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QUALITY EVALUATION OF CASHEW APPLE (*ANACARDIUM OCCIDENTALE* L.) FRUIT LEATHER FORMULATED WITH VARYING CONCENTRATIONS OF HONEY AND PECTIN

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Abstract

Cashew apple (CA) is a highly perishable and nutritionally rich pseudocarp that is commonly discarded as an agricultural waste despite its substantial ascorbic acid, dietary fibre, polyphenol, and mineral contents. This study evaluated the nutritional composition, °Brix indicators, colour parameters, and sensory acceptance of cashew apple fruit leather (CAFL) produced from five treatments with variation in cashew apple puree (CAP), honey and pectin concentrations: T1 (100% CAP: control), T2 (88.5% CAP, 10% honey, 1.5% pectin), T3 (88.0% CAP; 10% honey; 2.0% pectin), T4 (79.5% CAP; 20 % honey; 0.5% pectin), and T5 (79.0% CAP; 20% honey; 1.0% pectin). Nutritional analysis showed average moisture content of 11.08% dry weight basis (dwb) (T1) with water activity values between 0.52 at T1 and 0.76 for T3, under the condition of temperature at 25 °C. The control formulation (T1) displayed the greatest content of dietary fibre (17.9%) and most favourable water activity (0.52), while honey-added formulations were characterised by a significantly higher level of °Brix: 39.7–40.4. pH was equally low, from 3.67 to 3.75, in all CAFLs. Vitamin C content varied between 2.27 and 3.05 mg/100 g dwb. Colour analysis revealed that the higher honey concentration formulations exhibited increased values of redness (a) and chroma. Results of sensory evaluation showed that T4 (79.5% CAP + 20% honey + 0.5% pectin) had the highest acceptability score (6.1), and was superior to the control and formulations prepared with less honey in terms of taste, colour, aroma, and texture. The results indicated that adding 20% honey with 0.5% pectin recorded sensory quality with good physicochemical stability for CAFL. The findings of the study demonstrate a wider possibility of using honey and pectin as natural functional ingredients in the production of consumer-acceptable, fruit leather prepared from the cashew apple.*

Keywords
cashew apple, fruit leather, honey, pectin, nutritional composition, sensory evaluation

Introduction

Cashew (*Anacardium occidentale* L.) is a major tropical tree crop grown in West Africa, Asia, and Latin America, being appreciated for its nut. However, the cashew apple (fleshy pseudofruit attached to the nut) remains strongly underexploited, though it is made up of about 90% of total fruit weight (Gutiérrez-Paz et al., 2024). A study revealed that the by-product of cashew apple biomass produced per ton of processed nuts is discarded as waste at the farm gate level (Michodjehoun-Mestres et al., 2009). This is not only a huge economic loss but also an environmental challenge.

The cashew apple (CA) is considered a nutritionally rich food commodity, being a rich source of vitamin C, including sugars, minerals, dietary fibre, and bioactive phenolic compounds with antioxidant and anti-inflammatory activity (Akinwale, 2000; Cruz Reina et al., 2022). Notwithstanding this attractive nutritional profile, the CA has low fresh market acceptance due to its astringency, because of the presence of tannins, perishableness and high-water content, which posed post-harvest handling and long-distance transport problems (Dheeraj et al., 2023). The processing of CA into value-added food products presents an attractive nexus that can reduce post-harvest losses in cashew and drive the economic value chain on one hand, while enhancing the local food and nutrition situation and household-level income security within the cashew grower community.

Fruit leather is a shelf-stable product made from dried pureed fruit that is converted into thin, flexible sheets. It is generally consumed as an easy-to-carry snack and known for preserving most of the nutritional contents of fresh fruits, and is shelf-stable at room temperature (Riram et al., 2024). Processing of CA into fruit leather, which is referred to in this study as CAFL, represents a potentially viable opportunity for value addition. However, the production of quality fruit leather with favourable sensory and texture attributes demands precise formulation, because the physicochemical properties of raw puree are decisive in quality characteristics of the end product. Pectin and honey are two of the functional ingredients that has been widely used for the enhancement of fruit leather quality. Pectin is a natural polysaccharide present in plant cell walls, widely applied in food systems as a gelling and thickening agent. Its addition to fruit leather compositions can enhance gel strength, textural cohesiveness, and moisture retention of the product (Lemuel et al., 2014; Said et al., 2023). Honey, however, is a natural sweetener and has been documented to have antimicrobial, antioxidant, and humectant activities (Alvarez-Suarez et al., 2014). To this end, its application in fruit leather formulations can lead to enhanced microbiologi-

cal safety, thus becoming a functional ingredient of nutritional importance.

The levels of adding pectin and honey to food recipes determine the physicochemical, sensory, and nutritional properties of the product. Too little can lead to undesired texture or poor stability, and too much can adversely influence flavour balance, colour, and consumer acceptance. Although there has been increasing interest in CA processing and fruit leather technology, no study to our knowledge has ever systematically investigated the simultaneous influence of differing concentrations of pectin and honey on the overall quality of CAFL. Thus, this work aimed to fill this gap by studying physicochemical and sensory attributes of CAFL prepared with different concentrations of honey and pectin to identify formulations that were acceptable to consumers.

Materials and Methods

Sources of materials

Fresh yellow CA varieties were sourced from Wenchi in the Bono Region in Ghana, packed in an ice chest, and transported to the University for Development Studies Food Processing Laboratory for CAFL processing. The apples were then washed in running water and frozen for two days. The aim of this was to inactivate polyphenol oxidase enzyme, which has been observed to be the responsible factor for rapid browning and quality loss of CAs. Furthermore, freezing holds colour, fresh sweet taste, and nutrients up to the point of processing for microbial safety of CAs. The honey was purchased from Techiman in the Bono Region in Ghana. Lemon (*Bonnie Brae*) was purchased from fruit sellers at the Kumasi Central Market in the Ashanti Region of Ghana.

