Valorisation of Mango Fruit By-products: Physicochemical Characterisation and Future Prospect

Tamrat Tesfaye
EiTEX

Abstract

As a result of its high perishability and poor postharvest handling technique, large quantities of mango are wasted during the peak season annually. In the present study, the physicochemical characterization was investigated, with a view exploiting mango by-product as a source of high-value material. The result revealed that processing of mango fruit generates 35-55% by-product (seed and peel). Results revealed that mango seed (kernel and seed coat) had protein contents of 5.09 and 6.12%; moisture, 3.58 and 5.11%; crude fat, 18.67 and 11.33%; mineral ash, 2.65 and 1.98%; fibre, 5.47 and 2.02% while the carbohydrate was 64.24 and 72.24% respectively. The results revealed that the peel contained moisture (7.51%), crude protein (11.67%), crude fat (42.24%), mineral ash (1.65%) and total carbohydrates (31.24%). There is no significant difference on the functional properties and ultimate properties of the by-products. FTIR spectrum clearly identified the presence of carboxyl and hydroxyl groups besides cellulose, hemicellulose, and lignin. The result showed that mango fruit by-product could be a rich source of chemical composition for different application areas. Valorisation of mango fruit by-product through different routes not only helps reduce environmental pollution but also can create job opportunity and reduces the cost of waste disposal for processing industries.

Keywords: Mango by-products, physicochemical, Valorisation, proximate composition.

1. INTRODUCTION

In industrial production, agricultural processing, household consumption, and retail generate a huge amount of food waste (Table 1). Huge quantities of by-products are produced by the food industry raises serious economic, management and environmental problem besides being a great loss of valuable materials. Many of these residues could be converted into high-value materials trough bio-refineries. And most of the undeveloped countries have food security problem [1]. The present food insecurity problem in the world and the expected increase in demand, warrant the search for alternative sources to replace food based industrial raw materials [2-5]. The fruit processing sector is categorised under food processing sectors. The fruit processing results in high amounts of by-products (peels, seeds, and oilseed meals) and the disposal of these materials represent a problem that is further governed by international law. Thus, finding new possible application area to further exploit these wastes for the production of high-value products have gained increasing interest. These by-products could be used as antitumoral, antiviral, antibacterial, cardioprotective and antimutagenic activities because they are a source of organic acid, minerals, phenolics, sugars, and dietary fibre which have a wide range of action which includes [3].

Table 1. The proportion of food wastes in different sector.

	Sector	Proportion (%)
1	Household	42
2	Food manufacturing industry	39
3	Food service sector	14
4	Retail and distribution	5

Currently, the fruit processing industry dispose of their by-products (peel and seed) since they don't have commercial value. The disposal of these wastes incurs additional cost to the fruit processing industry due to limited availability of landfills and high transportation cost. Since these have high COD and BOD and they rapidly decay, they become a source of insect multiplication; so needs proper disposal technique [4-5].

Mango is one of the most important tropical fruits in the world and currently ranked 5th in total world production among the major fruit crops [7-12]. The total amount of mango production in the world was around 35 million tonnes by the year 2009 [9]. The amount of mango production in Africa during 2009 is 13.6 million tonnes [11]. 1-2% of the production is processed to make products such as jelly powders, nectars, jams, juices, fruit bars, flakes concentrates, and mango chips but the majority of mango production is consumed fresh [9-15]. Mango processing industries dispose of seeds (seed coat and kernel), cull fruits: fresh fruits unsuitable for human consumption, and peel (Figure 2) as a by-product. Since these by-products contain pectin and phenolic compounds (antioxidants) these by-products could be potential sources of high-value products [16-21]. The aim of this study, therefore, is to determine the physicochemical properties of mango fruit by-products in order to evaluate their structural potential for beneficiation.

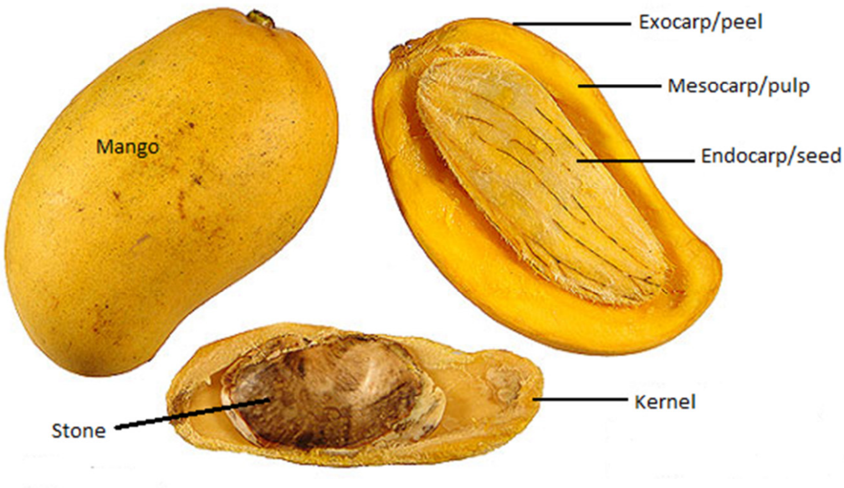

Figure 1. Mango fruit

2. METHODS

2.1. Material: Mango fruit by-products (peel and seed) were kindly supplied by juice houses in Bahir Dar city, Ethiopia.

2.2. Sample preparation: The seed kernel and the seed coat were separated manually and the by-products were washed using tap water to remove the adhered materials. The by-products were oven dried at 70 °C and ground into fine powder and packed in a plastic bag for further processing.

2.3. Proximate analysis: Proximate analysis was carried out on the processed samples to determine the percentage moisture, crude fibre, ash, protein, lipid, and carbohydrate using standard methods.

2.4. Moisture content: Known mass of the sample was dried at 105°C in drying oven until the weight of the sample becomes constant. The sample was cooled in a desiccator and the moisture content was calculated using the following formula:

$$Moisture\ content = \frac{W_1 - W_2}{W_1} * 100 \quad (1)$$

Where,
W_1 = Original mass of sample (g), and
W_2 = Oven dry mass of sample (g)

2.5. Ash Content: - The ash content is calculated on the basis of the dry weight of the original sample, and after the sample is ignited at a 575±25 °C.

$$Ash\ content\ (\%) = \frac{Weight\ of\ ash}{weight\ of\ test\ specimen} * 100 \quad (2)$$

2.6. Crude protein: - For the determination of crude protein, a Kjeldahl apparatus was used, as per the procedure described in AACC (2000) method no. 46-30. The percentage nitrogen content of each sample was calculated as shown below. This was multiplied by a conversion factor of 6.25 to obtain the percentage crude protein.

$$\%N = \frac{0.01*0.014*250*100}{5W} \quad (3)$$

Where,
T = titre value
W = Weight of sample used.

2.7. Crude fat: - 600 g of dried mango by-products were extracted in Soxhlet extraction method using n-hexane as a solvent for 2 hr. The oil-hexane mixture obtained after extraction was separated on a rotary evaporator at 70 °C to recover hexane. This study was conducted in triplicate.

$$Crude\ fat\ (\%) = \frac{Thimble\ (g) - Thimble\ (g)}{Sample\ (g)} * 100 \quad (4)$$

2.8. Crude fibre: - This test was performed according to the method described in AACC (2000) method no. 32-

10. Two g of dry sample was defatted using a soxhlet extractor. The fat-free sample was transferred into a one-litre beaker. Boiling water was added with 25 mL of 2.5M H_2SO_4. This was mixed, and the volume was made up to the 200 ml level and boiled for 30 minutes, then filtered, by means of suction, through a Buchner funnel. The residue was washed twice with boiling water and transferred into a beaker, and then, 25 mL of 2.5M NaOH was added to it and diluted to the 200 mL mark. The beaker was heated and boiled for 30 mins and the filtering procedure was repeated. The fibre cake was extracted and moisturised with a small portion of ethanol to drain between additions, which is permitted.

