

Solid Biowaste of Burkina Faso Mango Processing Units: Current Status and Biochemical Potential Analysis for Sustainable Valorization

Mamadou Sanou^{1,2*}, Mah Alima Esther Traoré¹, Hyacinthe Kanté-Traoré¹, Sophie Dofu Dem Somda¹, Inoussa Ky², Boubacar Diakité³, Karim Baquenon Soma⁴, Felix Offei⁵, Yifeng Zhang⁶, Mamoudou Hama. Dicko², Charles Parkouda¹

¹Institute for Research in Applied Sciences and Technologies (IRSAT), National Center for Scientific and Technological Research (CNRST-IRSAT), Ouagadougou, Burkina Faso

²Laboratory of Biochemistry, Biotechnology, Food Technology and Nutrition (LABIOTAN), Department of Biochemistry and Microbiology, Université Joseph KI ZERBO, Ouagadougou, Burkina Faso

³DAFANI-Tropical Fruit Processing Company, Orodara, Burkina Faso

⁴SANLE SECHAGE, EXPORT-Fruits and Vegetables, Banfora, Burkina Faso

⁵Department of Marine Engineering, Regional Maritime University, Accra, Ghana

⁶Department of Environmental & Resource Engineering, Technical University of Denmark, Lyngby, Denmark

Email: *mamadou_sanou@ujkz.bf

How to cite this paper: Sanou, M., Traoré, M.A.E., Kanté-Traoré, H., Somda, S.D.D., Ky, I., Diakité, B., Soma, K.B., Offei, F., Zhang, Y., Dicko, M.H. and Parkouda, C. (2026) Solid Biowaste of Burkina Faso Mango Processing Units: Current Status and Biochemical Potential Analysis for Sustainable Valorization. *Open Journal of Applied Sciences*, 16, 3700-3720.

<https://doi.org/10.4236/ojapps.2026.169204>

Received: August 14, 2026

Accepted: September 26, 2026

Published: September 29, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Mango fruits have high nutritional values due to their various components. Post-harvest operations are accompanied by the generation of high quantities of by-products that are poorly recovered. This study investigated the biochemical potential of mango biowaste for sustainable feed production and renewable energy generation. Biochemical parameters of the biowastes from five cultivars were determined using standard methods. Bioreaction modeling was carried out by experimental design method. Solid mango biowaste had a moisture content of $81.50 \pm 2.25\%$, a Brix index of $15.31 \pm 2.86^\circ$ Brix, a pH of 4.23 ± 0.38 and a total acidity of $3.51 \pm 0.74\%$ MS. The proximate composition (w/w, dry matter basis, DM) was $2.15 \pm 0.61\%$ fat, $3.63 \pm 0.88\%$ proteins, $3.42 \pm 0.54\%$ ash and $90.80 \pm 1.38\%$ sugars with an energy value of 397.03 ± 3.71 kcal/100g. Levels of minerals of metabolic importance such as potassium, phosphorus, magnesium, manganese, zinc, and copper were 1288.93, 403.11, 55.32, 2.921 ± 0.18 , 0.617 ± 0.15 and 0.018 ± 0.02 mg/100g DM, respectively. Levels of phenolic compounds were 80.81 ± 13.53 mg EAG/g DM, flavonoids 27.65 ± 7.65 mg Equiv. quercetin/g DM, antioxidant compounds 8.82 ± 0.18 mg Equiv. ascorbic acid/g DM, reducing sugars 81.06 ± 22.46 mg Equiv. D-

glucose/g DM, vitamin C 2.04 ± 1.12 mg/g DM and beta-carotene 1.88 ± 1.18 mg/g DM. Bioreaction modeling showed that substrate prepared with 40% of MBPs and 0.1% of SBF is the most optimal. Further optimisation could be achieved by enriching this formula with various external mineral sources and ammonium sulphate or yeast extract. Solid mango biowaste has interesting biochemical compounds of nutritional interest that can be recovered and economically valorized.

Keywords

Mango Processing, Biowaste, Biochemical Potential, Sustainable Recovery

1. Introduction

Mango (*Mangifera indica* L.) is one of the most popular tropical fruits in the world due to its flavour, taste quality and nutritional value [1]. It belongs to the *Anacardiaceae* family and is the most important fruit crop in Burkina Faso, with an annual production of about 239,637 tonnes [2]. Its production in Burkina Faso generates several jobs for about 28,000 individuals out of which 32% are from rural population [3]. Mango fruits are Burkina Faso's 7th largest exported products, with a value of about 33.191 million USD [3].

Despite this socioeconomic potential, stakeholders in the mango value chain face major challenges such as energy consumption (electricity and butane gas) and the management of by-products. Indeed, mango fruits are commonly processed into packed nectar and dried slices, which generates a significant quantity of biowaste. Mango drying companies in Burkina Faso use more than 30 tonnes of butane gas per year [4]. The processing sector, which represents 20% of national production [3], constitutes the largest source of solid biowaste in the country, with an average of 40,000 tonnes per year [5]. Mango biowaste or mango by-products (MBP), is generated in large quantities in processing units, but is rarely recovered. In mango drying units, by-products (BP) represents approximately 60% of the processed batches [5]. This represents a loss of revenue that could affect the competitiveness of these units. In addition, mango biowaste disposal in landfill is a potential source of greenhouse gas emissions [6]. It requires large areas and releases concentrated leachate of various pollutants, such as pathogenic microorganisms which can cause disease in populations living near landfill sites [4] [6]. Therefore, it is necessary to effectively recover MBP thereby making the sector more profitable. To overcome this challenge, availability of reliable scientific data on the biochemical characteristics of mango by-products, and their recovery and management within each category of processor is necessary.

The objective of this study is to investigate the biochemical potential of MBP and model an optimised bioreaction for the sustainable production of feed and renewable energy.

2. Material and Methods

2.1. Biological Material

Biological material consisted of by-products (BP) from the most commonly used mango cultivars (*Amelie*, *Lippens*, *Kent*, *Brooks* and *Keitt*) from small-scale and industrial fruit processing units in Burkina Faso. Samples were collected between April and June 2023 (mango availability period). They were taken directly from processing units in the *Haut-Bassins* ($10^{\circ}57'25''$ Latitude, $-4^{\circ}51'41''$ Longitude), *Cascades* ($10^{\circ}42'36''$ Latitude, $-4^{\circ}46'28''$ Longitude) and *Centre* ($12^{\circ}21'44''$ Latitude, $-1^{\circ}32'21''$ Longitude) regions of Burkina Faso (**Figure 1**). A total of 25 samples of *Amelie* (10), *Kent* (07), *Lippens* (04), *Brooks* (03), and *Keitt* (01) byproducts were collected, with each sample weighing approximately two (2) kilograms. It was sampled, packed in plastic bags, labelled, placed in a cool box with ice and sent to the laboratory. In the laboratory, part of the fresh samples was ground directly in the *XPREP Warning Commercial* (stainless-steel blades) mixer for moisture, pH, acidity and Brix analysis. The other part was dried in the *LAB-FREEZ-Instruments FD-10-MTP* freeze dryer, then ground before being repacked into sample jars, labelled and stored at 4°C for further analysis.



Figure 1. Map of data collection and sampling areas.

2.2. Survey Methodology

Data collection equipment consisted of a voice recorder and an android phone

with survey forms and an interview guide designed using *KoboCollect v2023.1.2* software. Data were collected between April and June 2023 from mango processors and contact persons (local authorities, health and environmental services and researchers) in four provinces in Burkina Faso, *i.e.* i) Houet: Bobo-Dioulasso, 11°14'13" Latitude, -4°19'7" Longitude and Toussiana 10°50'28" Latitude, -4°38'39" Longitude, ii) Comoé: Banfora, 10°41'36" Latitude, -4°47'31" Longitude, iii) Kénédougou: Orodara 10°58'25" Latitude, -4°54'35" Longitude and iv) Kadiogo: Ouagadougou 12°21'44" Latitude, -1°31'21" Longitude (**Figure 1**).

