



# **A Review Paper on Agro-food Waste and Food by-Product Valorization into Value Added Products for Application in the Food Industry: Opportunities and Challenges for Cameroon Bioeconomy**

**Pride Ndasi Ngwasiri <sup>a\*</sup>, Wilson Agwanande Ambindei <sup>b</sup>,  
Vivian Akah Adanmengwi <sup>a</sup>, Pinuh Ngwi <sup>a</sup>, Amei Tewang Mah <sup>a</sup>,  
Noumo Thierry Ngangmou <sup>a</sup>, Dobgima John Fonmboh <sup>a</sup>,  
Ngwa Martin Ngwabie <sup>c</sup>, Martin Benoit Ngassoum <sup>d</sup> and Ejoh Richard Aba <sup>a</sup>**

<sup>a</sup> Department of Nutrition, Food and Bioresource Technology, College of Technology,  
The University of Bamenda, P.O. Box 39 Bambili-Bamenda, Cameroon.

<sup>b</sup> Department of Process Engineering, ENSAI, University of Ngaoundere, P.O. Box 455,  
Ngaoundere, Cameroon.

<sup>c</sup> Department of Agriculture and Environmental Engineering, College of Technology,  
The University of Bamenda, P.O. Box 39 Bambili-Bamenda, Cameroon.

<sup>d</sup> Department of Applied Chemistry, ENSAI, University of Ngaoundere, P.O. Box 455,  
Ngaoundere, Cameroon.

## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

## **Article Information**

DOI: 10.9734/AJB2T/2022/v8i330128

### **Open Peer Review History:**

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/87188>

**Review Article**

**Received 15 March 2022**

**Accepted 23 May 2022**

**Published 11 July 2022**

## **ABSTRACT**

Agricultural production, agro-industrial food processing, distribution and consumption generate high Amounts of varied food by-products and waste which place a heavy burden on the environment and cause losses to the food industry. The most common disposal methods of food wastes are the use of landfills and incineration, which lead to several environmental, social, and economic issues. However, many of these by-products and wastes have been reported to be

higher than the final product in terms of nutritional or functional properties, making them potential raw materials for application in the agro-food industry. Together with the recent sustainable development goals of food security, environmental protection, and energy efficiency, these are the key reasons why food waste valorization is necessary. Valorization of food waste within the bio-economy approach offers an economical and environmental opportunity that can serve as a solution to the issues faced with the conventional disposal methods. Traditionally, in Africa, especially in Cameroon, food by-products and waste have been valorized into a range of products for application in food and food preparation, including food additives and spices, food emulsifiers and stabilizers, food salts and nutraceuticals. Traditional Waste valorization methods could achieve sustainable development in technologically underdeveloped countries by going beyond improving agro-food waste management to the production of useful biochemicals, food ingredients and food products, which can be referred to as value added products from waste. In addition, the processing and conversion of these agro-food by-products and waste generated in the poor regions of the world for the production and formulation of novel foods and biochemicals will directly benefit the local communities by reducing environmental pollution and increasing income in the food industry. This review aims at providing insight into current trends in food waste valorization using traditional methods in an African country such as Cameroon. This paper presents the variety and type of food waste within the food chain that can be valorized into various products using traditional methods. Furthermore, a series of examples of key food waste valorization schemes and value added products as case studies to demonstrate the advancement in traditional bioconversions are described, bringing out the opportunities and challenges for the Cameroon bioeconomy.

*Keywords: Food waste; pollution; feed-stock; valorization; Value-added products; Bioeconomy.*

## 1. INTRODUCTION

The ever increasing demand for food coupled with higher environmental standards is re-shaping agricultural activities toward ecologically sustainable and efficient systems [1]. While the existing literature has mainly focused on increasing food production, the magnitude of waste and by-products are too large to be ignored [2,3]. Agricultural production and agro-industrial processing generate high amounts of food by-products and waste, which have been reported to be higher than the final product in terms of nutritional or functional properties [4]. It has been estimated that about one-third of the edible parts of food produced for human consumption worldwide is either lost or wasted [5], and these losses have been valued at 1 trillion USD [6]. The transportation, storage, and processing stages of the food production chain are also sources of fruit and food waste.

Food wastes and byproducts are often rich in beneficial nutrients and bioactive compounds, making them a useful tool in meeting the need for more composite nutritional sources in present-day society [7]. Many waste valorization methods could achieve sustainable development by going beyond improving agro-food waste management to the production of useful biochemicals, food ingredients and food

products, which can be referred to as value added products from waste.

Food by products can be defined as secondary products derived from primary agro-food production processes, and they are an interesting and cheaper source of potential functional ingredients [8]. Food waste refers to “unwanted or unusable material, substances, or by-products” that are “eliminated or discarded as no longer useful or required after the completion of a process” [9]. The negative environmental, social, and economic problems caused by food by-products and waste remain a worldwide cause for concern [1]. According to FAO, [3], about one-third of all edible food (1.3 billion metric tonnes, MMT) is lost across the food chain each year. Most of these byproducts and wastes are dumped in municipal landfills where degradation by microbes and leachate production pose a variety of environmental issues. Economically, the handling of these waste products in land fills comes with great costs, and it is quite challenging to manage large amounts of different degradable materials with such differences in their properties [10, 11]. Social impacts may be attributed to an ethical and moral dimension within the general concept of global food security since 805 million people across the globe suffer from hunger [12]. Most of the studies on food waste and by-products in sub-Saharan Africa, particularly in Cameroon

have been concerned with estimating the extent of waste and by-product generation, without worries of the technological importance and potential on development of the bio-economy.

The most common traditional methods of food waste disposal are incineration and disposal in landfills, which cause air and water pollution and eventually lead to food and soil contamination. The European Union (EU) is promoting the reduction of food wastes and the search for new end-uses for food by-products to help in resolving these challenges [13]. Following these recommendations, food waste from several agro-food industries such as vegetables, fruits, beverages, sugar, meat, aquaculture, marine products and seafood represent an interesting and cheaper source of potentially functional or bioactive compounds. In this context, the biorefinery concept has emerged as the development of integrated and combined extraction or recovery processes for the conversion of biomass into many added-value products [14].