The resulting residue was transferred to a porcelain crucible. The crucible was dried, along with the materials, at 100 ^oC to achieve a constant weight, was cooled and weighed. The content of the crucible was then incinerated at 600 ^oC for 3 hrs in a muffle furnace until all the carbonaceous matter was burnt. The crucible containing the ash was cooled in the desiccator and weighed. Crude fibre content was calculated:

$$Crude\ fibre = \frac{100-(W_1-W_2)}{W} \quad (5)$$

Where,
W_1= weight in g before ashing
W_2= weight in g of crucible containing ash
W = weight of sample in g

2.9. Nitrogen Free Extract (NFE):- NFE was calculated:

$$NFE = 100 - (Crude\ protein\% + crude\ fat\% + crude\ fiber\% + moisture\ content + ash\ content) \quad (6)$$

2.10. Elemental analysis: - The amount of carbon, nitrogen, hydrogen and sulphur in the samples were determined using elemental analyser (CHNS analyser).

2.11. Estimation of volume and specific gravity: Fresh seed was weighed on the electronic balance (Weight of seed in air). Distilled water was poured into clean 250ml capacity measuring cylinder to the 100ml mark. The volume and weight of water displaced when the kernel is submerged were noted.

$$\text{Specific gravity} = \frac{\text{Weight of seed in air x Specific gravity of water}}{\text{Weight of displaced water}} \quad (7)$$

2.12. Determination of bulk density: A 100 ml capacity measuring cylinder was filled with distilled water up to the 60 ml mark. 20 g of dry powder mango fruit by-product was weighed into the cylinder before it was tapped 10 times against the palm and placed on the table until an equilibrium volume was reached. The final volume of the water was taken and then used to calculate the bulk density.

$$\text{Bulk density} \left(\frac{g}{ml}\right) = \frac{\text{Mass of sample}}{\text{Fvw} - \text{Ivw}} \quad (8)$$

Where Ivw = Initial volume of distilled water, Fvw = Final volume of distilled water after tapping

2.13. Determination of pH: Five g of fresh avocado seed was mashed into a 100 ml beaker, 45 ml of distilled water (pH 7.0) was added and allowed to stand for 30 mins while stirring occasionally with a glass rod. The pH was measured with a digital pH meter after allowing the suspension to stand still.

2.14. FTIR analysis: Fourier transform infrared/FTIR spectroscopy was done to identify the chemical functional groups present on mango seed by-products. IR absorbance data were obtained for wavenumbers in the range of 400–4000 cm^{-1}, representing the average of 64 scans and analysed using software.

3. RESULT AND DISCUSSION

3.1. Parts of mango fruit: Mango waste: mango processing units yield mango wastes made of variable proportions of peels, pulp, seeds and cull fruits. Percent distribution of mango fruit was studied and depicted in Table 2. Mango processing yields about 35-55% of by-products. Mango seed coat and kernel together represent 15-20 % of the whole fruit, out of which mango seed coat alone represents 3.75-11 % whereas mango kernel alone represents 6.75-15% of the whole fruit. Results of this investigation showed the considerable weight of the fruit will be throwing away without valorising it. Variations in seed and kernel percent of the mango fruits are attributed to the varietal difference.

Table. 2. Percent distribution of mango fruit parts

Fruit part	Weight (g)	Percent (%)
Whole fruit	200-600	100
Pulp	90-390	45-65
Peel	20-150	10-25
Seed	30-120	15-20
Kernel	13.5-90	6.75-15
Seed coat	7.5-66	3.75-11

Results of this investigation showed a considerable amount of the fruit will be throwing away without valorising it. This will affect the environment since they do have high BOD and COD value and even during degradation they will result in fly and insects, in addition to this it reduces the profit of the processing industry by increasing waste disposal cost. So valorising this waste will have positive implication in different areas.

3.2. Functional properties: Figure 2 shows the functional properties of the by-products. As it seen from the figure, there was no significant difference between all type of the by-products. The bulk density of the sample ranges from 0.32-0.43 g/cm^3 so this raw material could be used where high nutrient to low bulk density is needed because of its relatively low bulk density [35]. Because of high water absorption capacity (Figure 2), the by-products could be used as functional ingredients in bakery products to reduce moisture loss. The low foaming capacity of these materials (Figure 2) could be due to globular protein. The ability to absorb oil is essential for food processing because oil acts as a flavoured retainer and improves mouthfeel. The oil adsorption of mango by-products were higher (>2g/g), so they will have flavour retaining capacity. Foaming capacities of both flours were low compared to 35% reported for bush mango (Abulude et al., 2008). The range of pH obtained for the fresh by-products ranges from 4.5-6.5. This will be useful for further processing during valorisation.

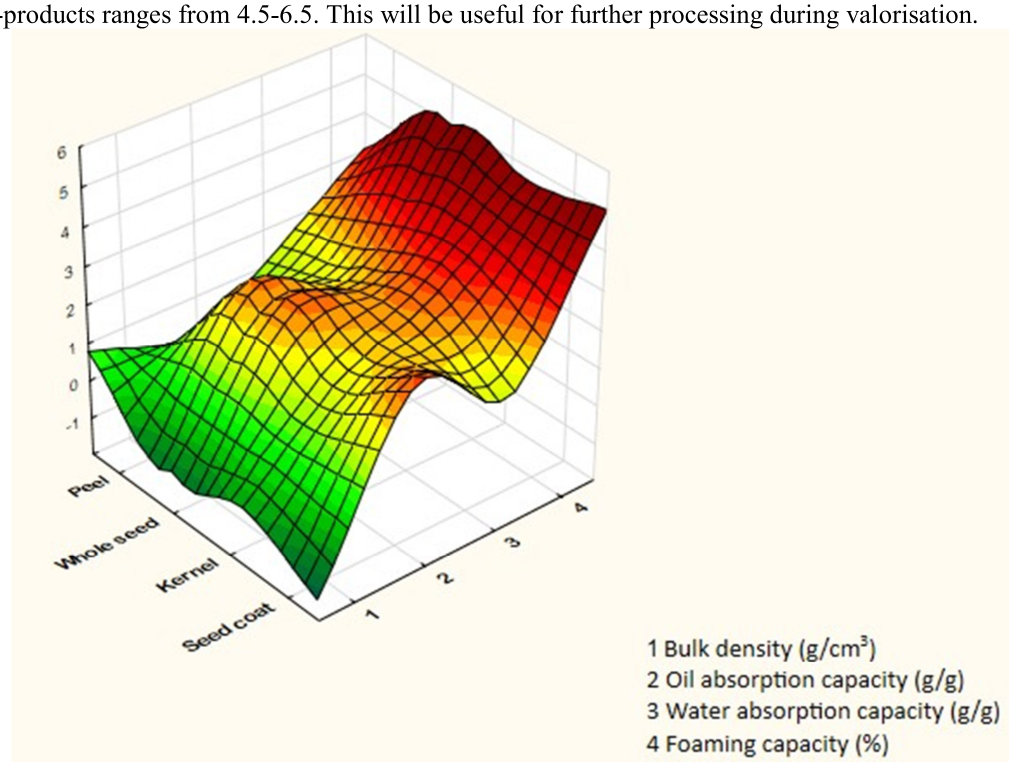

Figure 2. Surface plot showing the functional properties of mango by-products

3.3. Proximate analysis: **The results from Figure 3 showed there were significant differences in the moisture, crude fibre, crude fat, and total carbohydrate each type of wastes, however, there is no significant difference in ash and protein contents.** From Figure 3, it is seen that the moisture contents of the by-product range from 2.55% (seed coat) -7.63% (peel of mango). The moisture content of the raw material is crucial to determine further processing. The relative low **moisture content** of the by-products promises a long shelf life for further processing and the plant seeds before cultivation.