Pectin extraction

Solar-dried lemon peel was used to extract pectin. The dried lemon peels were powdered using a modified method of Akhter et al. (2024). Briefly, 500 mL of water and 10 g of peel were mixed in a 1000-mL beaker. About 300 mL of 0.05 M citric acid was adjusted to pH 2 using a 0.5 M Na_2CO_3 solution (pH = 11). The stirred paste was soaked well and then heated in a water bath for 90 min at 80°C to get the mixture. The mixture was filtered through a muslin cloth after cooling. The pectin precipitated after 2 volumes of 95% ethanol (1:2 v/v) were added, and the mixture was kept for an hour. The coagulated pectin obtained was crushed and filtered through a muslin cloth, dried in an air oven at 50°C to constant weight, and stored in a cool, dry place at ambient conditions.

Preparation of cashew apple puree (CAP)

CAs (150 g) were thawed at 4 °C in a refrigerator using the modified method of Fonteles et al. (2022). They were washed, sliced, blanched, and placed in a boiling water bath at 95 °C for 3 min. The blanched CAs were then cooled in running tap water, then homogenised by a robot cooker to obtain a silky slurry in 0.2 M citric acid buffer (pH 5.2). The 0.2 M citric acid may ensure the buffering capacity to withstand pH shifts through processing, thus helping to maintain the yellow colour of the CAP, also, it may produce an acidic condition that will inhibit the growth of spoilage microorganisms and enhance CAP safety. Thereafter, the slurry was stored in sterile flasks in a refrigerator's freezing compartment until required for preparation of the CAFL. The resulting puree was weighed and was 1740 g of CA mass. The formulae of the different ingredients in each treatment are presented in Table 1 based on preliminary experiments. This study was an analysis of five CAFL with treatments made with different honey and pectin content based on the weight of added cashew puree. T1 was the control (100% CA), and T2 – T5 were treatments with added honey (10 – 20%) and pectin (0.5 – 2.0 %) as functional ingredients.

Table 1. Percentage composition of CAFL

Treatment	Cashew puree (%)	Honey (%)	Pectin (%)
T1	100.0	0.0	0.0
T2	88.5	10.0	1.5
T3	88.0	10.0	2.0
T4	79.5	20.0	0.5
T5	79.0	20.0	1.0

Note: T1 (Control): 100% cashew puree with no honey or pectin added; T2: 88.5% cashew puree, 10% honey, 1.5% pectin. Low honey, moderate pectin; T3: 88.0% cashew puree, 10% honey, 2.0% pectin. Low honey, highest pectin level; T4: 79.5% cashew puree, 20% honey, 0.5% pectin. High honey, lowest pectin level; T5: 79.0% cashew puree, 20% honey, 1.0% pectin. High honey, moderate pectin.

Oven drying of CAFL

The CAFLs were dried in a Bosch built-in oven drier (China, HBN231. 2N) that was equipped with an electrical heater, a drying chamber, a fan, and temperature settings (up to 100°C). The CAFL was spread thinly with a metal spreader onto lightly cooking oil-greased stainless-steel trays and levelled out across the trays to achieve 3.0 $\pm$ 0.2 mm (tested using Vernier calliper). Temperature and drying time were adjusted to obtain the optimum dried CAP with pectin and honey, placed in the centre and upper part of the drier. The temperature of operation was 80°C for eight (8) h, and they were chosen after piloting to determine the initial CAFL processing conditions following Lemuel et al. (2014) methodology. The drying temperature and time were controlled by the Bosch Built-in electric oven dryer (China, HBN231. 2N) during the course of the experiment. The obtained CAFL was sliced by a sharp knife into uniform squares (2.5 cm $\times$ 2.5 cm) after drying. It was packed in low-density polyethene and stored in a cool, dry place until needed for analysis.

pH and total soluble acids (°Brix) determination

The pH of the CAFL was meeasured according to the approved method of AOAC, (2000). Hot distilled water (20 mL) was added to a clean dry beaker containing 2.0 g of dried, gorund CAFL . The CAFL hot distilled water mixture was stirred thoroughly untill homogenisation was complete. The pH electrode was callibrated agaist buffer solutions of pH

4.00, 7.00 and 10.01. After inserting the pH electrode into the CAFL sample , the pH was measured and recorded three times. The mixture was stirred well until homogenisation had taken place. The pH electrode was calibrated against a buffer solution with pHs of 4, 9, and 10. Following the insertion of the pH electrode in the sample, the pH was measured and recorded three times. Total soluble solids (TSS) were measured as °Brix using a refractometer (Reichert, handheld, AR200TM) calibrated with distilled water. Two to three drops of the sample were deposited over the refractometer glass prism with a pipette dropper. °Brix was measured in triplicate.

Colour determination

The surface colour of the CAFL was measured with a CR-400 Chroma Meter (Konica Minolta, USA) calibrated using an ordinary white porcelain tile (L* = 97.63, a* = 0.31, and b* = 4.63) according to Kim et al. (2025). A chroma meter was situated directly above the Pyrex petri dish of a CAFL, to obtain and record measurements in L*, a*, b* format. These represent the lightness, red/green chromaticity, and yellow/blue chromacity respectively of the samples.

Nutritional analysis of samples

All CAFL formulations were analysed in accordance with the standard methods of the Association of Official Analytical Chemists (AOAC International, 2005). All experiments were conducted in triplicate, and results are presented as means ± standard deviation based on dry weight basis (dwb).