Food waste is abundant in sub-Saharan Africa, especially in Cameroon, and earlier research on waste management in the area has been focused on waste collection and disposal practices and their environmental implications [15, 16] with minimal attention given to the potential of transforming these waste materials into value added products and biochemicals. In Cameroon for example, foods such as maize (*Zea mays*), rice (*Oryza sativa*), cassava (*Manihot esculenta Crantz*), fruits like oranges, lemons and pineapple, and vegetables such as amaranth (*Amaranthus cruentus*) are widely cultivated for subsistence [17, 18]. Numerous reports [19, 20, 3,21] have underlined the significance of food by-products and waste and the need to reduce them to improve food security and sustainability of food systems.

The available disposal options in under-developed technologically poor countries like Cameroon still largely remain slash and burn or land fillings, producing large quantities of greenhouse gases (GHG). Greenhouse gases are generated during incineration and composting, while eutrophication and acidification of local ecosystems is the result of the wastewater generated during anaerobic digestion [22, 23]. The processing and conversion of agro-food by-products and waste generated in the poor regions of the world for the production and formulation of novel foods and

biochemicals will directly benefit the local communities [24]. In Cameroon, for example, the use of plantain and banana byproducts has been suggested as the main raw material for the production of traditional food salts commonly called Nikkih, which are used in yellow achu-soup preparation due to their emulsification properties [25].

The valorization of agro-food byproducts and waste into different high-value products has been reviewed by numerous studies, [26, 27, 28, 29] while others [30-33] investigated and described the chemical processes involved in the conversion. However, these reviews focused on valorization using advanced technology, affordable to developed and industrialized countries, with little focus on the contribution of agro-food waste valorization for food security in undeveloped African countries. In this review paper we will therefore try to frame the key issues associated with traditional valorization of agro-food waste into value added food products and biochemicals within the context of the emerging bio-economy and circular-economy, suggesting that valorizing these agro-food wastes can significantly contribute to solving malnutrition and hunger in undeveloped African countries, especially in Cameroon. The following examples have been chosen as being a relevant set of materials for which there is sufficient information, and clear improvements and opportunities are envisaged.

## 2. AGRICULTURAL BY-PRODUCTS AND WASTE GENERATION IN CAMEROON

The country Cameroon is located in the Gulf of Guinea with Gabon, Guinea Republic and Nigeria as its neighbours, and it had a population of about 26.55 million as of 2020. The importance of agriculture, fishery and livestock and their contribution to the economy of Cameroon is significant as it is highly dependent on it, which provides 70 percent of its active population employment opportunity. Due to the high agricultural activities, both plantation and non-plantation waste biomass are abundant, which are highly under-utilized. Cameroon is one of the prominent world producers of crops like cocoa, coffee, bananas, palm products, tobacco, rubber, and cotton, due to its richness in natural resources. Other important products include cereals (maize, millet, sorghum and paddy), roots and tubers (cassava, cocoyam, taro, potato, yam), oilseeds (groundnut, cottonseed), fruits and vegetables (citrus,

pineapple, tropical fruits) legumes and pulses, spices and condiments, leafy vegetables and mushrooms, plants and ornamental flowers, just to name a few [34].

In terms of waste and by-products generation, the agricultural sector ranks among the top sectors due to the large amounts generated which will cause problems to worldwide health and threaten food security when allowed to accumulate unchecked [35, 36]. In Cameroon for example, wastes such as corncob, rice husk and groundnut husk are generated from the cultivation of crops like maize (*Zea mays*), rice (*Oryza sativa*) and cassava (*Manihot esculenta* Crantz) for subsistence alongside vegetables such as amaranth (*Amaranthus cruentus*) [17,18]. Reports have shown that the percentages of postharvest losses of amaranths and black nightshades are about 10% and 20% respectively [37]. Due to low heating value and high smoke production, these wastes are not used as fuel [38, 39]. Even though they contain large quantities of nutrients, bioactive compounds and phytochemicals which can be beneficial to both nutrition and health, their use in agriculture is limited as a result of low bulk density and slow decomposition rate [40, 41].

According to the World Food Program [42], Cameroon is currently facing one of its most serious food crises, with the approximate number of food-insecure households being 16% (about 3.9 million people) of which 1% are in a state of severe food insecurity. This may be due to an increase in food unavailability and inaccessibility, with a corresponding increase in food wastage. About 40 to 50% of the world's fresh products (30% for cereals and 20% for oilseeds, meat, and milk products) is estimated to be lost in the food supply chain yearly [43]. The Food and Agricultural Organisation [44] defines food losses and waste as a decrease in the quantity or quality of food along the food supply chain. In developing and developed countries, the quantities of fruits and vegetables lost after harvesting vary [45], and the figures can vary from 30% to even 50% in some African countries depending on the perishability of the foods concerned. According to Kughur et al. [46] the postharvest loss was reported to be 48.5% in Nigeria, while Zenebe et al. [47] reported a 45.9% postharvest banana loss in Ethiopia. Bangladesh on the other hand had values between 20 and 40% [48]. These studies mainly focused on the extent of losses without

considering the effects on the health of the population.

Though Cameroon coffee production fluctuated substantially in recent years, the total production in 2020 was 36,207 tonnes [49]. By-product recovery is one of the main target areas as far as the sustainability of the coffee production chain is concerned [50, 51]. About 60% of the wet weight of the fresh coffee fruit is discarded as by-products or waste, and this poses a significant threat to the environment [52, 53, 54]. Among the solid residues, the peel is the first to be generated and it represents 39% of fresh weight or 29% of fruit's dry matter, while the parchment represents around 12% of the fruit [55]. The production statistics from Cameroon clearly indicate availability of large amounts of coffee peels and parchment, which are highly underutilized.

Plantain and banana are essential components in the diet of West and Central African populations [56] but the large volume of waste and by-products generated during their production is an environmental challenge. Cameroon is not excluded from this situation, as it is the fourth largest plantain and banana producer in West and Central Africa [56] with an estimated annual production quantity of about 1.6 million tonnes [57]. The solid wastes from this production are mainly in the form of the peels, which make up about 40% of the fresh fruit weight. Bananas contain 60% pulp and 40% peel, 7.25 kg of peel produced from a banana box of 18.14 kg (Sharma et al., 2016). However, the shell contains carbon-rich organic compounds such as cellulose (7.6–9.6%), hemicellulose (6.4–9.4%), pectin (10–21%), lignin (6–12%), chlorophyll pigments and some other low molecular weight compounds. If not treated properly, these wastes create an annoying odor due to the natural decomposition and produce gases that contribute to the greenhouse effect [58].