The survey data were collected using a technique adapted from AGRIS manual of FAO on integrated agricultural surveys [7]. The scope of the survey and interview forms included the identification of the actor, the size of the processing unit, its production capacity with the quantities of by-products generated, the management of these by-products within the processing unit and the costs associated with this management. The sample was selected based on the availability of the actors. Only companies that had remained active in the mango processing industry over the past 5 years were surveyed. A total of 33 in 45 actors met the selection criteria. The data was collected online directly on the electronic form using *KoboToolBox*. The interviews were recorded using a voice recorder and transcribed into Microsoft Word®.

2.3. Determination of Physicochemical and Nutritional Characteristics

The pH and total acidity (expressed as citric acid equivalent) of the fresh mango by-product were determined by potentiometry and titration, using the *SI Analytics-Lab875P* pH meter and the Brix degree by refractometry using the *Bellingham + Stanley RFM712* refractometer [8].

Moisture content was determined according to AOAC method 925.10 [8] and the total ash content according to AOAC method 942.05-1943 [8]. The total protein content was determined by the Kjeldahl method described in AOAC 992.15-1992 [8] and the total fat content (TFC) was determined by the Soxhlet method described in AOAC 963.15-1973 [9]. Total sugars and reducing sugars were determined using the spectrophotometric methods described by Dubois [10] and GHANES [11], respectively. The potential energy value was calculated according to Merrill and Watt [12].

Total phenolic compounds were determined by the Folin-Ciocalteu colourimetric method [13]; total flavonoids were determined by the method described by Zhishen *et al.* [14] and the antioxidant capacity of the ethanolic extracts was tested by the DPPH (1,1-diphenylpicrylhydrazyl) reduction method described by Ben Moussa *et al.* [15].

Minerals were determined by flame atomic absorption spectrometry (AAS) using the AOAC 999.11-2005 method [16]; Amino acid contents were performed by reversed-phase HPLC using the AOAC 2018.06-2018 method adapted from the Waters Pico-Tag technique [17]. This involved hot acid digestion of the delipidated sample to release the amino acids, which were then complexed with phenyl

isothiocyanate (PITC) to form phenylthiocarbamyl amino acid, which can be quantified. The HPLC is equipped with UV detector and PICOTAG Column C18 (Waters, USA). The HPLC system was pre-calibrated with high-purity amino-acid standards. The sample injection volume for all the analytes was 10 µl, which was filtered using 0.45 µm puradisc syringe filters before injection into the HPLC.

Ascorbic acid (vitamin C) content was determined by Thermo Scientific UHPLC chromatograph method described in AOAC ZBH 26-1999 [8] coupled to UV-vis detector. Total ascorbic acid (TAA) was considered as the sum of ascorbic acid (AA) and its oxidized form (dehydro-ascorbic acid) [18].

Beta-carotene content was determined by UHPLC using the AOAC 2005.07-2005 method [19]. Carotenoids soluble in organic solvents are directly detectable on the Thermo Scientifica UHPLC chromatograph (coupled with a UV-visible detector) after extraction by maceration in chromatographic grade ether.

2.4. Bioreaction Recovery Modelling of Mango By-Products

This was carried out using the experimental design method described by Goupy and Creighton [20] [21]. A factorial design was created using *Minitab 18.1 v2014* software. The factors studied in 05 levels of combination were the proportion of mango by-products (MBPs) (combination values: 25%, 30%, 35%, 40% and 45%) and the proportion of soybean flour (SBF) (combination values: 0.0%, 0.1%, 0.5%, 1.0% and 1.5%). For each formula obtained by the factorial design, a bioreaction substrate was prepared according to Ouédraogo *et al.* [22]. The required proportions of MBP and SBF were weighed into a 1-L Erlenmeyer flask before adding the necessary amount of distilled water. The mixture was homogenized, and the pH was adjusted between 5.8 and 6.0. It was pasteurized at 75 °C for 10 min, followed by cooling to approximately 30 °C, before being inoculated with viable baker's yeast (*Saccharomyces cerevisiae*) at a rate of 0.1 g per 100 mL and covered with muslin cloth to facilitate aeration of the medium. The flasks were placed on a rotary shaker tray for the bioreaction. Reactions were carried out for 72 hours at laboratory temperature (25 °C - 30 °C) under continuous aeration (Figure 2). Response parameters included final pH, Brix reduction rate, crude protein content and optimised protein content of the final biomass. The optimized protein taut is calculated using the following formula:

$$\text{Optimised protein rate (\%)} = \frac{\text{Pns\%} * \text{Wns}}{\text{DM\%}} * 100 \quad (1)$$

Pns% = Nitrogen source Protein rate;

Wns = Nitrogen source weight added in the substrate;

DM% = Biomass dry matter.

The Proportion of Residual Brix (PRB) was calculated according to the following formula:

$$\text{PRB} = \frac{\text{Brix Degree Tn}}{\text{Brix Degree T0}} * 100 \quad (2)$$

Brix Degree T_n: Brix at time “n” of the bioreaction;

Brix Degree T₀: Brix at time “0” of the bioreaction.

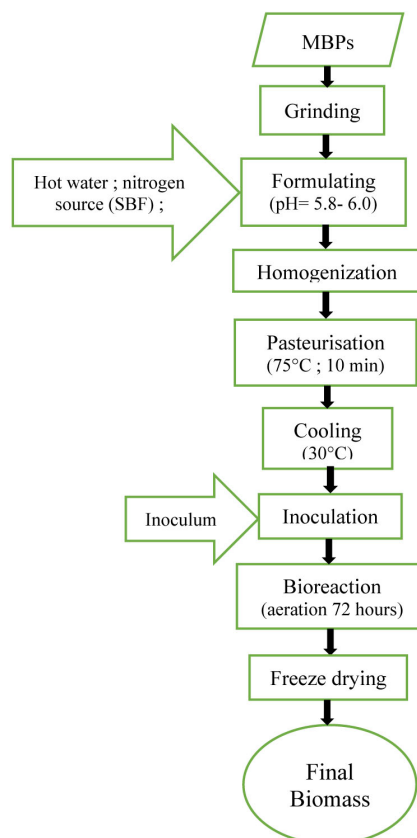


Figure 2. Diagram of mango byproducts bioreaction recovery.
(MBPs = Mango By-products).

2.5. Statistical Analyses

Analysis of variance (ANOVA) of the experimental results were statistically performed using XLSTAT 2016.02.27444 software. The statistical means of the data were compared according to Tukey (HSD) with a significance level of 5%.

The experimental design and the responses optimizing were performed with Minitab 18.1 version 2014. The response values were optimized using a 95% two-sided confidence level without any constraints to obtain the optimized formula.

Data collected from *KoboToolBox* were extracted and processed in using Microsoft office version 2021.

3. Results and Discussion

3.1. Production Potential of Mango By-Products in Processing Units

A total of 33 actors were interviewed in the mango production and processing areas of Burkina Faso. Based on the quantities of raw material processed per year, the mango processing units were classified as very small actor (VSA), small actor

(SA), medium actor (MA), large actor (LA) and very large actor (VLA) units (**Table 1**).

Table 1. Classification of mango processing units according to the volume of raw material processed per year.