Moisture content

Moisture was assessed by oven drying (AOAC International, 2005). About 2.000 ± 0.001g of the CAFL samples were weighed into pre-dried and pre-weighed porcelain moisture dishes. The plates, in the forced-air interior drying oven at 105 ± 1 °C, were dried to constant weight. They were regularly weighed every hour until a difference between two subsequent weighings was not more than 0.2 mg. For each weighing, dishes were placed in a desiccator with anhydrous silica gel and cooled for 30 min to avoid moisture reabsorption from atmospheric air. Moisture was reported on a dry weight basis and determined using the following formula:

$$\text{Moisture (\% dwb)} = \frac{(W_2 - W_3)}{(W_3 - W_1)} \times 100 \quad (1)$$

where W_1 is the weight of the clean pre-dried dish, g; W_2 is the weight of the dish and sample before drying, g; and W_3 is the weight of the dish and sample after being dried to constant weight, g. The dried residue left in the dish after moisture determination was considered as 100% and used for the expression of all subsequent proximate fractions on a dry weight basis.

Crude protein content

Crude protein content was assessed by the macro-Kjeldahl method (AOAC International, 2005). About 0.200 ± 0.001 g of the CAFL pre-dried samples were weighed accurately and put into a Kjeldahl digestion flask for each sample. Briefly, one Kjeldahl catalyst tablet consisting of potassium sulfate and copper(iv) sulfate in a 10:1 (w/w) ratio was added to the flask along with 10 mL concentrated sulfuric acid (H_2SO_4, 98%, analytical grade). The suspension was placed on a Kjeldahl digestion block in a fume hood and heated stepwise to a final digestion temperature of 400–420°C. Digestion was carried on until the digest was clear and light blue-green in colour, showing that total oxidative decomposition of the organic matter and conversion of organic nitrogen to ammonium sulphate had taken place. After cooling to room temperature, the digest was added cautiously to about 50 mL of distilled water in a 100 mL volumetric flask. The solution was diluted up to scale with distilled water after complete dissolution.
A portion of 10 mL of the diluted digest was pipetted into a distillation chamber, which is part of the Kjeldahl distillation set. To the digest, 40 mL of 40% (w/v) sodium hydroxide solution was added to alkalinise and to liberate the ammonia gas, which was steam-distilled and collected in a receiver flask containing 25 ml of 4% (w/v) boric acid indicator solution made of bromocresol green (30 mg) and methyl red (60 mg) as the mixed indicator. Distillation was extended to at least 150 mL of distillate. The ammonium borate, which had precipitated in the receiver, was titrated directly against standard 0.1 N hydrochloric acid to an endpoint, where a blue-green colour just turned faint pink. A reagent blank, containing all reagents subjected to the entire procedure without a sample, was performed with each set of analysis in order to compensate for the background nitrogen contamination. Total nitrogen was determined from the net volume of hydrochloric acid consumed, and crude protein contents were derived by multiplying the per cent-nitrogen value by 6.25 (a general factor for food nitrogen to protein conversion (Huber and BeMiller, 2017)).

$$\%\text{Nitrogen} = \frac{(V_s - V_b \times N_{\text{HCl}} \times 14.007)}{m} \times 100 \quad (2)$$

$$\text{Crude protein (\%)} = \%\text{Nitrogen} \times 6.25 \quad (3)$$

where V_s is the volume of standardised HCl used by the sample distillate (mL), V_b is the volume of blank distillate (mL), N_{HCl} is the normality of standardised HCl, 14.007 being the atomic weight of nitrogen, and m represents the dry weight (g) of a sample digested.

Crude fat content

Crude fat was analysed using Soxhlet continuous solvent extraction (AOAC International, 2005). Around 2.000–5.000 ± 0.001 g of each pre-dried then finely ground CAFL sample were weighed into a cellulose extraction thimble loosely plugged at the top with a small piece of defatted cotton wool so as to avoid escape of particles of sample material into the refluxing solvent. The loaded thimble was put in the Soxhlet extraction chamber, and petroleum ether (boiling point

40–60°C, analytical grade) was used as the extraction solvent. Extraction flasks were pre-dried in an oven at 105°C for 1h, cooled in the desiccator for 30min and weighed before use to the nearest 0.1mg.

The free ether-soluble material was extracted continuously for 6-8 h at reflux temperature, approximately 5-6 siphon cycles per hour, with thorough and full extraction of ether-soluble constituents from the sample matrix. After extracting, the petroleum ether was recovered by rotary evaporator, and the rest of the solvent remaining in the extraction flask was blown away gently on a water bath (40–50 °C) in a fume hood with good ventilation until no smell of the solvent could be detected. The extraction flasks were then placed into a drying oven at 105°C for 30 min to remove the last traces of the residual solvent, cooled in a desiccator for 30 min, and weighed to the nearest 0.1 mg. Reweighing was considered at regular 30 minutes interval on drying until a constant weight was obtained with a difference not exceeding 0.2 mg. All extractions were performed inside a fume hood in accordance with laboratory safety requirements for flammable organic solvent usage and waste disposal. Given that pre-dried samples were used, the crude fat was expressed as such on a dry matter basis and expressed as:

$$\text{Crude fat (\%, dwb)} = \frac{(W_2 - W_1)}{m} \times 100 \quad (4)$$

where W_1 = weight of empty pre-dried extraction flask (g); W_2 = weight of the flask and extracted fat residue after drying to constant weight (g), and m = dry weight of sample taken for extraction (g).