### 3. CURRENT USES AND VALORIZATION OF AGRO-FOOD WASTE AND FOOD BY-PRODUCTS IN FOOD PREPARATION IN AFRICA AND CAMEROON

Most of the studies on waste in Cameroon are concerned with estimating the extent of food waste, by-products and losses and their disposal without, however, worries of sustainable

valorization of these wastes into value added products. Identifying and properly valorizing these wastes will reduce losses of valuable nutrients and potential raw materials, and protect both the population and environment since waste is directly linked to human development [59].

### 3.1 Value Added Food Products from Plantain and Banana Wastes and By-products

Plantain (*Musa paradisiaca*) is a large herbaceous perennial crop which is a member of the family Musaceae together with bananas (*Musa sapientum* and *Musa cavandish*). Plantain (*Musa* spp) is an important global fruit that is widely cultivated in tropical countries for various food industry applications. Bananas and plantains have been said to be the 2<sup>nd</sup> largest fruit crops of the world [12]. The peel of banana represents about 30-40% of the total weight of fresh banana and has been underutilized. The world production is estimated to be 139 million tons, in which tropical Africa alone produces about 17 million tons of bananas annually. It has become a basic food crop for over 70 million people in Africa. Over 50 species of *Musa* are in existence, in which the main groups of edible bananas or plantains are derived from *Musa acuminata* and *Musa balbisiana* [60]. Even though plantains and bananas have similar methods of growth and development, they can be differentiated from one another by form of stem, colour and size, leaf colour, fruit shape and size, nutrient content, and plantains consist mostly of carbohydrates while bananas mainly contain sugar [61]. The parts of the banana and plantain plants which are generated as byproducts after cultivation and processing include the peels, leaves, sheaths, pseudostem, pith and male bud [62].

#### 3.1.1 Traditional food salts (Nikkih) from Banana and plantain peel

Plantain and banana peels are valorized using traditional technology for the production of a traditional food salt or potash, commonly called "nikkih" in many regions of Cameroon, especially the West and North West Regions. This traditional food salt (nikkih) is the crude brownish or blackish extract produced traditionally by leaching the ashes of combusted agro-food waste with water to obtain a potassium-carbonate-rich crude bio-extract [60, 63]. Nikkih can either be obtained from peels boiled at 90°C before drying, or directly dried raw peels which

are combusted to produce ash that is leached with water to obtain the crude blackish or brownish extract [25]. Their chemical composition shows that they are a mixture of salts and thus, made of cations and anions, the major cation being generally sodium or potassium whereas the major anions are generally carbonates, bicarbonates, sulfates, and chlorides [64, 65]. These bio-based functional plant extracts are fast replacing the common lake salt called 'kangwa', as they are regarded as cheaper, safer, less-toxic and readily available from food waste biomass and their production from waste biomass contributes to environmental protection.

Due to its potential for use in emulsification, tenderization, thickening, seasoning, and as a potentiating adjunct and preservative, Nikkih is being used in the preparation of a variety of foods [66]. Its functional properties can be linked to the alkalinity of the aqueous solution as shown in studies by Onwuka et al. [67]. Bergeson et al. [68] and Doumta et al. [69] also carried out studies on the ability of nikkih to reduce cooking time. It is an important household ingredient which is traditionally used in many food preparation processes in Cameroon, and also in food industries. It is used in the preparation of yellow "achu" soup, and gives vegetables a good texture and appearance during their preparation. In the dairy industry, when cream is separated from whole milk during the production of butter, lime water is often added to the cream to reduce acidity prior to pasteurization.

#### 3.1.2 Flour from banana and plantain pseudostem

The main nutritional components of banana pseudostem are cellulose, hemicellulose, protein, fat and dietary fibres along with other nutritive elements. One of the most popular ways of exploiting the underutilized plant resources has been through the preparation of composite flours, such as Banana and plantain pseudostem flour. Banana and plantain pseudostem flour is a product obtained by peeling the epidermis of the stem, after which the peeled pseudostem is washed, cut, boiled (for 10 minutes), sliced, dried (at 60°C for 24 h), ground in a blender and sieved to obtain a fine powder [70]. Flour made from banana pseudostem is rich in fiber, macro minerals like potassium, sodium, calcium, magnesium and phosphorus, and it can be used in the enrichment of food products such as dairy and bakery products [71].

Studies showed that by the partial substitution of wheat flour with banana pseudostem flour in bakery products, the dietary fiber content was increased [72]. Composite flours refer to mixtures of several flours gotten from either cereals, legumes or other plant products with or without the presence of wheat flour. Due to their enriched nutritional profile, better digestibility and potential for use in overcoming the wheat production deficit in some areas of the world, they have gained a lot of attention in the food industry.

### 3.1.3 Banana and plantain leaf extract

Banana and plantain leaves have been traditionally used for packaging of certain foods, but new techniques for the valorization of these byproducts are being studied [73], such as making use of the leaf extracts. Banana leaf extract is produced by passing the washed leaves three times through a mill called “trapiche”, after which the juice is collected and stored at low temperatures for further use [73]. It has been shown to be potent in the prevention of enzymatic browning and quality deterioration of freshly cut guava slices during storage [74]. This implies that banana leaf extract can potentially be used in the prevention of enzymatic browning in other food products as well. Studies have also shown that banana leaves present anti-diabetic properties such as a decrease in glucose levels and increase in glycogen and plasma insulin levels when administered to hyperglycemic rats [75], and can therefore serve as a good raw material in the development of functional foods for diabetes patients. Rutin, a pharmacologically active phytochemical that decreases glycemia, increases insulin secretion and inhibits  $\alpha$ -glucosidase is the major component responsible for the antidiabetic activity of banana leaves [75].

### 3.1.4 Banana and plantain inflorescences

Banana inflorescences have been used in some parts of the world to make pie fillings, salads, increase the yield of meat-based meals, and when converted into flour via drying and grinding, these inflorescences can be used in food enrichment and functional food development due to their low caloric content, high fiber, and high potassium content [76]. They have also been shown to have antioxidant, antidiabetic, antimicrobial, anti-inflammatory, anti-cancer and cardio-protective properties [77]. Extracts of banana inflorescences have been used in the production of both a beverage and flour which

were rich in alkaloids, saponins, glycosides, tannins, flavonoids, and steroids, showed antioxidant activity, and helped to increase breast milk production in lactating mothers [78].