<i>Classification</i>	<i>Quantity of fresh mango processed (tonnes/year)</i>
Very small actor	<100
Small actor	between 100 et 500
Medium actor	between 500 et 1000
Large actor	between 1000 et 5000
Very large actor	>5000

Among mango processing actors 84.85% were drying processors. The production of mango puree and nectar occupied only 15.15% among actors (**Table 2**). This could be explained by the fact that the production of puree requires more resources, including qualified personnel and more technical facilities for aseptic packaging of end-products. Levels of processed mangoes varied from 16.47 tonnes (VSA) to 6643.18 tonnes (VLA). All VSA are involved in mango drying, as are SA and MA. Each drying unit processes about 1247.87 tonnes of fresh mangoes in a production period which last 100.31 days, compared to 4673.92 tonnes for mango puree and nectar producers during the production period which last 120 days (**Table 2**). These processed quantities generate a significant amount of by-products, estimated on average at 64.73% (w/w) in drying units and 36.53% (w/w) in puree and nectar production units. The highest quantities were found for SA and MA (all drying promoters) with 66.33% and 67.50%, respectively (**Table 2**). This could be explained by the inadequacy of the infrastructure and the lack of mastery of the technology by these categories of actors. The by-products generated are made up of unripe spoiled fruits and ripe spoiled fruits. They were all obtained by sorting before processing and represent about 15% of the quantities processed in the drying and mango puree and nectar production units, respectively. They also include direct by-products, which are residues generated during the unit operations to produce mango pulp and end products. These direct by-products, consisting of peels, kernel, pulp residues and fibers, represent 49.06% and 21.14% of the quantities processed in the drying and puree and nectar production units, respectively. During ripening in the processing units, the mango is subject to evaporation in the ripening rooms, which results in a significant mass loss of about 10% of the fresh mango quantity. The total mass loss during the processing of fresh mango is therefore estimated at 74.73% and 46.53% in the drying units and mango puree and nectar production units, respectively (**Table 2**).

A study conducted in the Haut-Bassins region by Villard *et al.* [5] showed lower MBP rates, estimated at around 60% and 20%, respectively in drying units and purée and nectar production units. This difference could be explained by a lack of

control over the flows (incoming and outgoing) in the industrial processes of the mango processing units.

Table 2. Rates of by-products generated by categories of mango processors.

Categories of actors	Number/ catégorie	Actors surveyed rate (%)	Green mangoes (tons/year)	Evapo-transpiration rate (%)	Damaged (unripe + ripe) (%)	Direct residues from pulp extraction (%)	Duration of campaign (Days)	¹ Total by-products (%)	² Global mass loss (%)
Very small actor	2	6.06	16.47	10.00	15.00	50.00	90	65.00	75.00
Small actor	15	45.45	340.92	10.00	16.33	50.00	97.5	66.33	76.33
Medium actor	4	12.12	746.67	10.00	15.00	52.50	82.5	67.50	77.50
Large actor	8	24.24	2358.04	10.00	15.83	41.27	114	57.10	67.10
Very large actor	4	12.12	6643.18	10.00	13.29	32.97	120	46.27	56.27
Drying unit	28	84.85	1247.87	10.00	15.66	49.06	100.31	64.73	74.73
Puree and nectar unit	5	15.15	4673.92	10.00	15.39	21.14	120	36.53	46.53

¹**Total by-products** = Spoiled (unripe + ripe) + Direct pulp extraction residues, ²**Total mass losses** = Total by-products + Evapo-transpiration rate.

3.2. Management of Mango By-Products in Processing Units in Burkina Faso

In mango processing units, by-products are generated and evacuated to a waste disposal centre or landfill. These sites are located at 2.73 km and 0.20 km away from the drying plants and the puree and nectar production plants, respectively (Table 3). The long distance from the landfill sites of the drying plants is justified by the fact that they do not have a waste collection point on their premises. The MAs, all of which operate in the drying sector, have the longest disposal distance (4.50 km on average). They all use disposal areas allocated by the municipal authorities (Figure 3). The cost of disposing of these mango by-products in landfills is estimated to be between 4.57 and 6.09 €/m³, depending on the stakeholder. In mango drying plants, the disposal of by-products incurs costs related to the maintenance of tricycles and trucks, fuel costs and driver salaries [4].

On average, 27.78% of the actors have recovery initiatives that are not widely used, such as direct spreading on the fields, composting and biogas production. Although the puree and nectar production units have large-capacity landfills, they do not have facilities to recover the large quantities of by-products. On average, 72.22% of processors (Table 3) landfill the mango by-products they generate.



Figure 3. Means transportation (a) and mango by-products waste disposal site (b).

The direct use of mango by-products as fertilizer through controlled spreading [23] maintains the stability of the soil flora and the balance of minerals present in the soil [24]. Composting of mango by-products is a source of good quality organic fertilizer [25]. According to surveyed stakeholders, most of them are aware that mango by-products may be a high value source of feed for livestock, especially ruminants (Figure 4). With the microbial flora of the rumen, ruminants are able to biodegrade fruit by-products such as mango, which are rich in fibers and other compounds that monogastric animals cannot assimilate [24].



Figure 4. In field consumption of mango by-products by some animals.

Table 3. Management of mango by-products by stakeholder categories in Burkina Faso.

Categories of actors	Distance to landfill (km)	Rate of units recovering waste (%)	Type of recovery
Very small actor	0.00	5.56%	Spreading
Small actor	2.41	5.56%	Spreading
Medium actor	4.50	0.00%	None
Large actor	1.89	11.11%	Composting

Continued

Very large actor	3.15	5.56%	Biogas
Drying unit	2.73	27.78%	Composting, Spreading and Biogaz
Puree and nectar unit	0.20	0.00%	None

3.3. Biochemical Potential of Mango By-Products in Processing Units in Burkina Faso

3.3.1. Physicochemical and Proximate Composition of Mango By-Products

Mango by-products (MBP) had water content of $81.50 \pm 2.25\%$, $15.31 \pm 2.86^\circ$ Brix, with a pH of 4.23 ± 0.38 and a total acidity of 3.51 ± 0.74 g (Table 4).

The MBP had total fat content of $2.15 \pm 0.61\%$ g/g DM, the protein content ranged from 2.29 ± 0.03 to $4.66 \pm 0.70\%$, total ash content of $3.42 \pm 0.54\%$ and total sugars content of $90.80 \pm 1.38\%$, with energy value of 397.03 ± 3.71 kcal/100g (DM). There is significant variation in the composition of the BPs of the different mango cultivars processed.

The moisture values are higher than those obtained in India (72.50 to 75.25%) [26] and in Colombia (74.6%) [27] on fresh mango peels. In addition, the pH (3.33 to 4.95) and Brix values (11.00 to 21.13° Brx) obtained in our previous study [28] with the flesh of different mango cultivars are similar to present data. This could be explained by the fact that mango by-products in processing units are very pulpy. The protein, lipid and total ash contents are on average similar to that of mango by-products from different cultivars and different ecosystems reported in other studies [26] [29] [30]. However, slight difference in proximate composition could be justified by the difference in cultivar, agro-pedo-meteorological conditions. All protein contents are higher than those obtained by Kanté-Traoré *et al.* [28] on the pulps of different mango cultivars in Burkina Faso. This indicates that the mango skin is richer in protein than the pulp, which is sweeter and has a higher water content.

Comparison of total sugar and protein contents show that MBP displayed higher levels in carbon than nitrogen. This could result in a nutrient imbalance and interfere with the biochemical reactions during the organic (composting or mechanization) and biotechnological recovery of MBP in the single bio-reaction mode [4]. A substrate formulation co-digested with a nitrogen source would therefore be required for improved bio-reaction. Given the high content of moisture, sugars and other biogenic residues, MBP generated in mango processing units would be conducive to enzymatic and microbial hydrolysis reactions [31]. In addition to these properties, mango being a climacteric fruit, would enlighten the high perishability of MBPs, which are a source of carbon that can be exploited for biotechnological valorization as a substrate for several industrial microorganisms and a source of bio-active molecules [32].

