, iron, and lead contents regardless of season (Table 6).

Table 6. Effect of cassava meal feeding on the mineral composition of honey according to season

Mineral properties of honey (mg/l)	Seasons	Treatments		*p*
		T0 (n=5)	T1 (n=5)	
Ca	Dry	19.22±0.02^{aA}	20.30±0.10^{b}	0.001
	Rainy	9.25±0.05^{aB}	17.24±0.04^{b}	0.001
p_1		0.01	0.32	
Mg	Dry	5.30±0.01^{a}	5.45±0.32^{b}	0.001
	Rainy	4.59±0.01^{a}	5.28±0.50^{b}	0.022
p		0.11	0.58	
K	Dry	121.85±1.50^{a}	181.00±1.38^{b}	0.003
	Rainy	121.19±0.01^{a}	180.93±0.54^{b}	0.001
p_1		0.11	0.32	
Na	Dry	25.45±0.04^{a}	26.56±0.05^{b}	0.001
	Rainy	23.61±0.01^{a}	24.41±0.89^{b}	0.005
p_1		0.13	0.13	
P	Dry	24.35±0.46^{a}	28.96±0.02^{bA}	0.001
	Rainy	23.58±0.50^{b}	19.04±0.09^{bB}	0.001
p_1		0.92	0.01	
Pb	Dry	0.02±0.01^{a}	0.09±0.02^{b}	0.001
	Rainy	0.01±0.00^{a}	0.07±0.05^{b}	0.011
p_1		0.26	0.09	
Mn	Dry	0.11±0.01^{a}	0.10±0.03^{b}	0.001
	Rainy	0.09±0.01^{a}	0.09±0.00^{a}	0.283
p_1		0.19	0.09	
Zn	Dry	0,56±0,00^{a}	0.70±0.01^{b}	0.001
	Rainy	0,55±0,00^{a}	0.65±0.04^{b}	0.037
p_1		0,11	0.20	
Cu	Dry	0,30±0,02^{bA}	0.25±0.00^{a}	0.001
	Rainy	0,19±0,01^{aB}	0.21±0.02^{b}	0.052
p_1		0,01	0.15	
Fe	Dry	3.91±0.06^{bA}	3.87±0.26^{a}	0.010
	Rainy	2.76±0.57^{aB}	3.86±0.00^{b}	0.000
p_1		0.02	0.21	

a, b: means with the same letter in the same row are not significantly different at the 5% level.

A, B: means with the same letter in the same column are not significantly different at the 5% level.

p: probability; T0: control; T1: cassava meal treatment; n=number of replicates; p_1: inter seasonal comparison in the same group.

The same observation was made for phosphorus content in the dry season. However, manganese and copper contents were significantly ($p < 0.05$) lower in the dry season. With the exception of phosphorus, whose content decreased significantly ($p < 0.05$) in the rainy season, all other minerals were not significantly ($p > 0.05$) influenced by season.

DISCUSSION

Cassava flour consumption by honeybee colonies increased progressively throughout the study period, regardless of season, with a peak during the rainy season. This trend could be explained by its high carbohydrate content, particularly starch, despite its low protein and lipid levels (Montagnac et al., 2009; Lu et al., 2019). This type of energy supply is crucial during periods of intense activity when the nutritional requirements of bees increase (Brodschneider and Crailsheim, 2010; Sultana et al., 2024). The nutritional value and texture of feed supplements influence their acceptability (DeGrandi-Hoffman et al., 2010). During the rainy season, increased colony activity and reduced foraging distances favor better assimilation of the provided supplement. In contrast, during the dry season, the greater diversity and availability of floral resources in the environment may limit the utilization of cassava flour (Brodschneider and Crailsheim, 2010).

Feeding honeybee colonies with cassava flour significantly improved honey yield, with gains of 26.7% in the rainy season and 29.1% in the dry season. This improvement is likely related to the high content of complex carbohydrates in cassava flour, particularly starch, which provides readily assimilable energy, supporting physiological functions and foraging activity even under floral stress conditions (Lu et al., 2019; Al-Ghamdi et al., 2017; Sultana et al., 2024; Amera et al., 2024). In addition, the fiber and micronutrients in the flour may optimize digestion and the conversion of nectar into honey (De-Melo and Almeida-Muradian, 2011). Although yields are generally higher in the dry season, no statistically significant difference was observed between seasons, indicating a stable effect of supplementation. The relatively lower yield in the rainy season could result from reduced floral availability and increased internal consumption of honey reserves. These results support the benefits of energy supplements (DeGrandi-Hoffman et al., 2010; Kulhanek et al., 2026), while recalling that an exclusively carbohydrate-based diet may limit optimal colony development in the long term due to deficiencies in essential proteins and micronutrients (Alaux et al., 2010; Brodschneider and Crailsheim, 2010; Quinlan et al., 2023).