Ash content

Total ash was calculated through the dry ashing method (AOAC International, 2005). About 2.000 ± 0.001 g of each pre-dried CAFL sample was weighed in porcelain crucibles, which had already been ignited in a muffle furnace at 550°C, cooled, kept in a desiccator, and reweighed to an accuracy of within 0.1 mg of all materials used for the analysis. In order to avoid abrupt ignition and the danger of sample loss by sputtering portioning, the crucibles were initially thermally pretreated on a hot plate in a fume hood and gradually pre-charred under low or moderate heating until smoking ceased and no additional black smoke was formed. The pre-charred samples were then placed in a muffle furnace (Carbolite, UK) and incinerated at 550°C for 5–6 hours or until white to greyish-white ash, devoid of all black carbonaceous particles from char, remained, demonstrating that all organic matter had been totally combusted. The furnace was turned off at the end of incineration, and the crucibles were cooled in it to less than 200 °C. They were then removed and transferred to a desiccator. The crucibles were weighed to the nearest 0.1 mg after cooling for at least 1 h. Crucibles were cooled and reweighed again after an additional period of incineration for one hour, if any remaining black particulate was visible. This process was repeated until a constant weight was obtained. Because the initial material was pretreated samples, the ash content in this case was calculated on a dry weight basis according to:

$$\text{Crude ash (\%, dwb)} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100 \quad (5)$$

where W_1=empty weight of the pre-ignited crucible (g); W_2=weight of crucible with pre-dried sample before ashing (g), and W_3=weight of crucible with final incinerated residue (g).

Crude fibre content

Five (5) grams of the sample were filtered after being refluxed in trichloroacetic acid for forty (40) minutes. Acetone and boiling distilled water were used to wash the residue. After the washed residue was dry-heated in an oven at 150°C, it was scraped into a porcelain crucible, weighed, and ashed for two (2) hours in a muffle furnace before being removed, cooled in desiccators, and weighed. Crude fibre was calculated as a percentage according to the following equation:

$$\text{Crude fibre (\% dwb)} = \frac{P_1 - P_2}{P_0} \times 100 \quad (6)$$

Where: P_1 = Weight of crucible + ash, P_2 = Weight of crucible + residue, P_0 = Initial weight of the sample

Carbohydrate content

Total carbohydrate was estimated by the difference method according to the procedure recommended by Afoakwah et al. (2023) and calculated as shown below:

$$\text{Carbohydrate (\%)} = 100 - (\text{Moisture} + \text{Crude Protein} + \text{Crude Fat} + \text{Ash} + \text{Crude fibre}) \quad (7)$$

Energy value determination

The energy (E) value of the CAFL was obtained using the Atwater factor described by Afoakwah et al. (2023) with the formula:

$$E = (4 \times P) + (4 \times C) + (9 \times F) \quad (8)$$

Where P=% protein, C=% carbohydrate, F=% fat

Vitamin C content

Extraction of ascorbic acid

CAFL samples (0.5 g) were extracted with 20 mL of 3 % (w/v) metaphosphoric acid with vigorous shaking at 300 rpm for 30 min. The extract was then spun at 3,000 rpm for 10 min. The supernatant was decanted and subjected to an ascorbic acid assay (Vijayalakshmi and Ruckmani, 2016).

Ascorbic acid assay

Ascorbic acid was determined by a spectrophotometer based on the reducing ability of 2,6-dichloro-phenolindophenol (DCPIP). The principle of this assay is that the blue oxidised form of DCPIP is stoichiometrically reduced to its colourless leuco-DCPIP by ascorbic acid in an acidic medium, and the

degree of decolourisation correlated well with the aqueous phase ascorbic acid concentration (Sánchez-Moreno et al., 2003). A calibration curve was produced by using a standard curve solution with different known ascorbic acid solutions of 3% (w/v) metaphosphoric acid. The spectrophotometer absorbance was immediately read after shaking 3 mL of 0.2 mM DCPIP solution with exactly 1 mL of the sample extract for 15 s at a wavelength of 515 nm. The ascorbic acid content in mg per 100g dry weight (mg/100g dwb) of each CAFL suitability was calculated according to the equation:

$$\text{Ascorbic Acid (mg/(100 g) dwb)} = \frac{(C \times V \times D)}{(m \times 1000)} \times 100 \quad (9)$$

where C is the ascorbic acid concentration in terms of the extract obtained from the calibration curve, mg/L; V is the total volume of extracting solvent used during extraction (20 mL); D is dilution applied to the analyte before estimation; m is the dry weight of solids taken for extraction (g); 1000 is a factor to convert grams into litres and 100 is a factor used while expressing per 100 g of dry sample.

Sensory studies

A consumer acceptability sensory study was conducted at the sensory evaluation laboratory of the University for Development Studies with a method described by Afoakwah et al. (2023). The CAFL were stored at 28±2 °C for 24 h before testing. 30 g of the CAFL were served to each panellist on a clear plate with random three-digit numbers. To ensure reliability in the measurements, the panellists rinsed their lips with distilled water between assessments. Fifty untrained university student panellists agreed to participate voluntarily with their informed consent. They were aged between 20 and 35 years, with the inclusion of 22 females and 28 males at baseline who had previous experience with fruit leather and could eat it without triggering an allergic reaction. The panellists were further screened according to the method described by Ramírez-Rivera et al. (2017). Colour, visual appearance, aroma, mouth feel, texture, and overall acceptability were the properties of preference selected for CAFL. A nine-point hedonic scale in which ratings were made from "1-dislike extremely" to "9-like extremely" was used for the sensory evaluation. Information regarding the various forms of the CAFL was withheld from the panel members to avoid potential bias. The sequence in which the CAFL samples were presented was randomised using a Latin square test design (MacFie et al., 1989).