The crude fibre content of 4.86% for seed coat, 2.32% for the kernel, 3.43% for whole seed and 6.32% for peel were obtained. Compared to all the by-product type peel of mango has higher fibre content followed by a seed coat. So these materials could be regarded as valuable sources of dietary fibre in human nutrition. The result from Figure 3 revealed that there was no significant difference in ash content of all samples. The value was much higher in seed coat compared to other samples. This could be attributed, due to high levels of inorganic ions in seed coat (Calcium, Magnesium, and Sodium).

There were no significant differences in the crude protein content of the samples ranged from 4.95-7.36%. If the plant food provides more than 12% protein it is considered the rich source of protein [15]. But all the data from Figure 3 revealed that all samples have a lower value, so they did not meet this requirement and are not rich sources of protein. However, the bioavailability of these proteins to individual subjects is determined by other factors such as genetic factors and the anti-nutritional components of the plant foods [18]. Plant protein still remains a veritable source of food nutrient for the less privileged population in developing countries, where the cost of animal protein is beyond their income per capita [20]. Thus protein from mango by-products could be incorporated in human and animal nutrition to supplement protein.

Figure 3 show the carbohydrate content of the sample has a significant difference. The carbohydrate content of seed coat, kernel, whole seed and peel of mango were 64.95, 72.55%, 71.33% and 32.31% respectively (Figure 3). These values are, higher than carbohydrate content of potato and maize, however, lower than enset/false banana. This result revealed that mango seed could be a rich source of starch material for textile sizing, paper, leather, pharmaceutical, textile printing, cosmetics and others. Mango fruit by-products were a rich source of lipids (Figure 3). The crude lipid contents of the seed coat, kernel, whole seed and peel of mango were (18.67, 12.46, 10.31 and 42.11%, respectively) are high compared to reported values of 3.15-34% for most tropical plant seeds thus, mango fruit by-products are rich sources of lipids.

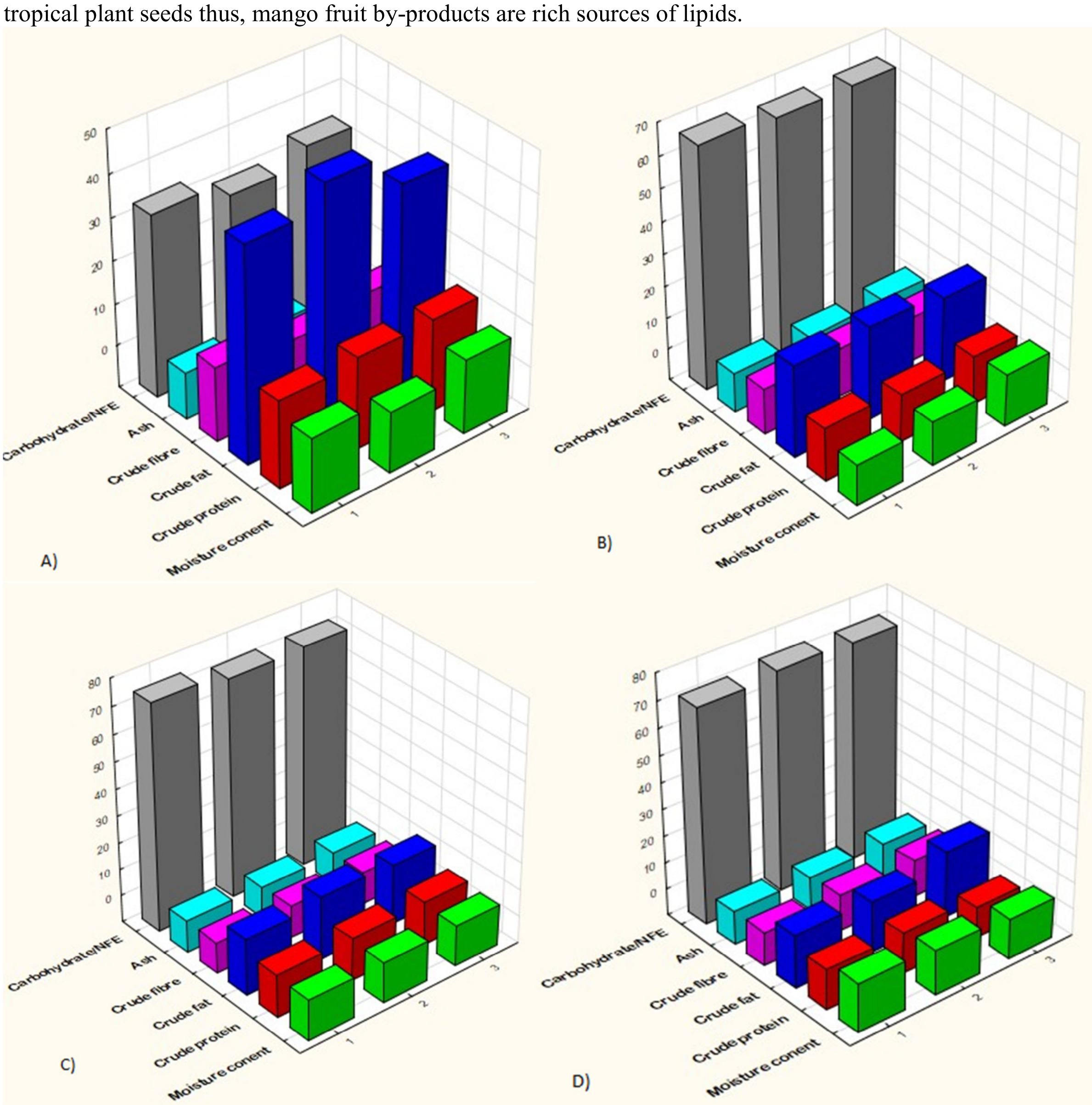

Figure 3. Proximate analysis of mango fruit by-product: Peel (A), Seed coat (B), Kernel (C) and Whole seed (D).

3.4. Ultimate analysis: The ultimate analysis (Figure 4) provides weight percentage of C, H, O, N, and S. Results from elemental analysis presented in Figure 4 showed relatively higher values for carbon in peel and higher value of oxygen in peel of the fruit whereas the contents of nitrogen and hydrogen content in all samples were very similar.