Table 4. Comparison of physicochemical characteristics and potential energetic values of MBP from different cultivars processed in Burkina Faso.

	Brix degree	pH	Acidity (%)	Moisture (%)	Total fat (%)	Proteins (%)	Total ash (%)	Total sugars (%)	Energy value (Kcal/100 g)
Amelie	16.07 ± 1.31	4.32 ± 0.53	3.42 ± 0.65	82.81 ± 2.23	2.57 ± 0.13	4.66 ± 0.70	3.27 ± 0.17	89.50 ± 0.79	399.76 ± 1.30
Lippens	14.73 ± 0.38	4.25 ± 0.10	3.24 ± 0.24	82.61 ± 1.43	2.84 ± 1.15	3.23 ± 0.62	4.03 ± 0.29	89.89 ± 1.47	398.08 ± 6.91
Brooks	12.33 ± 4.63	3.99 ± 0.17	4.20 ± 0.60	80.82 ± 2.82	1.84 ± 0.16	2.93 ± 0.28	3.63 ± 0.29	91.60 ± 0.62	394.66 ± 1.13
Kent	16.61 ± 1.73	4.20 ± 0.43	3.45 ± 0.90	81.11 ± 2.37	1.79 ± 0.46	3.92 ± 0.45	3.41 ± 0.41	90.88 ± 0.63	395.28 ± 3.79
Keïtt	17.94 ± 0.51	4.84 ± 0.04	2.59 ± 0.00	79.00 ± 0.07	1.84 ± 0.01	2.29 ± 0.03	2.10 ± 0.03	93.77 ± 0.01	400.83 ± 0.04
Mean	15.31 ± 2.86	4.23 ± 0.38	3.51 ± 0.74	81.50 ± 2.25	2.15 ± 0.61	3.63 ± 0.88	3.42 ± 0.54	90.80 ± 1.38	397.89 ± 3.71
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

3.3.2. Bioactive Compounds of Mango By-Products in Processing Units

From **Table 5**, mango by-products (MBP) had total phenolic compounds of 80.81 ± 13.53 mg GAE/g of dry mater (DM), with flavonoids, reducing sugars, and antioxidant compounds content of 27.65 ± 7.65 mg quercetin E./g of DM, 81.06 ± 22.46 mg D-glucose E./g of DM, and 8.82 ± 0.18 mg ascorbic acid E./g of DM, respectively. It had vitamin C content of 2.04 ± 1.12 mg/g of DM and beta-carotene content of 1.88 ± 1.18 mg/g of DM. There was a significant difference between BPs of mango cultivars in terms of bioactive compounds.

Table 5. Comparison of bioactive compounds in mango by-products among cultivars.

Mango cultivar	Total polyphenols (mg * GAE/g)	Flavonoids (mg Quercetin E/g)	Reducing sugars (mg D-glucose E/g)	A.Ox compounds (mg AAE/g)	Vitamin C (mg/g)	Beta Carotene (mg/g)
Keïtt	102.66 ± 0.98	37.78 ± 2.00	77.95 ± 0.25	8.72 ± 0.02	3.51 ± 0.10	1.20 ± 0.11
Amélie	80.90 ± 8.39	31.84 ± 7.84	67.31 ± 4.54	8.79 ± 0.35	2.33 ± 0.57	3.87 ± 2.92
Kent	70.28 ± 7.69	17.84 ± 0.36	117.09 ± 1.47	9.09 ± 0.01	1.04 ± 0.01	2.03 ± 0.14
Books	81.39 ± 4.61	23.45 ± 1.65	84.44 ± 4.53	8.89 ± 0.32	0.80 ± 0.34	1.14 ± 0.12
Lippens	68.80 ± 32.52	27.32 ± 10.01	58.50 ± 12.65	8.62 ± 0.11	2.51 ± 1.67	1.16 ± 0.61
Mean	80.81 ± 13.53	27.65 ± 7.65	81.06 ± 22.46	8.82 ± 0.18	2.04 ± 1.12	1.88 ± 1.18
P value	0.175	0.020	<0.001	0.004	0.011	<0.001
Significant	No	Yes	Yes	Yes	Yes	Yes

*Abbreviations: GAE: gallic acid equivalent; A.Ox: anti oxydant; AAE: ascorbic acid equivalent.

Phenolic compounds in this study are lower than that obtained by Vithana, Singh and Johnson [33] on mango peel in Australia (168.0 mg/g GAE). These authors found that phenolic compounds content of the mango increased as it ripens on the tree. On the other hand, a study by Aziah *et al.* [34] suggested that phenolic compounds content in unripe mango skin (102.41 mg/g EAG) is higher

than that in ripe mango skin (70.20 mg/g GAE). Another data [30] showed higher levels of phenolic compounds (96.2 mg/g GAE) than those in the present study, which were higher than those obtained by Sogi *et al.* [35] on freeze-dried mango peel (31.85 mg/g GAE). These differences could be explained by differences in cultivars as well as the variability of the agro-climatic conditions of the study areas.

Levels of flavonoids are similar to those obtained in un-ripped and ripped mango peels (33.00 and 29.24 mg/g quercetin E., respectively) by Aziah *et al.* [34], who obtained higher levels of antioxidant compounds in unripped and ripped mango peels (54.23 and 43.30 mg/g Trolox E., respectively). This difference in antioxidant activities could be explained by the different type of reducing agent used in the assay.

Levels of pro-vitamin A such as beta-carotene are lower than those of total carotenoids (3.09 mg/g) obtained by Ajila *et al.* [30]. They are also lower than those for total carotenoids (3.34 - 3.94 mg/g) found in ripped mango peel (*Raspuri* cultivar) from India [26]. However, they are higher than those for total carotenoids reported by Aziah *et al.* [34] (0.16 mg/g) and Izidoro *et al.* [29] (0.036 - 0.055 mg/g). These differences could be enlightened by a cultivar difference, but also by the variability of the agro-climatic conditions of the study areas. Our results are superior to those of total carotenoids obtained by Ajila, Bhat and Rao [26] (0.36 - 0.55 mg/g) and Aziah *et al.* [34] (0.10 mg/g), from unripe mangoes peels. This difference could be explained by the fact that carotenoid content increases as the mango ripens. Indeed, during ripening, there is a breakdown of chlorophyll and the increase in the activities of hydrolytic enzymes which may release carotenoids and phenolic compounds including anthocyanins [4] [36] [37].

Ascorbic acid levels are higher than those reported by Ajila *et al.* [30] (0.39 mg/g) and Izidoro *et al.* [29] (0.97 - 1.36 mg/g) in ripe mango peels. However, they are lower than those found (52.51 mg/g) by Aziah *et al.* [34] in ripe mango peels. These differences could be due to cultivar difference, but also by the variability of the agro-climatic conditions of the study areas. In line with previous data, ripe mango skin is richer in ascorbic acid than the flesh [28]. Similar data were found in other fruits such as pineapple peels [38].

Reducing sugar levels are similar to those from fresh mango peels [6]. They are also similar to the glucose contents (25 - 124 mg/g) from apple residues [24], but lower than those of reducing sugar contents (279.05 mg/g) in pineapple peels [39]. Thus, mango by-products are relatively low in reducing sugars with high total sugar content ($90.80 \pm 1.38\%$). Therefore, biotechnological valorisation and/or anaerobic digestion of mango by-products requires pre-treatment either by heating or enzymatic hydrolysis [4] to increase the content of fermentable sugars that can be easily catabolized by microbial strains. Yeasts are able to transform several free hexoses to produce ATP energy, for their growth [40].