Experimental Design

As presented in Table 1: The study employed a completely randomised design (CRD) with five treatment groups. Each treatment varied with composition of three key ingredients: cashew puree, honey, and pectin. Two independent variables were manipulated across the treatments: Honey level: 0%, 10%, and 20% (increasing sweetness and humectant effect) and pectin level: 0%, 0.5%, 1.0%, 1.5%, and 2.0% (modulating texture and gel formation).

Statistical analysis

The statistical analysis was conducted using SPSS, and the results are illustrated in figures and tables. The means of triplicate determination of all parameters were compared by one-way analysis of variance (ANOVA). Means were separated using Duncan's Multiple Range Test. Differences in means were deemed significant at $p<0.05$

Results and Discussion

Nutritional value of the CAFL

Moisture content and water activity

The moisture level and water activity (aw) are important factors affecting microbial stability and shelf life of fruit-based leather products. T1 exhibited the lowest moisture (11.08% dwb) and aw value (0.52 at 25°C), which signified better shelf stability. With an increase in the honey contents among these treatments (T2), moisture ascended markedly to 23.02 % (dwb), and aw was found to be in the range of 0.69–0.76, while T3 exhibited the highest aw of 0.76 at 25°C. Research on mixed-fruit leather has also demonstrated that variation in composition has a marked effect on moisture and aw parameters (Ho et al., 2018). Honey adds soluble solids and osmotic pressure (Sugar Nutrition Resource Centre, 2021) to the CAFL matrix, and can increase aw if drying parameters do not account for the extra hygroscopic capacity of the mixture when adding honey into a high moisture product formulation.

Dietary fibre, protein, fat, and carbohydrate content

The dietary fibre content was significantly highest ($p<0.05$) in T1 (17.9%), indicating that the CAP was a good source of dietary fibre. This agrees with findings of CA composition, which have revealed that the high fibre content of the fruit is one of its major nutritional characteristics (Akyereko, 2023). The highest carbohydrate was recorded for T1 (67.02%) and T3 (66.65%), but honey-enriched formulations (T4 and T5) exhibited a slight decrease. The lower carbohydrate content observed in the honey-containing formulations (T4 and T5) when compared with T1 and T3 may be due to the substitution effect of ingredients. Enzymes, organic acids, phenolic compounds, and free amino acids are a few of the non-carbohydrate substances introduced at higher honey levels. Together, these make up a greater percentage of the dry matter content (Bogdanov et al., 2008; White Jr, 1978). With higher honey addition rates, these minuscule but additive non-carbohydrate fractions replace available carbohydrates at the same rate within the matrix of dry matter, which causes the reported carbohydrate content on a dry weight basis to decrease. The values of protein (1.72–2.80 dwb %) and fat (0.80–1.22 dwb%) conform to the expected composition of a fruit-based snack. This was an anticipated response due to the fruit-dominant nature of the product, with such low protein and having been found among fruit leathers (Ho et al., 2018).

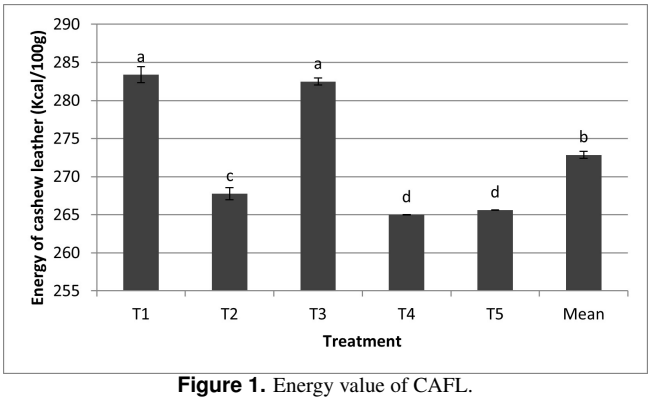

Figure 1. Energy value of CAFL.

Energy value

The energy contents of the various CAFL samples are shown in Figure 1. Energy content is a key nutritional attribute when developing a food product, as it represents the contribution from energy-yielding macronutrients (carbohydrates, proteins and fats) and is influenced by ingredient and processing factors. The energy values of the five treatments in this investigation are within the range of 264.98 kcal/100 g (T4) and 283.38 kcal/100 g (T1).

The highest energy content (283.38 kcal/100g) was obtained for the control treatment (T1), which was prepared with 100% CAP without any additives. These observations clearly emphasise the inherent calorigenic value of concentrated CAP, which is rich in naturally enhanced carbohydrates, mainly fructose and sucrose (Akyereko, 2023). The pseudofruit of the CA contains around 10% w/w sugars in its raw form (Gutiérrez-Paz et al., 2024), and these energy-yielding molecules could be significantly condensed in the dried product when the pseudofruit is dehydrated for making fruit leather. The higher energy value of T1 over all other formulations is not surprising, as the 100% CAP base supplies a concentrated source of metabolizable sugars with zero displacement by low-caloric ingredients like pectin.

The energy values of T2 (88.5% CAP, 10% honey, 1.5% pectin) and T3 (88.0% CAP, 10% honey, 2.0% pectin) were 268.16 kcal/100 g and 282.48 kcal/100 g, respectively. The energy value of T2 was lower than that of T1, although being higher in energy density than the honey, a source of simple sugars. Interestingly, a small increase in pectin concentration (1.5% to 2.0%) seems to influence the energy value of T3 (282.48 kcal/100 g) > T2 (268.16 kcal/10 g). Pectin is a soluble dietary fibre known as an indigestible polysaccharide; it has a trivial contribution to metabolizable energy and contains low calories (MedicineNet, 2024). Also, pectin is highly resistant to enzymatic degradation in the small intestine and thus does not provide the same caloric content as digestible carbohydrates (Lattimer and Haub, 2010). Thus, the higher energy in T3 compared to T2, despite the higher pectin content, might not be due to the pectin but rather to differences in moisture retention and macronutrient concentrations during drying. Slight changes in the thickness of the spread, rate of drying, or moisture content at the end of drying may cause considerable changes in caloric density (Kalsi et al., 2025; Pooja et al., 2022).