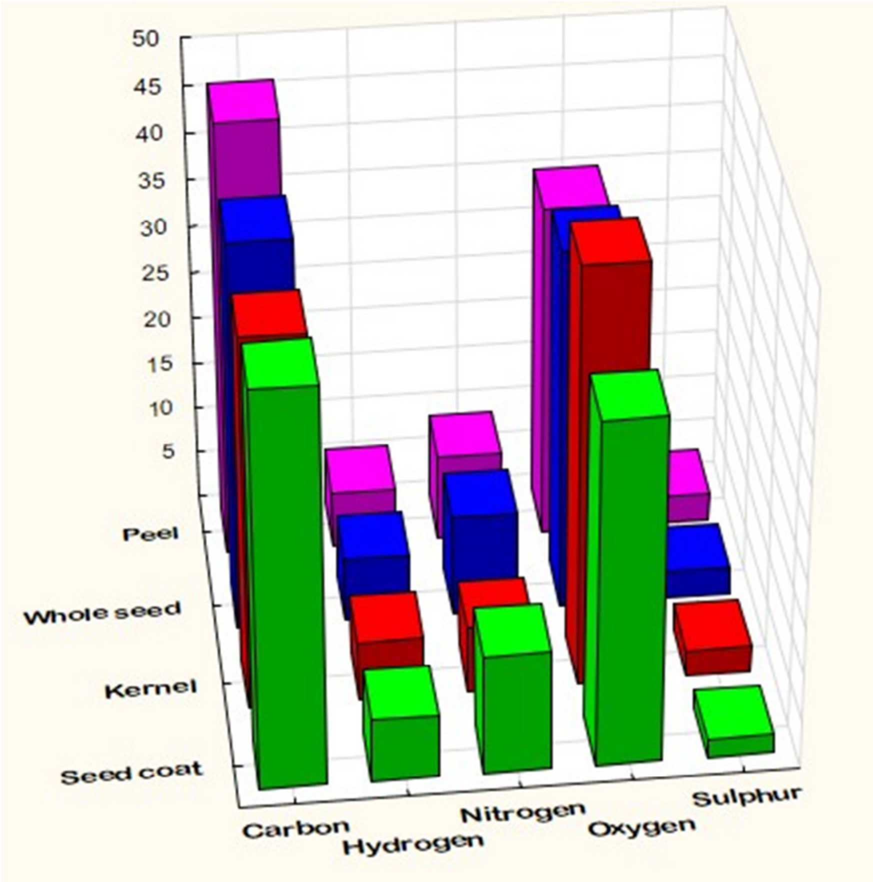

Figure 4. Ultimate analysis of mango fruit by-products.

3.5. Fourier transform infrared (FTIR) spectroscopy: FTIR spectroscopy was done to identify the major functional groups present in mango fruit by-products (Figure 5 and Table 3). There is no variation in FTIR spectra of mango fruit by-products. The peak at 1055 cm^{-1} can be assigned to stretching vibration of C-OH of alcoholic groups and carboxylic acids and aliphatic acid group vibration at 1230 cm^{-1} to deformation vibration of C-O and stretching formation of –OH of carboxylic acids and phenols [19]. The peaks at 1370 cm^{-1} may be assigned to symmetric stretching of –COO− of pectin while asymmetric and symmetric stretching vibrations of ionic carboxylic groups (–COO−), respectively, appeared at 1446, and 1619 cm^{-1} [20], [19].

The peak observed at 1733 cm^{-1} is the stretching vibration of the C-O bond due to non-ionic carboxyl groups or their esters acids (–COOH, –$COOCH_3$) [7]. The peak at 2850 cm^{-1} was the symmetric stretching vibration of CH_2 and the band at 2925 cm^{-1} indicates symmetric or asymmetric C-H stretching vibration of aliphatic acids [17]. The broad and intense peak at 3420 cm^{-1} was assigned to the stretching of O-H group due to inter- and intramolecular hydrogen bonding of polymeric compounds, such as alcohols, phenols and carboxylic acids, as in pectin, cellulose, and lignin. From FTIR spectrum in Figure 3, it is clearly identified the presence of carboxyl and hydroxyl groups. The presence of these groups in biopolymers may function as proton donors, and also they will make the starch a modified starch if it is used for the textile application.

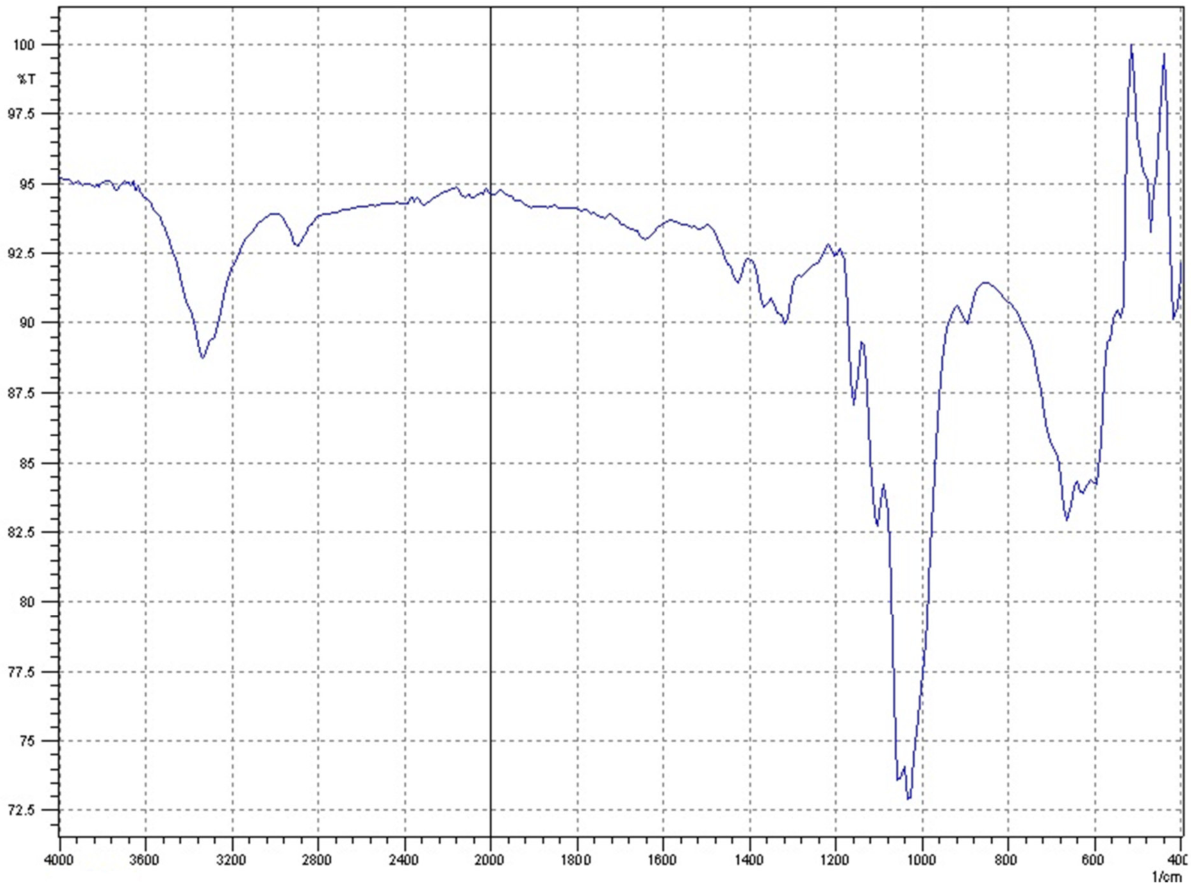

Figure 5. FTIR spectra of mango by-product

Table 3. FTIR spectral of mango by-product

Wavenumbers (cm^{-1})	Type of bond
900-1250	C-O and C-OH /Stretching
1240-1250	O-H/Bending
1375	$C-CH_3$/Stretching
1460	$C-H_2$ and C-H/Deformation
1640	O-H/Bending
1730-1740	C=O/Stretching
2920	C-H and(–COOH, $–COOCH_3$ /Stretching
3300-3900	O-H/Stretching

4. Valorisation of potential application areas based on physicochemical characterisation

To the author's knowledge, although the by-products represent a considerable percentage of the total fruit, scientific research on the phytochemistry and biotechnology potentials of these by-products is commercially feasible (Figure 6). Based on the proximate and ultimate analysis the by-products could be used in different application areas like:-