## 3.2 Value Added Products from Pineapple Waste and By-products

Pineapple (*Ananas comosus*) is one of the most produced fruits worldwide, with primary producers being Costa Rica, Philippines, Brazil, Thailand and India [79]. It is a uniquely shaped plant that belongs to the Bromeliaceae family and is cultivated in tropical and subtropical zones [80]. Due to its richness in vitamin C and Calcium, there has been a growing demand for its fruits and products over the years. It has attractive sensorial (mechanical properties, flavor, acidity/sweetness ratio, color) and nutritional (vitamin A, B and C, minerals, fibers, and antioxidants) properties. During pineapple processing, transportation and storage, about 80% of the parts such as the crown, peels, leaves, core and stems, are discarded and end up as waste [81]. About 30% to 35% of the fruit is discarded in the form of by-products such as peels and pomace during the processing stage [82]. Apart from processing, pineapple wastes are also generated from poor handling and storage of fresh fruit, or lack of good and reliable transportation systems [83]. The presence of sugars, trace elements (potassium, calcium and magnesium) and polyphenolic compounds in pineapple has caused increased interest in pineapple waste and by-product valorization. Several high-value products can be obtained from pineapple processing such as nanocrystals, bromelain enzyme, bioactive compounds, wine, vinegar, biopolymers, bio-packaging, organic acids, adsorbents, biofuel and biogas. Pineapple waste has been used in the production of phenolic antioxidants, anti-dyeing agents and animal feed [84, 85]. Vinegar can also be produced from pineapple peels via fermentation with acetic acid bacteria [86]. The addition of pineapple peel flour to wheat flour in the production of biscuits led to an increase in the proximate composition and the calcium, potassium, sodium and copper contents of the biscuits [87], indicating that pineapple peel flour can be used to enrich food products.

The increased demand for pineapple has led to a corresponding increase in its production, leading to even more waste generation in the form of the crown, peels, leaves, core and stems, which amount to about 80% of pineapple parts [88, 89].

Characterising these wastes is essential for their transformation into valuable products. The major polyphenolic compounds from pineapple waste include 31.76 mg of gallic acid, 58.51 mg of catechin, 50 mg of epicatechin and 19.5 mg of ferulic acid per 100 g of dry extracts [90]. Recent research by Dahunsi et al. [91] showed that pineapple waste contains 19.4% lignin, 32.4% cellulose and 23.2% hemicellulose.

### 3.2.1 Wine and Vinegar from pineapple peels

Pineapple wastes (particularly the peels) have great potential for wine and vinegar production due to their high sugar content [88]. Production of vinegar from pineapple peel using three different acetic acid bacteria strains showed that optimum acetic acid yield (6.15 g/L) was found at 72 h fermentation time using propionic acid bacterium and acetic acid bacterial strains [92]. The juice from pineapple waste was used together with *Saccharomyces cerevisiae* for the production of wine with 10.8% alcohol content [92]. A lower alcohol content of 7% was observed from wine prepared using pineapple peels and core [93], the difference was due to the different fermentation methods used in both studies. However, 5% acetic acid was obtained despite the low alcohol content, which is higher than in the previous study. Correspondingly, work done by Ekechukwu et al. [94] shows a lower alcohol content in wine produced from pineapples using *Saccharomyces cerevisiae* (6.60%) and *Saccharomyces bayanus* (6.75%) compared to the alcohol content in that of Umaru et al. [92]. Other studies carried out by Roda et al. [93] reported that physical and enzymatic combination before alcohol fermentation were necessary for the production of good quality wines. By varying the *Saccharomyces cerevisiae* strain and temperature, a substantial difference in the wine's fruity character was detected. Other than that, the sensory evaluation of pineapple organic side-stream syrup revealed its potential when combined in bakery products [95]. Although these studies proved that pineapple residues could be utilized as food enhancers and beverages, further studies should explore more the pineapple residue's utilisation potential in the food and beverage industries, in terms of its production by focusing on the quality and purity.

### 3.2.2 Cellulose Nanocrystals from pineapple leaf waste

The composition of pineapple leaf waste has been shown to be 13.05% lignin, 21.02%

hemicellulose and 41.15% cellulose [81]. As a result, pineapple leaves have been used in the development of nanofibers with desirable properties which can be applied in the food packaging sector [96], and being plant fibers they can serve as a good potential alternative to synthetic fibers from petroleum-based non-renewable resources [97]. Pineapple leaves have also been used for the extraction of ethanol, which is rich in phytochemicals such as *p*-coumaric acid, 1-*o-p*-coumaroylglycerol, caffeic acid and 1-*o*-caffeoylglycerol, and when administered to diabetic rats it inhibited the increase in blood glucose and postprandial triglycerides [98]. Pineapple leaf waste was shown by dos Santos et al. [99] to be a suitable raw material for the production of cellulose nanocrystals, which can be used as a source of dietary fiber in functional foods, and for the production of food thickeners, stabilizers and flavor carriers [100]. Cellulose nanocrystals (CNC) derived from the abundance of cellulose in the biomass are one of the most favourable materials for nanocomposites, and they currently serve as a reinforcing agent in the nanocomposites field. CNC have a large surface area, high mechanical strength, are non-toxic, hydrophilic, biocompatible and biodegradable [101, 99].

### 3.2.3 Bromelain Enzyme from pineapple peel waste

Pineapple peels are used to process fruit juices both locally and industrially, acting as flavor enhancers in juice making. Pineapple peel drying has been adopted in Cameroon as a strategy to extend the shelf life for the pineapples peels. Waste from pineapple processing could provide a range of value added ingredients for the food industry, including the proteolytic enzyme bromelain which is usually extracted from the stems or juice of pineapple. The main protease that exists in the bromelain enzyme is identified as stem bromelain (EC 3.4.22.32) and fruit bromelain (EC3.4.22.33) (Nor et al., 2015). Bromelain helps the digestion process and it has been used commercially in the food industry where it is known for meat tenderizing, brewing, baking and the production of protein hydrolysates, among other things [102].

Pineapple peels have also been used in the alkali extraction of ferulic acid, which is a widely used phenolic antioxidant in the food and cosmetic industries [98]. These peels which account for 35 to 50% of total pineapple fresh

weight [103] have been shown to be a potential raw material for the production of biofuels such as ethanol and hydrogen [104]. Work done by Cornelia and Kristyanti [105] showed that pineapple peels can be used in the production of cider, which is rich in phenolic compounds and has potential antioxidant activity. Gallic acid, catechin, epicatechin and ferulic acid were identified as the main polyphenolics in pineapple peels [90].