The T4 (79.5% CAP, 20% honey, 0.5% pectin) and T5 (79.0% CAP, 20% honey, 1.0% pectin) had the lowest calories among all the treatments, with 264.98 kcal/100 g and 265.60 kcal/100 g, respectively. Unexpectedly, despite the honey concentration in the leather being doubled from 10% to 20%, increasing its caloric content, both T4 and T5 showed the lowest energy content compared to T1, T2, and T3. This apparently paradoxical trend may be attributed to a drastic reduction in the amount of CAP from 100% (T1) to around 79% (T4 and T5). As reported in literature, energy density contributed by concentrated CAP due to higher reducing sugar content (Akyereko, 2023; Dakuyo et al., 2022).

The difference in energy values between T4 (264.98 kcal/100 g) and T5 (265.60 kcal/100 g), with only the pectin content differing (0.5% vs. 1.0%), also confirmed that the caloric content of pectin in fruit leather recipes was insignificant. This aligns with the fact that pectin is a non-digestible dietary fibre associated with low metabolizable energy (El-Shebini et al., 1988; Holloway et al., 1983). Even if pectin is an essential functional ingredient in gel network formation of the leather matrix and regulation of its textural features, the effect of pectin on the energy results of the CAFL products is negligible at such levels of addition. Compared to other fruit leather products in the literature, the energy content of all CAFL treatments (264.98 – 283.38 kcal/100 g) was lower than that of mixed indigenous fruit leathers reported by Kalsi et al. (2025) as 304.56 – 307.36 kcal/100 g in jackfruit-banana-silverberry leather. Yet, the values obtained in this study can be considered to be the maximum value found by Pooja et al. (2022) for lapsi (*Choerospondias axillaris*) fruit leather, a high-sugar sample, which had 284 kcal/100 g.

Pectin as a functional additive

Pectin is a naturally occurring polysaccharide found to be most abundant in plant cell walls and is a common food additive with gelling and thickening properties widely used (Xiang et al., 2024). Its addition to fruit leather recipes is meant to enhance mouthfeel, strength, and consumer preference. High-methoxyl pectin specifically forms gels in acidic conditions (pH 2.5–3.5) with high soluble solids (>55%) and is suitable for the acidic and sugar-rich content of fruit leather (Said et al., 2023). Pectin's gelling and textural properties help create the desired stability of good-quality and healthier fruit-based food products (Romero and Cerda, 2025).

In the present study, T3 (2.0% pectin) had an increased water activity value of 0.76 despite not being the highest in honey content; thus, it could be indicative of the extra water-holding capacity by pectin at higher concentrations. The increase of pectin from 0.5% (T4) to 1.0% (T5) in the 20% honey formulations did not imply a corresponding improvement of sensory perception, and this supported that a ceiling effect had been reached for texture improvement at these contents. This observation is consistent with the well-established understanding

Table 2. Proximate analysis of CAFL samples

Treatment	Moisture (% dwb)	Ash (% dwb)	Protein (% dwb)	Fat (% dwb)	Carbohydrate (%dwb)	Fibre (% dwb)	Water activity
T1	11.08±0.40^{d}	1.30±0.70	1.80±0.70^{b}	0.90±0.70^{b}	67.02±1.70^{c}	17.9±0.71^{d}	0.52±0.02^{c}
T2	23.02±1.94^{c}	1.22±0.79	2.32±0.79^{ab}	1.12±0.79^{ab}	62.1±0.79^{bc}	10.22±0.79^{b}	0.69±0.01^{b}
T3	21.03±1.48^{a}	1.50±0.07	1.72±0.07^{b}	1.00±0.07^{ab}	66.65±1.20^{bc}	8.10±0.70^{c}	0.76±0.01^{a}
T4	22.44±1.09^{bc}	1.02±0.02	2.50±0.02^{ab}	1.22±0.02^{a}	61.00±0.04^{b}	11.82±0.02^{a}	0.70±0.03^{b}
T5	21.9±0.69^{b}	1.10±0.02	2.80±0.02^{a}	0.80±0.03^{b}	61.80±0.08^{a}	11.60±0.09^{a}	0.70±0.03^{ab}
Mean	19.90±1.12	1.23±0.32	2.23±0.32	1.01±0.32	63.71±0.76	11.93±0.46	0.67±0.02

Note: Values are means ± standard deviation. Values with different superscripts within the same column are significantly different at p<0.05; T1 (Control): 100% cashew puree with no honey or pectin added; T2: 88.5% cashew puree, 10% honey, 1.5% pectin. Low honey, moderate pectin; T3: 88.0% cashew puree, 10% honey, 2.0% pectin. Low honey, highest pectin level; T4: 79.5% cashew puree, 20% honey, 0.5% pectin. High honey, lowest pectin level; T5: 79.0% cashew puree, 20% honey, 1.0% pectin. High honey, moderate pectin.

that pectin gelation depends on several interacting factors, such as pectin concentration, pH, and soluble solids content (Xiang et al., 2024).