The results show that mango by-products are a significant source of ascorbic acid, carotenoids and other phenolic compounds with strong antioxidant properties. Consumption of mango peels may have nutritional and health benefit

because of their endogenous bio-active compounds exhibiting anti-proliferative properties on cancer cells [41] [42]. Antioxidants may have the property of reducing mutagenesis (carcinogenesis), while reducing the damage caused by DNA oxidation, with a decrease in cell division [24]. With regard to ascorbic acid, its relatively high level presence in MBP may contribute to fight against the formation of microbial biofilms in foods, especially in liquid foods, due to its antibacterial properties on pathogenic germs such as *S. aureus*, *L. monocytogenes*, *Campylobacter jejuni*, *M. tuberculosis*, *Aspergillus spp.*, ... [43] [44]. This could be an advantage in biotechnological and/or organic recovery (methanisation or anaerobic digestion) of MBP. Indeed, the antibacterial activity of ascorbic acid against contaminants in the substrate would optimize the availability of carbon and nitrogen sources for better biological activity in a bioreactor or anaerobic digester.

3.3.3. Amino Acid Composition of Mango By-Products

Mango by-products (MBP) had amino acids (AA.) content of 3.08% g/g of DM, of which 1.50% is essential (Table 6). There is a significant difference in the content of Arginin, Threonin, Prolin and Leucin between MBPs of different cultivars of mangoes. Detailed analysis of specific amino-acid content of MBPs showed that they contain interesting levels of quantifiable essential amino-acid according to assays used. It showed that amino-acid content in MBPs are low levels relative to the protein content. To improve the dietary use of these MBPs, protein formulations or fortification technologies would be required to meet the nutritional requirements of amino-acid [45].

Table 6. Amino acid ¹composition of mango by-products in processing unit according to cultivars.

AA/ Cultivar	Amelie	Kent	Books	Lippens	Keïtt	Mean	P value	Significant
<i>Asp + Asn</i>	0.25 ^a	0.18 ^a	0.08 ^a	0.17 ^a	0.08 ^a	0.15	0.078	No
<i>Glu + Gln</i>	0.32 ^a	0.21 ^a	0.22 ^a	0.21 ^a	0.09 ^a	0.21	0.098	No
<i>Ser</i>	0.14 ^a	0.11 ^a	0.14 ^a	0.10 ^a	0.06 ^a	0.11	0.267	No
<i>Gly</i>	0.14 ^a	0.11 ^a	0.06 ^a	0.10 ^a	0.06 ^a	0.09	0.116	No
<i>Arg</i>	0.20 ^a	0.15 ^a	0.20 ^a	0.20 ^a	0.05 ^b	0.16	0.036	Yes
<i>Thr</i>	0.13 ^a	0.13 ^a	0.13 ^a	0.13 ^a	0.05 ^b	0.11	0.001	Yes
<i>Ala</i>	0.26 ^a	0.31 ^a	0.26 ^a	0.20 ^a	0.25 ^a	0.25	0.926	No
<i>Pro</i>	0.95 ^b	0.36 ^c	0.23 ^c	0.57 ^{bc}	0.89 ^a	0.60	0.000	Yes
<i>Tyr</i>	0.14 ^a	0.14 ^a	0.14 ^a	0.14 ^a	0.03 ^a	0.12	0.080	No
<i>Val</i>	0.27 ^a	0.28 ^a	0.23 ^a	0.16 ^a	0.05 ^a	0.20	0.235	No
<i>Met</i>	0.27 ^a	0.13 ^a	0.08 ^a	0.10 ^a	0.27 ^a	0.17	0.365	No
<i>Ile</i>	0.18 ^a	0.13 ^a	0.18 ^a	0.10 ^a	0.18 ^a	0.16	0.293	No
<i>Leu</i>	0.32 ^{ab}	0.23 ^{ab}	0.09 ^b	0.22 ^{ab}	0.49 ^a	0.27	0.040	Yes
<i>Phe</i>	0.15 ^a	0.15 ^a	0.15 ^a	0.15 ^a	0.07 ^a	0.14	0.067	No

Continued

<i>Lys</i>	0.33 ^a	0.31 ^a	0.29 ^a	0.34 ^a	0.40 ^a	0.33	0.814	No
Total aa (%)	4.05^a	2.94^{abc}	2.48^c	2.88^{bc}	3.03^{ab}	3.08		
aa essentiels	1.80	1.50	1.29	1.33	1.55	1.50		
aa non essentiels	2.25	1.43	1.19	1.55	1.47	1.58		

¹Data were expressed in proportion (% w/w, dry matter basis).

3.3.4. Minerals Composition of Mango By-Products in Processing Units

There was a significant difference in mineral content between BPs of mango cultivars in processing units (Table 7). Major minerals were potassium (1288.93 ± 77.31 mg/100g, DM), phosphorus (403.11 ± 172.22 mg/100g, DM), calcium (162.25 ± 34.28 mg/100g, DM), and magnesium (55.32 ± 9.80 mg/100g, DM). Minor elements were iron (3.054 ± 0.52 mg/100g, DM), manganese (2.921 ± 0.18 mg/100g, DM), zinc (0.617 ± 0.15 mg/100g, DM), and copper (0.018 ± 0.02 mg/100g, DM).

Table 7. Mineral element composition of MBP in processing units.

Mango cultivars	Cu (mg/100g)	Zn (mg/100g)	Mn (mg/100g)	Fe (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	K (mg/100g)	P (mg/100g)
Amelie	0.027 ± 0.01 ^a	0.720 ± 0.02 ^{ab}	2.913 ± 0.05 ^{ab}	2.672 ± 0.07 ^{ab}	162.01 ± 1.16 ^{ab}	68.39 ± 0.32 ^a	1247.31 ± 10.20 ^{ab}	448.99 ± 0.04 ^b
Keïtt	0.013 ± 0.001 ^b	0.333 ± 0.06 ^b	3.547 ± 0.02 ^a	2.798 ± 0.05 ^{ab}	144.16 ± 6.57 ^{ab}	60.71 ± 1.18 ^{ab}	1327.29 ± 4.67 ^a	587.47 ± 0.05 ^a
Brooks	0.012 ± 0.02 ^b	1.059 ± 0.56 ^a	3.016 ± 0.30 ^{ab}	2.245 ± 0.07 ^b	142.80 ± 3.86 ^b	53.84 ± 7.02 ^{bc}	1336.84 ± 113.83 ^a	376.04 ± 21.55 ^c
Lippens	0.022 ± 0.04 ^a	0.447 ± 0.08 ^b	2.573 ± 0.09 ^b	2.490 ± 0.34 ^b	221.64 ± 79.84 ^a	42.45 ± 1.17 ^c	1359.92 ± 42.57 ^a	126.63 ± 0.64 ^d
Kent	0.015 ± 0.02 ^b	0.526 ± 0.11 ^b	2.558 ± 0.48 ^b	5.062 ± 2.07 ^a	140.63 ± 20.03 ^b	51.22 ± 7.36 ^{bc}	1173.30 ± 43.57 ^b	476.43 ± 25.42 ^b
Mean	0.018 ± 0.01	0.617 ± 0.28	2.921 ± 0.40	3.054 ± 1.14	162.25 ± 34.28	55.32 ± 9.80	1288.93 ± 77.31	403.11 ± 172.22
P value	<0.001	0.011	0.004	0.006	0.014	<0.001	<0.001	<0.001
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Levels of calcium, magnesium and copper found in MBP are lower than those reported by Izidoro *et al.* [29] who obtained lower contents of phosphorus (101 - 178 mg/100g), manganese (10.15 - 30.50 mg/Kg) and iron (2.20 - 16.00 mg/Kg). On the other hand, they obtained potassium (1124 - 1380 mg/100g) and zinc (6.10 - 9.08 mg/Kg) contents similar to those in the present study. The mineral contents of mango pulp obtained by these authors are lower than those of mango peel. Levels of minerals is important for a better metabolism of the substrates by fermentative strains in bioreactors in biotechnological processes (cellular proteins production) or anaerobic digestion (biogas production). This is because the energy