### 3.2.4 Bioactive compounds

Pineapples and their wastes serve as a good source of antioxidants, which aid in preventing the formation of free radicals caused by the oxidation of biological molecules [106]. Studies done by Sepúlveda et al. [107] showed that the application of autohydrolysis to pineapple waste produced polyphenols with high antioxidant activity. The study also revealed that pineapple waste is a good source of antioxidants compared to readily available antioxidants in the market, and all pineapple waste extracts showed higher antioxidant activity.

## 3.3 Value Added Products from Cereal Waste and Byproducts

The term “cereals” refers to members of the Gramineae family and it includes nine species which are wheat (*Triticum* spp.), rye (*Secale* spp.), barley (*Hordeum* spp.), oat (*Avena* spp.), rice (*Oryza* spp.), millet (*Pennisetum* spp.), corn (*Zea* spp.), sorghum (*Sorghum* spp.), and triticale (x *Triticosecale* Wittmack which is a hybrid of wheat and rye). Cereals are cultivated for the edible components of their grain or the kernel. A cereal is a caryopsis which is composed of the fruit coat (pericarp) that adheres tightly to the seed coat and a seed consisting of germ and endosperm. The aleurone layer lies next to the pericarp, and it is rich in protein and minerals. The endosperm is the large central portion of the kernel made up mostly of starch, and the germ/embryo is the small structure at the lower end of the kernel [108]. Cereal grains are usually milled to remove the fibrous bran, which is one of the major by-products of cereal processing.

Although the outer part of the cereal grain is usually richer in micronutrients, it is often undervalued and used as animal feed [109]. Cereal bran is the nutritional storehouse of the grains and it contains nutrients like proteins, vitamins, minerals, fats, and functional food ingredients in the form of bioactive compounds

such as dietary fiber, phytosterols, polyphenols and phenolic acids which may provide a wide spectrum of biological activities and other health benefits as seen among populations consuming diets based on cereal grains [110]. Its multiple beneficial effects could be exploited by incorporating it into the daily diet.

### 3.3.1 Products obtained from rice bran

Rice bran is the most attractive byproduct generated during rice processing because even though it accounts for only 9% of the rice weight, it contains about 65% of the nutrients of the whole rice grain and is rich in proteins, oil, fiber, micronutrients such as vitamins, and minerals, such as aluminum, calcium, chlorine, iron, magnesium, and manganese [111]. It can be used in the production of rice bran oil and as a dietary fiber source in bakery products since it has anti-oxidant and anti-inflammatory properties [112, 113]. The production of rice bran oil is one of the most common uses of rice bran due to the fact that rice bran oil is very rich in  $\gamma$ -oryzanol, tocopherols, tocotrienols, and phytosterols, a powerful antioxidant mixture of bioactive molecules [111, 114]. Rice bran oil can be used as an alternative to bakery shortening, and has shown improvement in the baking quality when added to baked products [115]. The presence of Gamma-oryzanol in rice bran makes it a very attractive potential food ingredient because this compound has been shown to decrease animal serum-cholesterol levels and anti-inflammatory activities while inhibiting cholesterol oxidation *in vitro* [115]. Due to its high fiber content, rice bran can give texture, gelling, thickening, emulsifying and stabilizing properties to certain foods [115], which is very useful in the food industry. Rice bran wax has been used in the formation of corn germ oil oleogels, and this formulation showed potential to act as a replacer of commercial shortening in the baking industry [117].

Other than oil, rice bran also has a 10-15% protein content, and these proteins have been found to be of high quality and application in food and pharmaceutical industries due to their unique hypoallergenicity and anticancer effects [116]. The partial replacement of gelatinized corn flour with rice bran flour in the production of corn flakes and tortilla chips led to an increase in the protein content of these products [118], making rice bran a potential beneficial ingredient for the enrichment of bakery products. A protein formulation based on rice bran can be used to target and overcome protein related nourishment



disorders [115] in some of the underdeveloped countries of the world.

### 3.3.2 Products obtained from corn bran

Corn bran is mainly made of insoluble fiber, cellulose, hemicellulose, and xylooligosaccharides making it indigestible by enzymes in humans and monogastric animals, but it can be degraded by colon bacterial communities [119]. It can be used as a natural food additive in cellulosic fiber gel (commercially available as Z-Trim), cellulose fiber gum and in corn fiber oil. Submerged fermentation of corn bran with *Monascus purpureus* led to the production of pigments belonging to a group known as azafilones which can be used as colour additives in the food industry [119]. Purple corn bran can be used for the recovery of anthocyanins, which are water-soluble pigments that can provide attractive colors to foods and have potential beneficial health effects such as antioxidant, anti-inflammatory, anticancer, antiobesity, and anti-diabetic properties [120]. Corn bran hydrolysates have been used in the production of pullulan, which can be used in food stabilization, coating and the production of packaging materials [121]. It can be concentrated and dried to produce crude bio-based fiber gums which can serve as emulsifiers in the food industry [122]. Corn bran has also been used in the production of ferulic acid which has many beneficial functions such as antioxidant, antimicrobial, anti-inflammatory, anticancer and free radical scavenging activities [123].

### 3.4 Value Added Products from Palm Kernel Waste and Byproducts

The oil palm (*Elaeis guineensis* Jacq) is a native plant of the humid tropics of West Africa. Cultivation originated where oil palm trees were inter-planted in traditional agricultural production systems along with other annual and perennial crops. After the extraction of oil from the palm kernel, several by-products are generated such as the empty fruit bunches, palm pressed fibers and shells which are mainly composed of lignin, cellulose, hemicellulose and other carbonaceous materials [124].

#### 3.4.1 Products from palm kernel cake

Palm kernel oil is obtained from the seed (the kernel or endosperm) which contains about 50 per cent oil. When the oil has been extracted, the residue known as "palm kernel cake" (PKC) is

rich in carbohydrates (48%) and proteins (19%), and the ash contains large amounts of potassium. A portion of these wastes is used as feed supplements for livestock [125].