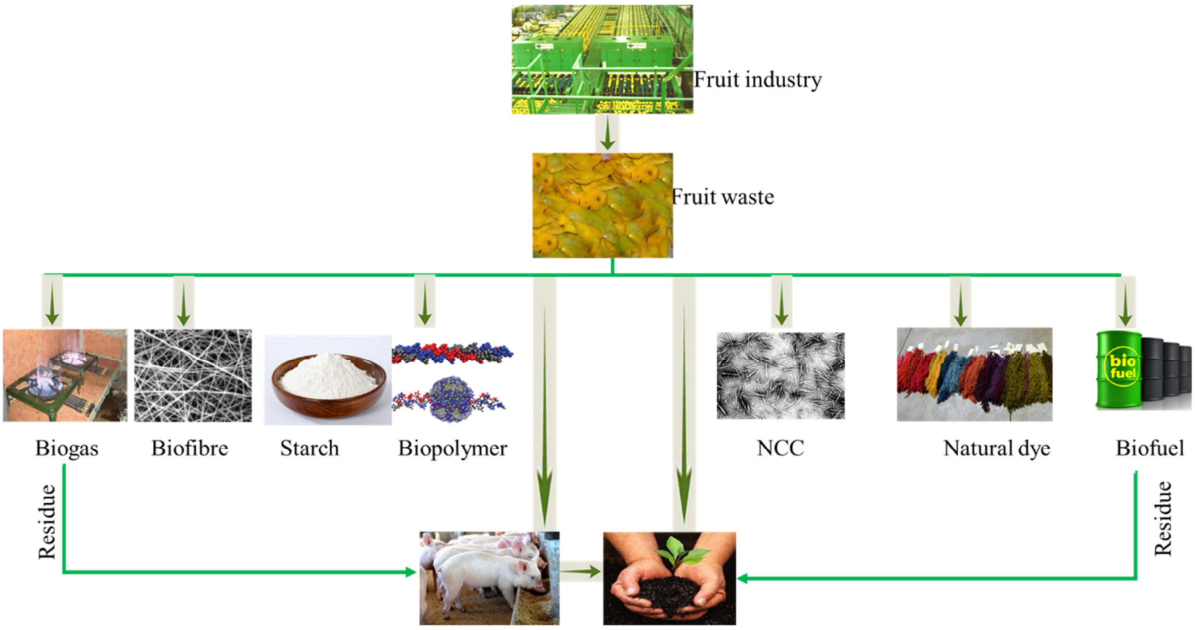

Figure 6. Possible valorisation areas of mango fruit waste.

4.1. Animal feed: Mango by-products can be used as animal feed, and could partly replace energy concentrations in diets for ruminants. The physicochemical composition of the by-product revealed that they have high sugar content, so they are palatable especially to ruminants. Due to their chemical composition, favourable volatile fatty acid and in vitro digestibility, mango by-product could have promising potential for utilisation as animal feed or feed additives. Since they contain low protein content, supplementation of protein source to is necessary, and this could be done using fermentation. Fermentation of those by-products could enhance the protein content, essential amino acids, vitamins, and fibre digestibility and decrease antinutrients level such as tannins. This way the low-grade mango fruit by-product could be upgraded after fermentation with selective microorganisms and such fermented products could be used as healthy animal feed.

4.2. Starch extraction: Starch, the principle carbohydrate constituent of most plant materials, merits a detailed investigation to better understand its biochemical and functional characteristics as well as its variations. Extensive research has been conducted on the structure and functional properties of the main starches of commerce, such as wheat, corn, potato, and rice, due to their ready availability and their extensive utilisation in food and non-food applications. The result from Figure 3 revealed that mango by-products are a potential starch source due to their high starch content (more than 50%). Using aqueous extraction technique one can extract starch from those sources [1 and 57]. The extracted starch could be used in textile industries for yarn sizing, for paint, paper, pharmaceuticals, leather, and Bioplastics industries.

4.3. Natural dye: In today's ecologically conscious world, we're constantly looking for new ways to reduce our impact on the environment. Whether it is through recycling and proper waste management, finding renewable sources of energy, or eating locally grown produce, our collective awareness of our carbon footprint and how we manage it has grown exponentially over the past few decades. One of these issues is replacing the petroleum-based synthetic dyes with natural dyes. Natural dyes could be extracted from different colour yielding plants and food wastes, some examples of which are: mango waste, carrot tops, pomegranate rinds and mixed herbs [55 and 57]. By allying ourselves with the sustainable food movement, it is possible to partly replace the toxic synthetic dyes in textile industries. By diazotization of mango by-products, the natural azo dye could be extracted. This indicates mango waste could be a good source of natural dye to substitute petroleum-based synthetic dyes.

4.4. Enzymes production: From the physicochemical properties of mango by-products, the result revealed that this waste could be used in the production of carboxymethyl cellulose, pectinases, and cellulase enzyme (Figure 7). Carboxymethylcellulose and cellulase enzyme could be used in food industry as a viscosity modifier or thickener, and to stabilise emulsions in various products including ice cream, as toothpaste, laxatives, diet pills, water-based paints, detergents, lubricants, textile sizing, and various paper products. As mango by-products are a rich source of pectin, [2-3] so degrading pectin using any microorganisms could be used for fermentative production of pectinases. Pectinase enzymes could be used in processes involving the degradation of plant materials, especially in wine production.

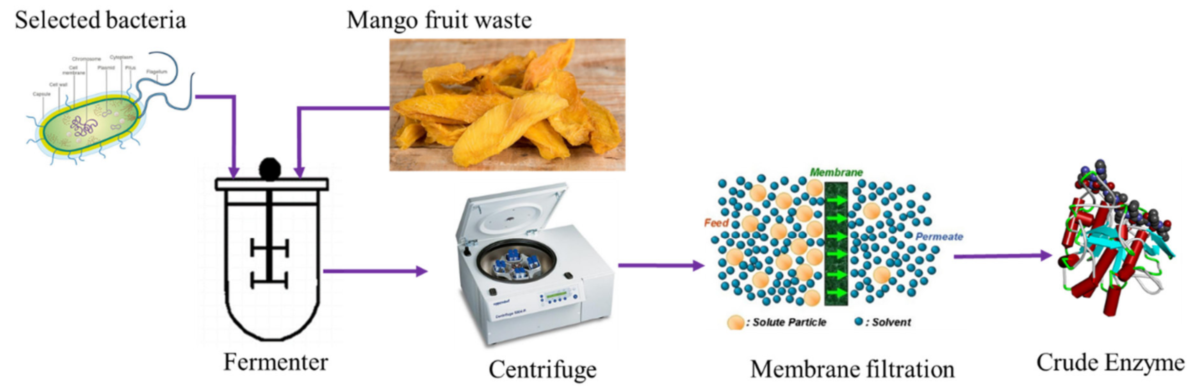

Figure 7. Schematic diagram of enzymatic production from mango fruit waste

4.5. Lactic acid fermentation: Lactic acid is used as a food preservative, an ingredient in processed foods and is used as a decontaminant during meat processing curing agent, and flavouring agent. It is also used as a starting material in the production of polylactic acid polymer. Lactic acid is produced commercially by fermentation of carbohydrates such as glucose, sucrose, or lactose, or by chemical synthesis but the production of this substance is very costly [14]. The use of agro-industrial wastes would provide an alternative way to produce lactic acid from less costly raw materials. Seeing that the chemical composition of mango by-products they could be used as a source of lactic acid [16]. The production of lactic acid takes place through a two-step procedure; pre-treatment followed by acid hydrolysis of the by-product followed by microbial fermentation. The production of lactic acid from mango by-products seems to have a practical advantage because the method is economically viable since the cost of the raw material (mango by-product) has low cost.