Pectin, a natural polysaccharide of plant cell walls, is widely used by the food industry as a gelling agent, thickener, stabiliser, and emulsifier (Xiang et al., 2024). Its Inclusion in the compositions of fruit leathers contributes more to texture, flexibility, and structural integrity. Studies to evaluate the use of different hydrocolloids in fruit leathers have shown that the inclusion of hydrocolloids, such as pectin, enhanced textural properties and increased overall quality (Wang et al., 2025). There was a marked influence of the high-methoxyl pectin as a gelling agent in acidic, high-soluble-solids systems, which is similar to the cashew apple-honey matrix model system used in the present study.

Vitamin C

The vitamin C content of all treatments was lower (2.27–3.05 mg/100 g dwb), with the highest recorded in T4 (Table 3). The initial ascorbic acid content of cashew apple fruit in its raw form is among the highest found in fruits, although the relatively low contents observed in this study conform to vitamin C susceptibility to thermal and oxidative destruction during drying. Ascorbic acid, a heat-labile water-soluble vitamin, is highly sensitive to losses during common drying technologies that increases at high temperature and prolonged drying (Giannakourou and Taoukis, 2021). Higher drying temperatures have been demonstrated to result in greater degradation due to accelerated oxidation of ascorbic acid to dehydroascorbic acid (Hidalgo and Brandolini, 2008). Lemuel et al. (2013) also reported that added pectin levels greatly affected the ascorbic acid content of apple-blackcurrant fruit leather.

pH and °Brix

As seen in Table 3, the pH of all treatments remained relatively constant (3.67–3.75), and all treatments were in the acidic range. This low pH is beneficial for preservation; the combination of pH and water activity forms a combined hurdle, which prevents the growth of pathogen microorganisms and prolongs product shelf-life (Tapia et al., 2020). For acid fruit leathers, the low pH level also serves to enhance the antimicrobial protection offered by lower water activity. The °Brix reading reflected a pronounced and highly significant treatment effect, with T1 (16.80°Brix) as against 39.7–40.4°Brix measured for honey-enriched treatments. This rise may be due to the soluble solids content added by honey.

Table 3. pH, B of the CAFL

Samples	pH	°Brix	Vitamin C (mg/100 g DW)
T1	3.73±0.02^{a}	16.80±0.20^{b}	2.27±0.15^{a}
T2	3.71±0.02^{a}	39.70±0.61^{a}	2.71±0.30^{b}
T3	3.67±0.01^{b}	39.73±0.64^{a}	2.53±0.54^{b}
T4	3.75±0.06^{a}	40.33±0.06^{a}	3.05±0.99^{c}
T5	3.72±0.04^{a}	40.40±0.10^{a}	2.63±0.02^{c}
Mean	3.72±0.03	35.39±0.32	2.64±0.40

Note: Values are means ± standard deviation. Values with different superscripts within the same column are significantly different at p<0.05. T1 (Control): 100% cashew puree with no honey or pectin added; T2: 88.5% cashew puree, 10% honey, 1.5% pectin. Low honey, moderate pectin; T3: 88.0% cashew puree, 10% honey, 2.0% pectin. Low honey, highest pectin level; T4: 79.5% cashew puree, 20% honey, 0.5% pectin. High honey, lowest pectin level; T5: 79.0% cashew puree, 20% honey, 1.0% pectin. High honey, moderate pectin

Table 4. Colour characteristics of the CAFL

Samples	L*	a*	b*	Chroma	°Hue
T1	27.4±0.1^{d}	1.0±0.1^{c}	-0.2±0.1^{b}	1.0±0.1^{dc}	353.2±2.2^{a}
T2	29.3±0.1^{a}	0.2±0.1^{d}	0.8±0.1^{a}	0.8±0.1^{d}	94.2±76^{b}
T3	28.6±0.3^{b}	3.1±0.3^{b}	-0.1±0.1^{b}	3.1±0.3^{b}	299.7±1.0^{a}
T4	28.1±0.2^{c}	1.3±0.1^{c}	-0.1±0.0^{b}	1.3±0.1^{c}	358.5±0.6^{b}
T5	29.3±0.1^{a}	4.3±0.1^{a}	-0.4±0.0^{c}	4.3±0.1^{a}	311.8±0.8^{a}
Mean	28.5±0.2	1.7±0.1	-0.1±0.1	2.1±0.1	283.5±2.4

Note: Values are means ± standard deviation. Values with different superscripts within the same column are significantly different at p<0.05. T1 (Control): 100% cashew puree with no honey or pectin added; T2: 88.5% cashew puree, 10% honey, 1.5% pectin. Low honey, moderate pectin; T3: 88.0% cashew puree, 10% honey, 2.0% pectin. Low honey, highest pectin level; T4: 79.5% cashew puree, 20% honey, 0.5% pectin. High honey, lowest pectin level; T5: 79.0% cashew puree, 20% honey, 1.0% pectin. High honey, moderate pectin.

Colour characteristics

From Table 4, it was clear that colour is a major factor influencing consumer acceptability of fruit leathers. The L* values were generally fairly constant across treatments (27.4–29.3), reflecting broadly similar lightness. The a* (redness) values had higher variation: the highest values were observed in T5 (4.3) and the lowest in T2 (0.2); for chroma reflecting colour intensity or vividness, higher scores were recorded