According to Sahin and Elhussein [126], palm kernel cake is rich in various phytochemicals such as caffeic acid, vanillic acid, d glucuronic acid, ferulic acid, glutaric acid, protocatechuic acid, quinic acid p-coumaric acid, p hydroxybenzoic acid, salicylic acid, shikimic acid, sinapic acid and syringic acid, which have a great role to play in extending the shelf life of several products as well as providing added-value properties with their antioxidant and antimicrobial properties.

Phenolic extracts of palm kernel cake can be used as antioxidants in the food industry, due to the fact that their experimental addition to sunflower oil showed an increase in its induction time by more than 50% [127]. Hydrolysis of palm kernel cake protein using different proteases led to the production of useful protein hydrolysates or bioactive peptides which showed radical scavenging activity, with the protein hydrolyzed by papain resulting in the production of the hydrolysate with the highest antioxidant activity [128]. This further supports the potential of palm kernel cake in the production of antioxidants for use in the food industry.

In a study carried out by Belo et al. (2018) to evaluate the potential of polysaccharides extracted from palm kernel cake for use as prebiotics, it was found that these soluble polysaccharides showed high resistance to hydrolysis when subjected to artificial human gastric juice and promoted the proliferation of *Lb. plantarum* and *Lb. rhamnosus* with a decrease in the pH of the medium and the production of organic acids. This implies that palm kernel cake polysaccharides can be exploited as prebiotics.

Through solid-state lacto-fermentation, low molecular weight peptides were generated from palm kernel cake and when added to bread, these peptides increased its shelf life by inhibiting fungal growth since they showed strong antifungal activity against *Aspergillus flavus*, *Aspergillus niger*, *Fusarium* sp., and *Penicillium* sp. [129]. This shows that peptides extracted from palm kernel cake have potential to be used in the food industry to extend the shelf life of bakery products and other food products thereby promoting food safety, security, and sustainability. Via solid state fermentation, palm

kernel cake has also been used in the production of tannase, the enzyme which catalyzes the hydrolysis of tannic acid by breaking its ester and depside bonds releasing glucose and gallic acid. This enzyme has various uses in the food industry such as the processing of tea, production of gallic acid, treatment of tannery effluents, stabilization of malt polyphenols, clarification of beer and fruit juices, and for the prevention of phenol-induced madeirization in wine and fruit juices [130].

### 3.4.2 Products from palm pressed fibre

Palm pressed fiber is a form of recovered fiber from pressed palm fruits which is rich in carotenoids, vitamin E (tocopherol and tocotrienols), and sterols, and has been used for the recovery of palm pressed fiber oil which contains significant quantities of carotenoids (4000–6000 ppm), vitamin E (2400–3500 ppm), sterols (4500–8500 ppm), and coenzyme Q10 quantities greater than those found in crude palm oil [131]. As a result, palm pressed fiber oil has antioxidant and anti-inflammatory properties [132] which can be applied in the development of functional foods. The presence of phosphorus in palm pressed fiber oil further enhances its antioxidant properties, and this phosphorus can be extracted for use as a food additive [133].

### 3.4.3 Products from palm kernel shells

Palm kernel shell is a natural fiber which is rich in lignin, cellulose and hemicellulose, and can be used in the production of fiber-reinforced plastics, thereby contributing to the food packaging sector [134]. It can also be used as an adsorbent for the treatment of heavy metal contaminated water [135], making it a useful material for food wastewater treatment processes.

### 3.4.4 Products from empty palm kernel fruit bunches

Palm kernel empty fruit bunches are rich in cellulose and nanocellulose. and they have the lowest phenolic content among all the side streams derived from the palm oil production process [127]. However, their phenolic extracts still showed antioxidant activity. Cellulose and nanocellulose have been extracted from empty fruit bunches [136], and these compounds can be used as food additives or in the development of food packaging materials. Xylan can also be extracted from these fruit bunches and used as a thickening agent, or converted to xylo-

oligosaccharides which are prebiotics [136]. These empty fruit bunches can also be converted into valuable compounds such as ethanol, biovanillin, p-hydroxybenzoate and lignin-containing cellulosic nano fibrils [137, 138].

## 3.5 Value Added Products from Mango Wastes and Byproducts

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 [139, 140, 141]. In 2009, global mango production was around 35 million tonnes while for Africa it was 13.6 million tonnes [142]. Majority of mango fruit produced is consumed fresh, while 1-2% is transformed into products such as jelly powders, nectars, jams, juices, fruit bars, flakes concentrates, and mango chips [143, 141, 142]. As a result of this processing, the seeds, peels and fruits unsuitable for human consumption are discarded as by-products and waste.

The waste generated from the mango processing industry, derived mainly from the epicarp and endocarp has been estimated at 75000 MT [144], and it is increasing due to a corresponding increase in mango fruit production and processing. However, there is virtually no commercial utilization of mango seed kernel which in most cases is discarded as waste in the fruit processing industry.

Mango seed is a good source of carbohydrates (58-80%), protein (6-13%) with good profiles of essential amino acids and lipids (6-16%) rich in oleic and stearic acids [145]. The seed has a high protein content with the presence of all essential amino acids at higher levels than those referenced by the FAO as good quality protein. The seed also has high lipid content, and these lipids have typical characteristics of a vegetable butter [146]. The carotenoid content was found to be 4–8 times higher in ripe mango peels compared to raw fruit peels. Carotenoids play a potentially important role in human health by acting as biological antioxidants, protecting cells and tissues from the damaging effects of free radicals and singlet oxygen, and they are used as natural colorants in the food industry [147].

Dietary fiber content in mango peels was estimated according to the different varieties of mangoes. In dry peel, the total dietary fiber content varied between 45 to 78% [148]. For soluble dietary fiber content, both raw and ripe

mango peels possessed more than 35% of total dietary fiber. Soluble dietary fiber associates with cholesterol in blood and diminishes its intestinal absorption meanwhile insoluble dietary fiber relates to both water absorption and intestinal regulation.

Reports state that mango seed kernel oil is a good source of polyunsaturated fatty acids which have health benefits like oleic and linoleic acids [149]. The mango kernel extracts demonstrates a level of antimicrobial activity which could be attributed to the presence of specific phytochemicals such as coumarins, terpenes, flavonoids, and tannins. The kernel powder of South African mango variety portrays high antimicrobial and antifungal activity against *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Candida albicans* (Ahmed et al., 2005).