Feeding honeybee colonies with cassava flour resulted in significant changes in several physical properties of honey, varying according to season. This influence could be attributed to the biochemical composition of cassava flour, which is rich in complex carbohydrates, particularly starch, a source of readily assimilable energy (Lu et al., 2019), as well as to the availability of flowers in the apiary environment at certain times of the year. Indeed, honey pH increased significantly in both the dry and rainy seasons, while remaining within the limits set by the Codex Alimentarius (2001) for acidic honeys. This increase may be due to the presence of buffering organic acids in cassava flour (Lu et al., 2019). Concurrently, free acidity of honey decreased significantly,

suggesting improved product stability (Bogdanov et al., 2004), probably linked to better nutrient assimilation and a less acidifying metabolism (De-Melo and Almeida-Muradian, 2011). The electrical conductivity of honey, an indicator of its mineral content, slightly increased in colonies fed cassava flour, which could be explained by the mineral enrichment provided by cassava flour (Montagnac et al., 2009; Ramos et al., 2018). However, a decrease in honey density and viscosity was observed. This decrease would be due to higher water content and reduced total sugars, influenced by the hydrophilic nature of cassava flour and ambient humidity, particularly during the rainy season (Bertoncelj et al., 2007). Water content slightly increased following cassava flour feeding, especially in the rainy season (16.15% vs. 15.62%), which corroborates observations that ambient humidity and the nutritional value of the feed influence water retention in honey (Bogdanov et al., 2004; Bille et al., 2017; Ramadhan et al., 2025).

Cassava flour feeding led to a significant decrease in the dry matter content of honey in both the dry and rainy seasons. This reduction could be linked to an increase in honey moisture due to the ingestion of water-soluble nutrients present in cassava flour (Oboh and Akindahunsi, 2003). In contrast, ash content, an indicator of mineral richness, increased significantly in honey from colonies fed cassava flour. This increase may reflect the mineral composition of the flour, which is rich in calcium, phosphorus, potassium, and magnesium (Montagnac et al., 2009), thereby contributing to the nutritional enrichment of the honey. Furthermore, protein and total nitrogen contents increased significantly across all seasons. This increase could be attributed to greater availability of nectariferous plants rich in organic nitrogen and essential amino acids, or to the direct supply of amino acids contained in cassava flour and their metabolic transformation (Bogdanov et al., 2004). Fiber and lipid contents, although low, also increased significantly. The fibers may originate from insoluble particles of cassava flour or other plants in the environment, while lipids are probably related to starch and oil residues naturally present in cassava flour (Ubalua, 2007). A slight decrease in organic carbon and total organic matter was observed, while remaining within the standards for pure honeys (Codex Alimentarius, 2001; Human and Nicolson, 2006). Finally, the content of simple sugars (glucose and fructose) slightly decreased, probably due to dilution or modification of the sugar profile (Human and Nicolson, 2006; Mostafa et al., 2019). However, the slight increase in sucrose suggests incomplete fermentation or a slowdown in enzymatic activity (De-Melo and Almeida-Muradian, 2011; Ramadhan et al., 2025).

Cassava flour feeding resulted in a significant increase in the contents of minerals such as calcium, potassium, magnesium, zinc, and iron in honey, reflecting the mineral richness of cassava flour in essential minerals (Montagnac et al., 2009). These elements, essential for human health, also

influence honey quality (Bogdanov et al., 2008). Potassium, which is predominant, contributes to the osmotic regulation of honey (Terrab et al., 2003). Zinc and magnesium, as enzymatic cofactors, enhance the antioxidant properties of the product (Krell, 1996). Phosphorus showed seasonal variation, probably influenced by climatic conditions affecting floral availability. In addition, a notable increase in lead (Pb) content was observed in honey from supplemented colonies, although concentrations remained below the maximum permitted limit of 0.10 mg/kg according to the Codex Alimentarius (2001). This increase could be attributed to environmental contamination, particularly from pollution, metallic materials used in beekeeping equipment, or agricultural practices near the apiary (Bogdanov, 2006). These results highlight the need to implement preventive measures to reduce potential sources of heavy metal contamination. Finally, the decrease in copper during the dry season could result from unfavorable mineral interactions (Underwood, 1977). Iron (Fe) showed relative stability in the dry season but an increase in the rainy season, which may reflect variability related to the environment and bee physiology.

CONCLUSION

The study on the effect of cassava flour feeding on honey yield and its physicochemical and mineral characteristics shows that the use of cassava flour as a dietary supplement for honeybee colonies compensates for nutritional deficiencies, thereby enhancing colony resilience during humid periods (rainy season). The use of cassava flour as a feed supplement for honeybee colonies improves honey yield by approximately 26.7% in the rainy season and 29% in the dry season. A cassava flour-based diet has a beneficial effect on certain characteristics of the produced honey, particularly the improvement of physical properties and the increase in protein, ash, lipid, and essential mineral contents such as calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and iron (Fe). These parameters remain generally compliant with international honey quality standards. However, a significant decrease in density, viscosity, dry matter, and total carbohydrates (glucose and fructose) was observed in both the dry and rainy seasons.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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