metabolism pathway of microbial cells requires most of these mineral elements as cofactors during glycolysis, the tricarboxylic acid (TCA) cycle and oxidative phosphorylation [46] [47]. This metabolism involves the mineral phosphate (Pi), which combines with ADP to form ATP molecules [40]. For instance, during cell division of strains, phosphate is involved in the formation of the cell membrane (phospholipid bilayer). Magnesium content showed that in a bioreactor fed with MBP substrates, the microbial cells involved in the bioreaction had a biologically active energy source [46]. On the other hand, high levels of potassium may help to limit excessive acidification of biomass during biotechnological or anaerobic digestion recovery. Potassium plays a buffering role, limiting pH variation in the cellular environment and allowing polarization of the cytoplasmic membrane [47]. Under aerobic conditions, the reduced forms of certain mineral elements, including iron and manganese, can act as electron donors to allow rapid biodegradation of wet bio-waste such as MBPs, with heat production [4] [48].

3.4. Responses Parameters of Experimental Design and Optimization Solution

The mathematical combination of the factor values resulted in a total of 25 test formulations (Table 8). The biomasses obtained after the bioreaction of the substrate of each formula were characterised by a final pH, a Brix reduction rate, a crude protein rate and an optimised protein rate varying respectively from 3.68 to 4.93, from 54.79% to 131.37%, from 3.45% to 15.88% and from -6.03% to 6.79% (Table 8). Low Brix reduction rate indicate efficient sugar metabolism by the inoculum strain, accompanied by a decrease in the Brix degree of the medium. The best decrease in the Brix degree was observed in the biomasses from substrates formulated with 40% or 45% MBP. The Brix reduction rate above 100% shows an increase in the soluble dry matter content during the bioreaction. This could be explained by an excessively long hydrolysis phase of the medium's carbohydrate macromolecules. The best Brix reductions were obtained with substrates from formulas containing 40 and 45% mango by-product. All formulas containing 1.0% and 1.5% organic nitrogen source had the lowest optimised protein levels, despite their high crude protein content. During the bioreaction, from the sixtieth hour, an increase in the pH of the medium was observed in the formulas containing 0.1% of the organic nitrogen source. This could be explained by a better metabolism of the inoculum strain in these substrates, resulting in an optimal synthesis of nitrogen and therefore an increase in the pH of the medium for these formulations. The best optimised protein contents were obtained with the formulations whose substrates were prepared with 0.1% of the nitrogen source and 40 and 45% of mango by-products. Statistical optimisation of the experimental design using response parameters with Minitab software showed that MBPs = 40% and SBF = 0.1% gave the most optimal response (Table 9) with 6.79% optimised protein rate and 0.8123 composite desirability. The crude protein contents of our study are all lower than those obtained (30.84 - 56.40%) by Somda *et al.* [49] from substrates

prepared with mango biowaste powder. They are also lower than those obtained (26.47%) by Umesh, Thazeem and Preethi, [50] from pineapple peels. This difference could be explained by the fact that these authors used ammonium sulphate and yeast extract as nitrogen sources. Their substrates were also enriched with different mineral sources such as KH_2PO_4 , $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, NaCl and CaCl_2 . Formula F23 is therefore the basis for better optimization when substrates are enriched with these reagents and ammonium sulphate or yeast extract are used as additional nitrogen sources to reduce the nutritional imbalance of the fermentative strain during the bioreaction [4] for single cell protein production and renewable energy generation.

Table 8. Expérimental design and responses optimizing.

Formulas	MBPs (%)	SBF (%)	Final pH	Brix reduction rate (%)	Raw protein rate (%)	Optimized protein rate (%)
F1	40	1.5	4.6	65.28	14.07	4.40
F2	25	0	4.52	108.82	3.45	3.45
F3	45	1.5	4.71	58.59	13.48	4.80
F4	35	0	4.19	93.75	4.30	4.30
F5	45	1	4.16	59.70	13.08	3.28
F6	25	1	4.5	97.44	6.90	-6.03
F7	25	0.5	4.54	117.50	7.21	2.62
F8	45	0.1	4.56	77.94	7.41	6.65
F9	30	0.5	4.6	114.58	8.59	4.55
F10	45	0	4.39	74.65	5.83	5.83
F11	30	0.1	4.48	77.08	5.15	3.94
F12	30	0	3.99	107.32	3.91	3.91
F13	35	1	4.39	131.37	8.61	1.35
F14	35	0.1	4.57	92.45	5.81	4.97
F15	30	1	4.93	129.55	7.65	-1.02
F16	25	1.5	4.49	111.63	13.30	-0.42
F17	40	0	4.35	74.55	4.87	4.87
F18	25	0.1	4.39	97.30	3.76	2.62
F19	30	1.5	4.48	100.00	15.88	4.50
F20	35	1.5	4.42	100.00	13.06	3.16
F21	45	0.5	4.39	54.79	9.34	5.14
F22	40	1	4.58	56.25	14.18	3.75
F23	40	0.1	4.57	60.00	7.72	6.79
F24	40	0.5	4.8	60.61	9.69	5.37
F25	35	0.5	3.68	96.43	8.14	4.71

Table 9. Optimized solution.

Solution	MBPs	SBF	Optimized protein rate (Adjusted value)	Raw protein rate (Adjusted value)	Brix reduction rate (Adjusted value)	Final pH (Adjusted value)	Composite desirability
1	40%	0.1%	6.78983%	7.72238%	60%	4.57	0.8123

4. Conclusion

This study showed that mango by-products (MBP) in Burkina Faso are produced in abundance and have a highly exploitable biochemical potential. The MBP generation survey in this study showed that MBP generated along the processing chain were mainly produced by mango drying actors, who form the major stakeholders in mango processing sector. The main mode of management of these MBPs is through evacuation for landfilling. Direct spreading, composting and biogas production have also been used by some actors in the mango drying units but are not widely used. Puree and nectar production units, despite their high activity volumes, do not have platforms to recover MBP they produce. The biochemical potential of characterised MBPs were their high levels of carbohydrates, bioactive compounds and mineral elements. It appeared that MBPs are high in carbon but low in nitrogen. MBP would therefore be conducive to enzymatic and microbial biochemical hydrolysis reactions, due to their high content of moisture, minerals, sugars and other biogenic residues. They can also be used to produce biogas and high-value molecules such as cellular proteins, which can be used in various feed formulations. However, this would require substrate formulations in co-digestion with an external nitrogen source. Statistical optimisation of a factorial substrate bioreaction experimental design shows that formula obtained with an aqueous mixture of 40% MBPs and 0.1% SBF, is the most optimal with 0.8123 composite desirability. This formula is therefore the basis for better optimisation when external mineral source and ammonium sulphate or yeast extract are used to reduce the nutritional imbalance in the bioreactor.

Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Funding

The research leading to these results received funding from the Ministry of Foreign Affairs of Denmark and administered by Danida Fellowship Centre under Grant Agreement No 21-08-DTU.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Mamadou Sanou, Sophie Dopho

Somda, Aboubacar Diakité, Karim Baquenon Soma and Inoussa Ky. The first draft of the manuscript was written by Mamadou Sanou and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Lingani, S.n. and Hagrétou (1993) Valorisation technologique de la variété améliorée de mangue du Burkina Faso: Maîtrise des paramètres physico-chimiques pour une meilleure stabilisation des produits de transformation. Université de Ouagadougou. <https://dicames.online/jspui/handle/20.500.12177/2343>
- [2] Samandoulougou, R. (2024) Quantification et caractérisation des Déchets de Mangue au Burkina Faso. *European Scientific Journal, ESJ*, **20**, 162-186. <https://doi.org/10.19044/esj.2024.v20n31p162>
- [3] Agro-Dev (2020) Rapport de l'étude sur la filière mangue dans les régions des hauts—Bassins, des cascades et du centre. https://cmacooperation.fr/wp-content/uploads/2021/03/rapport-etude-filiere-mangue_archipelago-mangue.pdf
- [4] Sanou, M., Kanté-Traoré, H., Haro, K., Somda, S., Offei, F., Zhang, Y., et al. (2024) Biochemical Properties and Biotechnological Potential of Mango Biowastes for Economical Valorization in Burkina Faso. *Waste and Biomass Valorization*, **16**, 53-73. <https://doi.org/10.1007/s12649-024-02691-1>
- [5] Villard, S., Baguignan, Y., Sancho, J.A. and Sacla, M.A. (2018) Action 2: Capitalisation des technologies innovantes de valorisation des biodéchets. Nitidae and Fúnteni. https://www.nitidae.org/files/8106890b/etude_economie_circulaire_aura_hbcapitalisation_des_technologies_innovantes_de_valorisation_des_biodechets.pdf
- [6] Puligundla, P., Reddy Obulam, V.S., Sang, E.O. and Mok, C. (2014) Biotechnological Potentialities and Valorization of Mango Peel Waste: A Review. *Sains Malaysiana*, **43**, 1901-1906. <https://doi.org/10.17576/jsm-2014-4312-12>
- [7] FAO (2018) Manuel AGRIS sur les enquêtes agricoles intégrées. <https://www.fao.org/in-action/agrisurvey/resources/resource-detail/en/c/1198081/>
- [8] Latimer, G.W. (2023) Official Methods of Analysis of AOAC INTERNATIONAL. 22nd Edition, Oxford University Press.
- [9] AOAC (1973) AOAC 963.15-1973, Fat in Cacao Products—Soxhlet Extraction Method. AOAC International. http://www.aocofficalmethod.org/index.php?main_page=product_info&cPath=1&products_id=164
- [10] DuBois, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A. and Smith, F. (1956) Colorimetric Method for Determination of Sugars and Related Substances. *Analytical Chemistry*, **28**, 350-356. <https://doi.org/10.1021/ac60111a017>
- [11] Ghanes, T. (2021) Dosage des sucres réducteurs et évaluation de l'activité antioxydante du jus nature et jus commercialisé (jus Ramy). Université Mouloud Mammeri De Tizi Ouzou.
- [12] Merrill, A.L. and Watt, B.K. (1973) Energy Value of Foods: Basis and Derivation. 74th Edition, United States: Department of Agriculture.

- [13] Blouin, J., Llorca, L., Montreau, F.R. and Dufour, J.H. (1972) Etude des conditions optimales pour la détermination des composés phénoliques totaux par le réactif de Folin-Ciocalteu. *OENO One*, **6**, 405-413.
<https://doi.org/10.20870/oeno-one.1972.6.4.2072>
- [14] Zhishen, J., Mengcheng, T. and Jianming, W. (1999) The Determination of Flavonoid Contents in Mulberry and Their Scavenging Effects on Superoxide Radicals. *Food Chemistry*, **64**, 555-559. [https://doi.org/10.1016/s0308-8146\(98\)00102-2](https://doi.org/10.1016/s0308-8146(98)00102-2)
- [15] Ben Moussa, M.T., Cherif, R.A., Lekhal, S., Bounab, A. and Hadeif, Y. (2022) Dosage des composés phénoliques et détermination de l'activité antioxydante des extraits méthanoliques de *Broccchia cinerea* VIS d e l'Algérie (Sud-Est). *Algerian Journal of Pharmacy*, **4**, 49-59. <https://www.asjp.cerist.dz/en/PresentationRevue/436>
- [16] Latimer, G.W. (2023) AOAC 968.08, Minerals in Animal Feed and Pet Food: Atomic Absorption Spectrophotometry Method. In *Official Methods of Analysis of AOAC INTERNATIONAL*, 22nd Edition, Oxford Academic, p. 19.
- [17] AOAC (2018) AOAC 2018.06-2018 Total Amino Acids in Infant Formulas and Adult. AOAC International.
http://www.aocofficialmethod.org/index.php?main_page=product_info&products_id=3028
- [18] Van de Velde, F., Pirovani, M.E., Cámara, M.S., Güemes, D.R. and Bernardi, C.M.d.H. (2012) Optimization and Validation of a UV-HPLC Method for Vitamin C Determination in Strawberries (*Fragaria ananassa* Duch.), Using Experimental Designs. *Food Analytical Methods*, **5**, 1097-1104. <https://doi.org/10.1007/s12161-011-9347-5>
- [19] AOAC (2005) AOAC 2005.07-2005, B-Carotene in Supplements and Raw Materials—Reversed-Phase High Pressure Liquid Chromatographic Method. AOAC International.
http://www.aocofficialmethod.org/index.php?main_page=product_info&products_id=283
- [20] Goupy, J. and Creighton, L. (2008) Introduction to Design of Experiments with JMP Examples, Third. North Carolina, SAS Institute Inc.
- [21] Goupy, J. and Creighton, L. (2006) Introduction Aux Plans d'expériences. 3e edition, L'Usine Nouvelle.
- [22] Ouédraogo, N., Savadogo, A., Somda, M.K., Zongo, C. and Traore, A.S. (2012) Essai de production de protéines d'organismes unicellulaires par des souches de levures à partir de résidus de tubercules de patate douce et d'igname. *Biotechnology, Agronomy, Society and Environment*, **16**, 463-467.
<https://popups.uliege.be/1780-4507/index.php?id=9119&gathStatI-con=true&lang=en>
- [23] Alix, B. (2014) Analyse de la filière d'épandage de déchets organiques dans le Bas-Rhin: Etat actuel et étude de nouvelles possibilités d'épandage. Lyon.
<https://www.calameo.com/books/0027570793a87ec3f47f5>
- [24] Grigora, C. (2012) Valorisation des fruits et des sous-produits de l'industrie de transformation des fruits par extraction des composés bioactifs. Université d'Orléans et Université «Vasile Alecsandri» de Bacău. <https://theses.hal.science/tel-00772304>
- [25] Bicaba, F.L.D. (2017) Evaluation des paramètres physico-chimiques des composts à base des résidus de mangue dans le village de samagan, Bobo-Dioulasso (Burkina Faso). Université Nazi Boni (UNB).
- [26] Ajila, C.M., Bhat, S.G. and Prasada Rao, U.J.S. (2007) Valuable Components of Raw and Ripe Peels from Two Indian Mango Varieties. *Food Chemistry*, **102**, 1006-1011.