Table 5. Mean preference scores of sensory evaluations (± SD) for CAFL samples

Treatment	Appearance	Aroma	Taste	Mouth feel	Colour	Texture	Overall acceptability
T1	4.5±2.4^{a}	4.3±2.3^{a}	4.4±2.5^{a}	4.6±2.3^{a}	4.3±2.3^{a}	4.5±2.5^{a}	4.8±2.4^{a}
T2	5.5±2.0^{b}	5.1±2.2^{b}	5.1±2.2^{b}	5.2±1.9^{b}	5.3±1.8^{b}	5.7±1.9^{b}	5.5±1.8^{b}
T3	5.5±1.8^{b}	5.3±2.0^{b}	5.1±2.2^{b}	5.3±1.9^{b}	5.2±1.9^{b}	5.2±2.2^{a}	5.6±1.9^{c}
T4	5.4±1.9^{c}	5.6±1.7^{c}	5.6±1.8^{c}	5.5±1.8^{c}	5.7±1.8^{c}	5.9±1.7^{c}	6.1±1.6^{d}
T5	5.5±2.0^{b}	5.6±1.7^{c}	5.8±1.8^{c}	5.6±1.7^{c}	5.5±2.0^{c}	6.0±1.9^{c}	5.9±2.0^{d}
Mean	5.3±2.0	5.2±2.0	5.2±2.1	5.2±1.9	5.2±2.0	5.5±2.0	5.6±1.9

Note: Values are means ± standard deviation. Values with the same superscripts within the same column are not significantly different at p<0.05. T1 (Control): 100% cashew puree with no honey or pectin added; T2: 88.5% cashew puree, 10% honey, 1.5% pectin. Low honey, moderate pectin; T3: 88.0% cashew puree, 10% honey, 2.0% pectin. Low honey, highest pectin level; T4: 79.5% cashew puree, 20% honey, 0.5% pectin. High honey, lowest pectin level; T5: 79.0% cashew puree, 20% honey, 1.0% pectin. High honey, moderate pectin.

for T5 with a value of 4.3, and the smallest scores for T2, with a value of 0.8. Differences seen between treatments in the intensities of redness and chroma may be most plausibly associated with variable levels of non-enzymatic browning, including Maillard browning. The Maillard reaction is an intricate set of non-enzymic reactions between amino acids and reducing sugars, which produces brown melanoidin pigments and characteristic flavour and aroma compounds during heat treatment (Tamanna and Mahmood, 2015). Honey is high in reducing sugars, glucose, and fructose, both of which are highly reactive substrates of Maillard browning, and liquid sweeteners, including honey, invert syrup, etc., this increase the progress of Maillard reactions significantly due to their increasing concentration (Huber and BeMiller, 2017). Formulations containing 20% honey (T4 and T5) supplied an increased substrate pool for the browning reactions occurring during drying, in line with higher a* and chroma values compared to lower-honey treatments.

In the case of guava fruit leathers, this influence has been conclusively demonstrated: the type and concentration of added sugars (e.g., fructose, glucose) are shown to have a clear impact on non-enzymatic browning indices and consequent indicators by way of hydroxymethylfurfural or furfural, with glucose or fructose-treatments producing far more intense browning than sucrose or sorbitol do toward applied leathers (Nayaka et al., 2022). This observation is consistent with the view that the reducing sugars of honey were responsible for the different colour development patterns obtained in CAFL treatments.

Sensory evaluation

The sensory evaluation data are presented in Table 5. In this research, 100% CAP consistently had the lowest scores for all attributes except for overall acceptability, with an average score of 4.8 out of 9. The CA bears a naturally astringent taste based on its tannin and polyphenolic properties, which is not palatable (Kaprasob et al., 2017). Astringency masking with the aid of sweeteners may lead to consumer acceptance of cashew-based products.

T4 (79.5% CAP, 20% honey, and 0.5% pectin) was rated highest in overall acceptability score (6.1) as well as maximum in the taste, mouthfeel, colour, and texture, which all resulted in the statistically significant treatment effect ($p < 0.05$). T5 rated closely at 5.9, and both the 20%-honey formulations were much better compared to the lower-honey treatments in all sensory attributes. This confirms that honey is not intended to be a sweetener exclusively, but also adds to texture (and therefore flavour) and aroma complexity in fruit leather (Kalsi et al., 2025). The 20% honey CAFL formulations also confirmed similar observations in a previous study that the addition of sugar to fruit leather had beneficial effects, which included improving taste, mouthfeel, and overall acceptability by reducing perception of astringency and increasing perception of sweetness (Săpoi et al., 2025).

No differences were found between treatments for appearance ($p = 0.15$) or mouthfeel ($p = 0.25$), meaning that panellists perceived these sensory attributes similarly across all formulated products. Colour ($p = 0.001$), aroma ($p = 0.003$), flavour ($p = 0.003$), and texture ($p = 0.002$), on the other hand, were significantly impacted by treatment composition. Colour and aroma differences are likely related to the different levels of Maillard browning and caramelisation processes as influenced by varying honey concentrations (Huber and BeMiller, 2017; Tamanna and Mahmood, 2015), while textural differences may be attributed to the combined effects of pectin content, honey concentration, and overall physicochemical properties of all formulations (Wang et al., 2025).

Conclusion

In conclusion, the data pinpoint T4 (79.5% CAP, 20% honey, and 0.5% pectin) as being the most rationally balanced formulation; it scored highest for sensory attributes yet had a water activity of 0.70. Higher pectin levels, such as T3 (2.0%), did not provide any sensory advantage proportionate to the concentration, presenting also the highest water activity (0.76). The most nutritionally beneficial formulation (T1) with the highest content of dietary fibre (17.9%) and lowest aw value (0.52) also had the lowest sensory preference rankings. This reflects a common challenge in the development of functional foods, where nutritional density and sensory quality may work in opposition. The addition of honey and pectin acts as a lever-

age at such juncture by enhancing the consumer acceptance without the incorporation of artificial preservatives or sweeteners. The impact of lower-sugar formulations with different natural alternative sweeteners, as well as that of the drying temperatures, on vitamin C retention, and within these CAFL treatments, should be further studied. Also, microbial and phytochemical characteristics, and shelf life of the CAFLs should be explored.

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