### 3.5.1 Starch extraction

In most plant materials, their principal carbohydrate constituent is starch which needs to undergo a detailed investigation so as to understand its variations, biochemical and functional characteristics. A good amount of research has been carried out on the functional and structural properties of the common starches in the market like, corn, potato, wheat and rice because of their availability and extensive usage in both food and non-food applications. This resulted in a theory that mango by-products could be a good source of starch given their high starch content (more than 50%). This starch can be extracted from these sources with the use of the aqueous extraction technique [150, 151]. This starch gotten could then be used for paint, paper, yarn sizing in textile industries, pharmaceuticals, and leather industries.

### 3.5.2 Enzymes production

Results from studies carried out on the physicochemical properties of the by-products of mango shows that its waste can be used in the production of cellulose, carboxymethyl cellulose, and pectinases enzymes. These enzymes, cellulose and carboxymethyl cellulose can play different roles in the food industry such as modification of viscosity (thickener), stabilise emulsions in various products including ice cream, as toothpaste, laxatives, diet pills, water-, lubricants, based paints, detergents, textile sizing, and many other paper products. Mango by-products are a good source of pectin [152, 153]. Pectinase enzymes which can be produced

by degrading pectin with the use of microorganisms through fermentative production could be used to produce wine in a process which involves degradation of plant materials.

### 3.5.3 Lactic acid production

In the food industry, lactic acid has a number of roles such as food preservative, curing agent in the processing of meats, a food ingredient in processed foods and flavouring agent. It is also used in the production of polylactic acid polymer as a starting material. Commercially, lactic acid is produced when carbohydrates such as glucose, lactose or sucrose are fermented. Chemical synthesis could also be used in its production but this method is very expensive [143]. Using agro-industrial wastes provides an alternative in the production of lactic acid from low cost raw materials after noticing that mango by-products have a chemical composition which could be used to produce lactic acid [120]. Lactic acid production is a two step process; waste pretreatment followed by acid hydrolysis of the by-product which is followed by microbial fermentation. Using mango by-products in the production of lactic acid has a very practical advantage because of the low cost of raw materials.

## 3.6 Value Added Products from Citrus Fruit Wastes and Byproducts

A very wide family of fruits consumed worldwide is the citrus fruits (CF). Citrus plants belong to the family of Rutaceae, and they include fruits like Mandarin, grape, lime, orange, and lemon. They are well known for their promising source of multiple beneficial nutrients to humans.

Unlike other types of fruits, citrus fruits have a small edible portion hence a larger quantity of waste materials like the peels and seeds, which are thrown away during processing. The principal residues of citrus fruit juice are water, fiber, soluble sugars, organic acids, amino acids and proteins, minerals, oils and lipids, and they also contain flavonoids and vitamins.

One of the most diversified and underutilized biowaste globally is the citrus peel. The peel residue still accounts for about 50% wt of the fruit after juice extraction, and this poses as an environmental problem [154]. With about 15.6 million metric tonnes of waste produced from 31.2 million metric tonnes of processed citrus fruit annually, utilizing this resource is a real

challenge [155]. Orange peel waste is made up of 20% dry matter which includes sugars, cellulose, pectin, hemicellulose, and d-limonene and 80% water [156]. So far, research carried out on citrus waste valorization has mostly been focused on transforming specific components like n-pectin or bioethanol [157], d-limonene, [158].

Seeds, exhausted peel, pressed pulp, secondary juice (obtained by pressing the residual pulp after the primary juice extraction) and leaves, are a good source of sugars (glucose, fructose and sucrose), dietary fibers (pectin and cellulose), polyphenols (flavonoids and phenolic acids), proteins, lipids (linolenic, oleic, palmitic and stearic acids), organic acids (i.e., citric, malic and oxalic acids) carotenoids (carotene and lutein), vitamins (vitamin C and vitamin B complex) and monoterpenes (i.e., limonene and linalool) [159]. The method in which these fruits are cultivated results in the variations in the molecular composition of each by-product. It could also be affected by harvesting time and the degree of ripeness of the fruit.

About 50% the wet mass of citrus fruits is the peel after juice extraction [160]. It is high in dietary fibers, natural pigments, pectin, fragrant compounds as well as polyphenols [161]. The citrus fruit peels contain oil sacs of peels and cuticles and they can also be found in seeds and leaves in very limited amounts so they are used in the extraction of essential oils. Monoterpenes and sesquiterpenes compounds (i.e., hydrocarbons with two or three isoprene units in their structure) and oxygenated derivatives (i.e., alcohols, ketones, aldehydes and esters) make up the chemical composition of essential oils, while the main constituent of essential oil gotten from Citrus by-product is Limonene.  $\beta$ -pinene, sabinene and  $\beta$ -ocimene are characteristic of the essential oils from Citrus leaves [162]. Some of the uses of essential oils from citrus fruit by-products include being used as flavorings in the food industry, pharmaceutical and cosmetic products. Recently, they are being evaluated for their beneficial health properties [163, 164].

Pectin, a complex polysaccharide made up of D-galacturonic acid units linked together by  $\alpha$ -1,4 glycosidic bonds, and esterified partially either with methanol or acetic acid, mostly exists in complex insoluble forms, usually from white to light brown color and, act as a natural gelling agent. It can be found in citrus fruit juice and pulp. It is also presented in exhausted citrus peels [165]. Some domestic and industrial uses of

pectin include being used as a thickener, partial texturizer and a stabilizer in the preparation of confectionery, jams and jellies, as well as biodegradable products.

Carotenoids are pigments biosynthesized in different fruits and vegetables. They are subdivided into two groups: xanthophylls (oxygenated carotenoids), for example lutein and violaxanthin, and carotenes (hydrocarbon carotenoids), for example  $\beta$ -carotene and lycopene [166, 167]. These are vitamin A precursors, involved in the growth of epithelial tissues, strengthening of the immune system and improving vision [168].

Secondary citrus fruit juices are a good source of flavonoids and carotenoids. These compounds can also be found in the peels in small amounts. Flavonoids represent a wide class of secondary metabolites, produced by plants to protect them against ultraviolet radiation or pathogenic injuries. They have six subgroups, flavonoids, flavones, flavanols, flavanones, isoflavones, and anthocyanidins [169, 170, 171, 172]. An extensive study has been conducted on citrus flavonoids to study their neuroprotective activities [173], anti-inflammatory [174] and anti-cancer [173]. The main flavanones in "satsuma mandarin" juice processing waste includes naringin, hesperidin, hesperetin, neohesperidin, narirutin and rutin [175].