- <https://doi.org/10.1016/j.foodchem.2006.06.036>
- [27] Sánchez-Camargo, A.d.P., Gutiérrez, L., Vargas, S.M., Martínez-Correa, H.A., Parada-Alfonso, F. and Narváez-Cuenca, C. (2019) Valorisation of Mango Peel: Proximate Composition, Supercritical Fluid Extraction of Carotenoids, and Application as an Antioxidant Additive for an Edible Oil. *The Journal of Supercritical Fluids*, **152**, Article ID: 104574. <https://doi.org/10.1016/j.supflu.2019.104574>
 - [28] Kanté-Traoré, H., Dufrechou, M., Le Meurley, D., et al. (2020) Caractéristiques physico-chimiques et biochimiques de 14 variétés de mangue du Burkina Faso peu vulgarisées, pour une meilleure valorisation. *Sciences Naturelles et Appliquées*, **39**, 32.
 - [29] Izidoro, M., Leonel, M., Leonel, S., Lossoli, N.A.B., Cândido, H.T., Züge, P.G.U., et al. (2023) Nutritional and Technological Properties of Pulp and Peel Flours from Different Mango Cultivars. *Food Science and Technology*, **43**, e107922. <https://doi.org/10.1590/fst.107922>
 - [30] Ajila, C.M., Aalami, M., Leelavathi, K. and Rao, U.J.S.P. (2010) Mango Peel Powder: A Potential Source of Antioxidant and Dietary Fiber in Macaroni Preparations. *Innovative Food Science & Emerging Technologies*, **11**, 219-224. <https://doi.org/10.1016/j.ifset.2009.10.004>
 - [31] Menzel, T., Neubauer, P. and Junne, S. (2020) Role of Microbial Hydrolysis in Anaerobic Digestion. *Energies*, **13**, Article No. 5555. <https://doi.org/10.3390/en13215555>
 - [32] Aggarwal, P., Kaur, A. and Bhise, S. (2017) Value-Added Processing and Utilization of Mango By-Products. In: Muhammad Siddiq, J.S.S. and Brecht, J.K., Eds., *Handbook of Mango Fruit*, John Wiley, 279-293.
 - [33] Vithana, M.D.K., Singh, Z. and Johnson, S.K. (2019) Harvest Maturity Stage Affects the Concentrations of Health-Promoting Compounds: Lupeol, Mangiferin and Phenolic Acids in the Pulp and Peel of Ripe “Kensington Pride” Mango Fruit. *Scientia Horticulturae*, **243**, 125-130. <https://doi.org/10.1016/j.scienta.2018.08.019>
 - [34] Abdul Aziz, N.A., Wong, L.M., Bhat, R. and Cheng, L.H. (2012) Evaluation of Processed Green and Ripe Mango Peel and Pulp Flours (*Mangifera indica* var. Chokanan) in Terms of Chemical Composition, Antioxidant Compounds and Functional Properties. *Journal of the Science of Food and Agriculture*, **92**, 557-563. <https://doi.org/10.1002/jsfa.4606>
 - [35] Sogi, D.S., Siddiq, M., Greiby, I. and Dolan, K.D. (2013) Total Phenolics, Antioxidant Activity, and Functional Properties of “Tommy Atkins” Mango Peel and Kernel as Affected by Drying Methods. *Food Chemistry*, **141**, 2649-2655. <https://doi.org/10.1016/j.foodchem.2013.05.053>
 - [36] Kapoor, L., Simkin, A.J., George Priya Doss, C. and Siva, R. (2022) Fruit Ripening: Dynamics and Integrated Analysis of Carotenoids and Anthocyanins. *BMC Plant Biology*, **22**, Article No. 27. <https://doi.org/10.1186/s12870-021-03411-w>
 - [37] Nguyen, T.T., Uthairatanakij, A., Srilaong, V., Laohakunjit, N., Kato, M. and Jitareerat, P. (2021) Impact of Electron Beam Irradiation on the Chlorophyll Degradation and Antioxidant Capacity of Mango Fruit. *Applied Biological Chemistry*, **64**, Article No. 19. <https://doi.org/10.1186/s13765-021-00592-8>
 - [38] Teshome, E., Teka, T.A., Nandasiri, R., Rout, J.R., Harouna, D.V., Astatkie, T., et al. (2023) Fruit By-Products and Their Industrial Applications for Nutritional Benefits and Health Promotion: A Comprehensive Review. *Sustainability*, **15**, Article No. 7840. <https://doi.org/10.3390/su15107840>
 - [39] Casabar, J.T., Unpaprom, Y. and Ramaraj, R. (2019) Fermentation of Pineapple Fruit

- Peel Wastes for Bioethanol Production. *Biomass Conversion and Biorefinery*, **9**, 761-765. <https://doi.org/10.1007/s13399-019-00436-y>
- [40] Weil, J.-H. (1990) Biochimie Générale. 6th Edition, Masson.
- [41] Fenech, M., Amaya, I., Valpuesta, V. and Botella, M.A. (2019) Vitamin C Content in Fruits: Biosynthesis and Regulation. *Frontiers in Plant Science*, **9**, Article No. 2006. <https://doi.org/10.3389/fpls.2018.02006>
- [42] Kim, H., Moon, J.Y., Kim, H., Lee, D., Cho, M., Choi, H., *et al.* (2010) Antioxidant and Antiproliferative Activities of Mango (*Mangifera indica* L.) Flesh and Peel. *Food Chemistry*, **121**, 429-436. <https://doi.org/10.1016/j.foodchem.2009.12.060>
- [43] Przekwas, J., Wiktorczyk, N., Budzyńska, A., Walecka-Zacharska, E. and Gospodarek-Komkowska, E. (2020) Ascorbic Acid Changes Growth of Food-Borne Pathogens in the Early Stage of Biofilm Formation. *Microorganisms*, **8**, Article No. 553. <https://doi.org/10.3390/microorganisms8040553>
- [44] Mumtaz, S., Mumtaz, S., Ali, S., Tahir, H.M., Kazmi, S.A.R., Mughal, T.A., *et al.* (2023) Evaluation of Antibacterial Activity of Vitamin C against Human Bacterial Pathogens. *Brazilian Journal of Biology*, **83**, 1-8. <https://doi.org/10.1590/1519-6984.247165>
- [45] Joint FAO/WHO/UNU (2002) Protein and Amino Acid Requirements in Human Nutrition: Report of a Joint FAO/WHO/UNU Expert Consultation. https://iris.who.int/bitstream/handle/10665/43411/WHO_TRS_935_eng.pdf?ua=1
- [46] Tardy, A., Pouteau, E., Marquez, D., Yilmaz, C. and Scholey, A. (2020) Vitamins and Minerals for Energy, Fatigue and Cognition: A Narrative Review of the Biochemical and Clinical Evidence. *Nutrients*, **12**, Article No. 228. <https://doi.org/10.3390/nu12010228>
- [47] Killilea, D.W. and Killilea, A.N. (2022) Mineral Requirements for Mitochondrial Function: A Connection to Redox Balance and Cellular Differentiation. *Free Radical Biology and Medicine*, **182**, 182-191. <https://doi.org/10.1016/j.freeradbiomed.2022.02.022>
- [48] Gourdon, R., Bayard, R. and Valla, G. (1996) Biodétérioration microbienne des déchets: Définitions, principes et méthodes d'évaluation. *Déchets, Sciences et Techniques*, No. 1, 13-21.
- [49] Marius, K.S., Mahamadi, N., Ibrahim, K., Iliassou, M., Sonagnon, H.S.K., Yerobessor, D., *et al.* (2018) Production of Single Cell Protein (SCP) and Essentials Amino Acids from *Candida Utilis* FMJ12 by Solid State Fermentation Using Mango Waste Supplemented with Nitrogen Sources. *African Journal of Biotechnology*, **17**, 716-723. <https://doi.org/10.5897/ajb2017.16361>
- [50] Umesh, M., Thazeem, B. and Preethi, K. (2019) Valorization of Pineapple Peels through Single Cell Protein Production Using *Saccharomyces Cerevisiae* NCDC 364. *Applied Food Biotechnology*, **6**, 255-263.