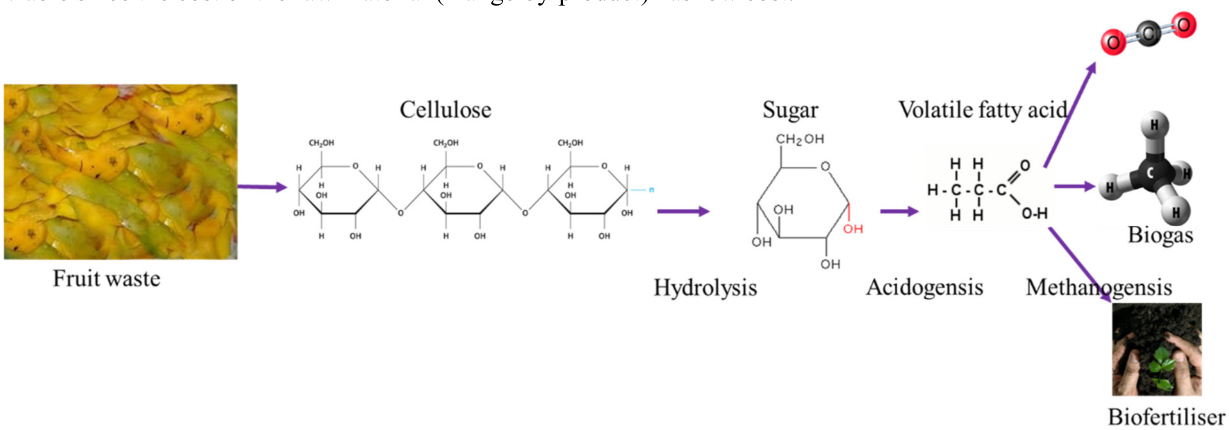

Figure 8. Process flow diagram for biogas and fertiliser production from mango fruit waste.

4.6. Biodiesel and biogas production: Because of continuous increment of the price of petroleum-based fuels, biofuels became one of the most wanted bio-products. Seeing the proximate analysis especially the crude fat content of the by-product, these wastes could be used in the production of biodiesel. In order to produce biodiesel (Figure 9), lipids are extracted based on ethyl acetate/methanol and chloroform, followed by acid or base catalysed transesterification with methanol as a catalyst; in order to convert fatty acids into biodiesel.

Anaerobic digestion has been widely used for the treatment of organic industrial wastes and agricultural wastes including fruit processing wastes (Figure 8). Physico-chemical characterisation revealed that mango fruit by-products contain a high amount of carbohydrates, this indicates the treatment of this wastes using selected bacteria could convert carbohydrates into volatile fatty acid and finally into biogas.

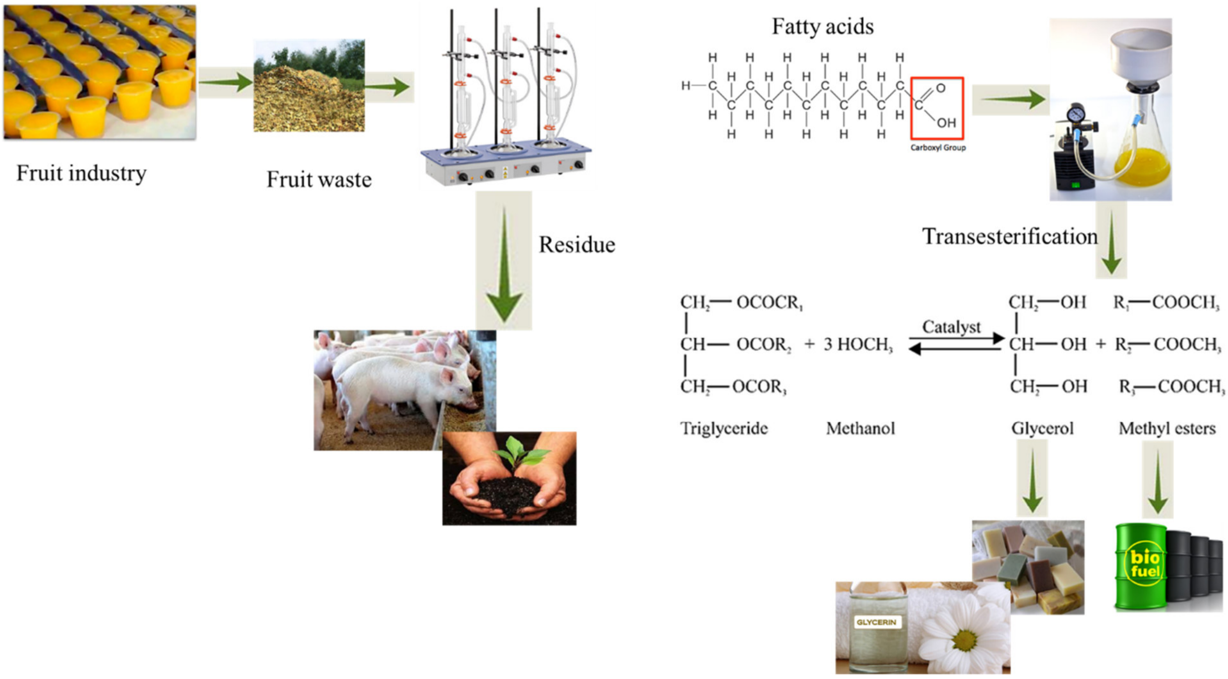

Figure 9. Schematic diagram showing biodiesel production from mango fruit waste

4.7. Ethanol production: The production of bioethanol from waste material is economically and environmentally viable to substitute petroleum-based products. Fruit processing wastes can be used as potential feedstock for bioethanol production and this could also be an attractive alternative for disposal of the polluting residues [6-10]. Mango peel extract has been used for bioethanol production. To release fermentable sugars from this waste, direct fermentation, simple aqueous extraction, enzymatic treatment or alkaline treatment could be used results in ethanol production.

4.8. Source of bioactive compounds: Bioactive compounds are found in both plant and animal products or can be synthetically produced [4, 10, 11]. Bioactive compounds protect against diseases because of antioxidant activity. Some examples of bioactive compounds are flavonoids, anthocyanins prebiotics, caffeine, phytosterols, polysaccharides, phytoestrogens, carotenoids, dithiolthiones, choline, creatine, carnitine, glucosinolates, polyphenols, and taurine. Mango by-products contain carotenoid, pectin, vitamin C, and a phenolic compound. These bioactive components could be used as a potential source of antioxidant, antiviral, anticancer, antiallergenic, antimicrobial, anti-inflammatory, immunomodulatory and analgesic [15]. So mango by-products could be a rich source of polyphenols with the potential to reduce diseases such as cancer and diabetes.

4.9. Food ingredient: As mango by-products are a rich source of polyphenols, carotenoids, and vitamins with different health-promoting properties [4, 6, 13], these sources could be used in food products such as bread, sponge cakes biscuits, and noodles. Because of their anticarcinogenic and antioxidant properties of dietary fibres is gaining attention. The result from physicochemical characterisation revealed that mango fruit by-products have good fibre content with high hydration capacities and this could be potentially used in dietary fibre-rich foods preparation. Because of the high dietary fibre content, waste products from mango processing can be added as a dietary fibre for the enrichment of food.

4.10. Pharmaceutical application: Mango fruit by-products are rich in phenolic compounds [2], and these could play a role in the putative health effects. The pectin in mango fruit by-product could be used as a super disintegrating agent and to make solid oral dosage. Due to its good solubility in the biological fluid and better swelling index, it can be used to prepare fast dispersible tablets.

4.11. Others: Nanocrystalline cellulose and Silver nanoparticles which have antibacterial properties could be extracted from these wastes and the nanoparticles can be applied to non-woven fabrics and used for antibacterial finishing. By carbonisation these waste it is possible to produce carbon nanotubes/thermally cracked carbons with high porosity and high surface and this material could be used in adsorption of pollutants from gaseous and liquid streams, removal of colour from effluents and used as reinforcement agents for the production of eco-friendly nanofillers for diverse application.

5. CONCLUSION

In recent years, scientists are looking for alternative uses of wastes to replace costly materials, for environmental protection and food security. The physicochemical characterisation of this study clearly demonstrates that mango fruit by-products contain a rich source of valuable components. Based on the results, it could be concluded that mango by-products could be used as a potential source starch, tannin, phenolic compound, crude fat, and protein. So they can be processed into different high-value products like a carbon nanotube, starch, biodiesel and much more. Thus, through novel scientific and technological methods, environmentally spoiling wastes of mango fruit could be extracted and converted into high-value products.

REFERENCES

[1] Tamrat, T., & Bruce S., 2016. Valorisation of mango seed via extraction of starch, Organic Waste book valorisation, South Africa.
[2] Malviya, R., Srivastava, P., Bansal, M. & Sharma, P.K. 2010. Mango peel pectin as a super disintegrating agent. Journal of Scientific & Industrial Research 69: 688-690.
[3] Koubala, B.B., Kansci, G., Garnier, C., Thibault, J.F. & Ralet, M.C. 2013. Physicochemical properties of dietary fibres prepared from ambarella (Spondias cytherea) and mango (Mangifera indica) peels. Food Bioprocess Tech. 6: 591-597.
[4] Varakumar, S., Sudheer Kumar, Y. & Vijaya Sarathi Reddy, O. 2011. Carotenoid composition of mango (Mangifera indicaL.) wine and its antioxidant activity, J. Food Biochem. 35: 1538-1547.
[5] Varakumar, S., Naresh, K. & Reddy, O.V.S. 2012. Preparation of mango (Mangifera indica L.) wine using a new yeast mango peel immobilised biocatalyst system. Czech J. Food Sci. 30: 557-566.
[6] Walia, N.K., Bedi, S.S., Kundu, K. & Karmakar, R. 2013. Production of bioethanol from mango peel. International Journal of Engineering Research & Technology 2: 1-7.
[7] Wyman, Ch.E. 2001. Twenty years of trials, tribulations, and research progress in bioethanol technology. Appl. Biochem. Biotech. 91: 5-21.
[8] Bhalerao, S.D., Mulmuley, G.V., Anathakrishna, S.M. & Potty, V.H. 1989. Wash and waste water management in the food industry. Fruit and vegetable processing. Indian Food Packer 43: 5-11.
[9] Madhukara, K., Nand, K., Raju, N.R. & Srilatha, H.R. 1993. Ensilage of mango peel for methane generation. Process Biochem. 28: 119-123.
[10] Abdeldaiem, M.H. & Hoda, G.M.A. 2012. Use of irradiated mango (Mangifera indica) peels powder as a potential source of dietary fibre and antioxidant in a beef burger. Journal of Applied Sciences Research 8: 3677-3687.
[11] Ajila, C.M. & Prasada Rao, U.J.S. 2013. Mango peels dietary fibre: Composition and associated bound phenolics. Journal of Functional Foods 5: 444-450.
[12] Berardini, N., Knodler, M., Schieber, A. & Carle, R. 2005. Utilisation of mango peels as a source of pectin and polyphenolics. Innov. Food Sci. Emerg. 6: 442-452.
[13] Central Food Technological Research Institute (CFTRI). 1985. Mango pulp concentration, Mysore, India. pp. 25-39.
[14] Ajila, C.M., Aalami, M., Leelavathi, K. & Prasada Rao, U.J.S. 2010b. Mango peel powder: A potential source of antioxidant and dietary fiber in macaroni preparations. Innov. Food Sci. Emerg. 11: 219-224.
[15] De la Cruz Medina, J. & Garcia, H.S. 2002. Mango: Postharvest operations. In Compendium on Post-harvest Operations, edited by Mejia, D. & Lewis, B. AGSI/FAO.
[16] Chen, J.P., Tai, C.Y. & Chen, B.H. 2004. Improved liquid chromatographic method for determination of carotenoids in Taiwanese mango (Mangifera indica L.). J. Chromatogr. A 1054:261-268.
[17] Ajila, C.M., Jaganmohan Rao, L. & Prasada Rao, U.J.S. 2010a. Characterization of bioactive compounds from raw and ripe Mangifera indica L. peel extracts. Food Chem. Toxicol. 48:3406-3411.
[18] Cojocaru, M., Droby, S., Glotter, E., Goldman, A., Gottlieb, H.E., Jacoby, B. & Prusky, D. 1986. 5- (12-heptadeconyl)-resorcinol, the major component of the antifungal activity in the peel of mango fruit. Phytochemistry 25: 1093-1095.
[19] Devi, S.S. & Nand, K. 1989. Microbial pretreatment of mango peel for biogas production. J. Microb. Biotechnol. 4: 110-115.
[20] Qin, L-J., Wu, Z. & Wu, L-Y. 2007b. Preliminary study on antifungal activities of different extracts of the peel of mango (Mangifera indica Linnaeus). Chinese Journal of Tropical Agriculture 2: 21-25.
[21] Ramteke, R.S. & Eipeson, W.E. 1997. Effect of additives on the stability of mango aroma concentrate during storage. J. Food Sci. Technol. 34: 195-199.
[22] Iqbal, M., Saeed, A. & Zafar, S.I. 2009a. FTIR spectrophotometry, kinetics and adsorption isotherms modelling, ion exchange, and EDX analysis for understanding the mechanism of Cd2+ and Pb2+ removal by mango peel waste. J. Haz. Mater. 164: 161-171.
[23] Geerkens, C.H., Schweiggert, R.M., Steingass, H., Boguhn, J., Rodehutscord, M. & Carle, R. 2013.

Influence of apple and citrus pectins, processed mango peels, a phenolic mango peel extract, and gallic acid as potential feed supplements on in vitro total gas production and rumen methanogenesis. J. Agric. Food Chem. 61: 5727-5737.
[24] Hertog, M.G.L., Feskens, E.J.M., Hallman, P.C.H., Katan, M.B. & Kromhout, D. 1993. Dietary antioxidant flavonoids and risk of coronary heart disease: The Zutphen Elderly Study. Lancet 342: 1007-1014.
[25] Iqbal, M., Saeed, A. & Kalim, I. 2009b. Characterization of adsorptive capacity and investigation of the mechanism of Cu2+, Ni2+, and Zn2+adsorption on mango peel waste from constituted metal solution and genuine electroplating effluent. Separ. Sci. Technol. 44: 3770-3791.
[26] Ajila, C.M., Bhat, S.G. & Prasada Rao, U.J.S. 2007. Valuable components of raw and ripe peels from two Indian mango varieties. Food Chem. 102: 1006-1011.
[27] Anhuradha, S. & Mullai, P. 2010. Mesophilic biodigestion of cow dung and mango peel in relation to bioenergy – Batch study. Environmental Science: An Indian Journal 5: 320-324.
[28] Aziz, N.A.A., Wong, L.M., Bhat, R. & Cheng, L.H. 2012. Evaluation of processed green and ripe mango peel and pulp flours (Mangifera indica var. Chokanan) in term of chemical composition, antioxidant compounds and functional properties. J. Sci. Food Agr. 92: 557-563.
[29] Sogi, D.S., Siddiq, M., Greiby, I. & Dolan, K.D. 2013. Total phenolics, antioxidant activity, and functional properties of 'Tommy Atkins' mango peel and kernel as affected by drying methods. Food Chem. 141: 2649-2655.
[30] Somayaji, D., Padshetty, N.S. & Nand, K. 2001. Recycling of mango peel waste for biogas production. Asian J. Microbiol. Biotechnol. Environ. Sci. 3: 339-341.
[31] Somda, M.K., Savadogo, A., Quattara, C.A.T., Quattara, A.S. & Traore, A.S. 2011. Thermotolerant and alcohol tolerant yeasts targeted to optimise hydrolyzation from mango peel for high bioethanol production. Asian Journal of Biotechnology 3: 77-83.
[32] Sruamsiri, S. & Silman, P. 2009. Nutritive value and nutrient digestibility of ensiled mango by-products. Maejo Int. J. Sci. Technol. 3: 371-378. Tunchaiyaphum, S., Eshtiaghi, M.N. & Yoswathana, N. 2013.
[33] Zgórka, G. & Kawka, S. 2001. Application of conventional UV, photodiode array (PDA) and fluorescence (FL) detection to the analysis of phenolic acids in plant material and pharmaceutical preparation. J. Pharm. Biomed. Anal. 24: 1065-1072
[34] Jawad, A.H., Alkarkhi, A.F.M., Jason, O.C., Easa, A.M. & Norulaini, N.A.N. 2013. Production of lactic acid from the mango peel waste-factorial experiment. Journal of King Saud University-Science 25: 39-45. Kittiphoom, S. 2012. Utilisation of Mango seed. International Food Research Journal 19: 1325-1335.
[35] Koubala, B.B., Kansci, G., Garnier, C., Ralet, M.C. & Thibault, J.F. 2012. Mango (Mangifera indica) and Ambarella (Spondias cytherea) peel extracted pectins improve viscoelastic properties of derived jams. African Journal of Food, Agriculture, Nutrition and Development 12: 6200-6212.
[36] Arumugam, R. & Manikandan, M. 2011. Fermentation of pretreated hydrolyzates of banana and mango fruit wastes for ethanol production. Asian J. Exp. Biol. Sci. 2: 246-256.
[37] Azevêdo, J.A.G., Valadares Filho, S.deC., Pina, D.dosS., Detmann, E., Valadares, R.F.D., Pereira, L.G.R., Souza, N.K.de P. & Costa e Silva, L.F. 2011. Intake, total digestibility, microbial protein production and the nitrogen balance in diets with fruit by-products for ruminants. Rev. Bras. Zootec. 40: 1052-1060.
[38] Kumar, D., Ashfaque, M., Muthukumar, M., Singh, M. & Garg, N. 2012. Production and characterization of carboxymethyl cellulase from Paenibacillus polymyxa using mango peel as substrate. J. Environ. Biol. 33: 81-84.
[39] Kumar, Y.S., Kumar, P.V. & Reddy, O.V.S. 2012. Pectinase production from mango peel using Aspergillus foetidus and its application in the processing of mango juice. Food Biotechnol. 26: 107-123.
[40] Larrauri, J.A., Rupérez, P. & Saura-Calixto, F. 1997. Mango peel fibres with antioxidant activity. Z. Lebensm Unters Forsch A 205: 39-42.
[41] Luo, F., Lv, Q., Zhao, Y., Hu, G., Huang, G., Zhang, J., Sun, C., Li, X. & Chen, K. 2012. Quantification and purification of mangiferin from Chinese mango (Mangifera indica L.) cultivars and its protective effect on human umbilical vein endothelial cells under H_2O_2 -induced stress. Int. J. Mol.Sci. 13: 11260-11274.
[42] Malviya, R. & Kulkarni, G.T. 2012. Extraction and characterization of mango peel pectin as a pharmaceutical excipient. Polim. Med. 42: 185-190.
[43] Mercadante, A.Z. & Rodriguez-Amaya, D.B. 1998. Effects of ripening, cultivar differences and processing on the carotenoid composition of mango. J. Agr. Food Chem. 35: 262-265.
[44] Mudaliyar, P., Sharma, L. & Kulkarni, C. 2012. Food waste management-Lactic acid production by Lactobacillus species. International Journal of Advanced Biological Research 2: 34-38. Ojokoh, A.O. 2007. Effect of fermentation on the chemical composition of mango (Mangifera indica L.) peels. Afr. J. Biotechnol. 6: 1979-1981.
[45] Palmeira, S.M.V., Gois, L.M. & Souza, L.D. 2012. Extraction of phenolic compounds from mango peels. Latin Am. Appl. Res. 42: 77-81.

[46] Puravankara, D., Bohgra, V. & Sharma, R.S. 2000. Effect of antioxidant principles isolated from mango (Mangifera indica L.) seed kernels on oxidative stability of buffalo ghee (butterfat). J. Sci. Food Agr. 80: 522-526.
[47] Qin, L-J., Wang, Q. & Wu, L-Y. 2007a. Stability of antimicrobial activities of mango (Mangifera indica L.) peel extracts. Guangxi Agricultural Sciences 4: 423-426.
[48] Rashad, M.M., Moharib, S.A. & Jwanny, E.W. 1990. Yeast conversion of mango waste or methanol to single cell protein and other metabolites. Biol. Waste. 32: 277-284.
[49] Reddy, L.V., Reddy, O.V.S. & Wee, Y.J. 2011. Production of ethanol from mango (Mangifera indica L.) peels by Saccharomyces cerevisiae CFTRI101. Afr. J. Biotechnol. 10: 4183-4189.
[50] Saravanan, P., Muthuvelayudham, R. & Viruthagiri, T. 2012. Application of statistical design for the production of cellulose by Trichoderma reesei using mango peel. Enzyme Research 2012: Article ID 157643.
[51] Berardini, N.; Knodler, M.; Schieber, A.; Carle, R., 2005. Utilisation of mango peels as a source of pectin and polyphenolics. Innovative Food Science & Emerging Technologies, 6 (4): 442-452.
[52] Jedele, S.; Hau, A. M.; von Oppen, M., 2003. An analysis of the world market for mangos and its importance for developing countries. Deutscher Tropentag 2003, Göttingen, October 8-10, 2003. Conference on International Agricultural Research for Development.
[53] Sruamsiri, S.; Silman, P., 2009. Nutritive value and nutrient digestibility of ensiled mango by-products. Maejo Int. J. Sci. Technol., 3 (03): 371-378.
[54] Schieber, A.; Stintzing, F. C.; Carle, R., 2001. By-products of plant food processing as a source of functional compounds-recent developments. Trends in Food Science & Technology, 12: 401–413.
[55] Tamrat, T., 2017. Natural dye extraction from mango seeds, Journal of Cleaner Production, submitted.
[56] Tamrat, T., and Sithole, B.B., 2016. Techno-economic feasibility of starch extraction from mango seeds, Journal of Cleaner Production, submitted.
[57] Tesfaye, T., Begam, R., Sithole, B.B. and Shabaridharan, K., 2015. Dyeing Cotton with Dyes Extracted from Eucalyptus and Mango Trees. *The International Journal of Science and Technoledge,* **3**(8), pp. 310.