Citrus fruit by-products could also be applied in the manufacture of animal feed, especially ruminants. The by-products that can be used in the production are pulp (fresh or dried), citrus molasses, citrus silage, citrus activated sludge, citrus meal and fines, and citrus peel liquor. The physical and nutritional composition, digestibility, fermentation and effects of these feeds on ruminants (weight and lactating production) were characterized by Bampidis and Robinson, [156]. These authors stated that these wastes could be effectively used as feedstuff in rations that support growth and lactation in ruminants.

### **3.7 Value Added Products from Potato Peels**

Increase in urban populations and subsequent increase in cost of living has led to the drastic increase in demand of processed foods [176]. The main product from potato processing is potato chips which give an excessive amount of potato peels as waste (by-product) which is considered to have zero value. It could range

from 15 to 40% of the first product mass depending on the method used in peeling. The most common cause of environmental pollution in food processing industries is the decomposition of organic waste caused when bacteria and other biological molecules use the compound as a food source. The need to avoid such issues led to the exploration of potato waste and how its high phenolic content could cause it to be used as an antioxidant in food systems [177].

After maize, wheat and rice, potato is the world's fourth-largest food crop. 10% of cultivated area produces 225 to 285 million tons of potato [178]. It is grown in over 130 countries around the world, with Cameroon accounting for 0.1% of the world's total production and 0.8% of Africa's total production (220,000 tons of 29 million tons) [179]. These days, the type potato processed products has increased to meet the massive demand of the ever growing consumer population. Food processing industries produce a large volume of wastes as byproduct [180, 181]. Potato production has a steady increase rate of 5% per year in developing countries. according to FAO 2008, the share of developing countries to global potato production rose from 20% to 52%. It was a remarkable achievement when compared to the last two decades [182]. Potato waste contains phenols which are applied as preservatives in the food and pharmaceutical industries [183]. Food processing industries generate phenolic- rich vegetable by- products, and this has been an area of research investigations as a sources of antioxidants and antimicrobial for food preservation [184]. The entire tissue of fruits and vegetables is rich in bioactive compounds or phenols but the by-products have higher contents of antioxidant [185]. Potato peel is one of the most important waste products with sufficient amount of phenolic compound so this could be used as a replacement for the current synthetic antioxidant and antimicrobial compounds. The dominant phenolic compounds of potato peel extracts are chlorogenic and gallic acids, which are natural antioxidants that prevent oxidation of vegetable oil, and they have been shown to inhibit soybean oil oxidation reactions by minimizing peroxide, tolox, and p-anisidine indices [186, 187].

In the food industry, we can either use synthetic food preservatives alone or combine them with natural preservatives; however, the use of synthetics preservatives has carcinogenic effects while using natural preservatives alone has an

advantage for human health with low side effects. This has led attention to be paid on vegetable waste products with high phenolic content [185, 188]. Phenolic compounds are always present in plants and their antioxidant and antimicrobial properties is of noticeable interest [184].

### **3.8 Value Added Products from Coffee Wastes and Byproducts**

Coffee is cultivated in over 70 countries globally. They are gotten from two species: *Coffea canephora* (Robusta), which happens to be the most widely cultivated variety, especially in Central Africa, Southeast Asia and Brazil and *Coffea arabica* (Arabica), cultivated in Latin America, Eastern Africa and Asia. Arabica coffee makes up about 60% of coffee beans worldwide production is arabica and the rest of 40% is Robusta [189].

To get coffee beans, the berries are picked when ripe, processed and then dried. One of the most important stages in the process of coffee production is roasting of the coffee beans. Roasting influences the physical and chemical properties of the beans and is important in determining their sensory quality, especially flavour and colour. After roasting, the beans are ground and brewed with near-boiling water to obtain the coffee beverage. After petroleum, coffee is one of the most sold commodities worldwide,. It also doubles as the second most popular beverage, after water [190, 191]. This gives it a global interest for its production and commercialization.

The increase in organic waste from the coffee industry as a result of increase in coffee consumption poses a difficult problem; after coffee beans are roasted and brewed, the resulting solid residue is called spent coffee grounds. It represents the greater half of coffee by-products worldwide (45%) [192].

Spent coffee grounds contain large amounts of organic compounds (proteins, phenolics, cellulose, lipids, lignin, hemicellulose and other polysaccharides), which showcases its value as a by-product [193]. Polysaccharides fraction covers about 50% the total mass of spent coffee grounds, of which about 50% are galactomannans, 25% arabinogalactans and 25% cellulose [194]. Presence of mannose, galactose, glucose and arabinose, polymerized into hemicellulose and cellulose (Ballesteros et

al., 2014) [195] and high content of galactomannans are highlighted in spent coffee grounds, lignin being also present in a significant amount [196]. About 43% of total spent coffee grounds is made up of dietary fiber which represents coffee spent grounds dry weight (42% insoluble, 1% soluble fibre respectively), which are approved to be used as raw material to develop functional foods. Some of the types of fibre from spent coffee grounds are, among others, resistant starch, oligosaccharides and manno-oligosaccharides [197, 198, 199]. Some secondary bioactive metabolites are also present, such as caffeine, sterols, flavonoids and diterpenes [200]. The major bioactive compound in spent coffee grounds is caffeine [201]. Over the years, many experiments have been carried out on spent coffee grounds valorization including the use as composts and animal feed, biofuels, bio-composite materials, a functional ingredient for food products with real health benefits, decontaminants of waste waters.

Aside these applications, studies are being carried on its usage as a functional ingredient (additive) or in nutraceuticals in improving both health and nutrition [202]. Spent coffee grounds make up a valuable source of phenolic compounds and melanoidins, which can also be included as a functional ingredients in human diet [203, 204, 205, 206]. This led to the discovery that spent coffee grounds exhibited an important role in preventing diseases related to free radicals [207] and also portrays antioxidant, antihypertensive and antimicrobial activities in intestine microbiota [197]. Phytochemicals from spent coffee grounds can be digested, absorbed and fermented in colon, exerting healthy effects by influencing the metabolic activity of the microbiota [208]. Spent coffee grounds phenolic extracts can also be used as anti-inflammatory additives [208] and dermatological antimelanogenesis agents [209]. Regarding extracting of natural antioxidants and caffeine from spent coffee grounds, there were proposed different methods, such as solid-liquid extraction using aqueous alcohol solution (methanol, ethanol and isopropanol) [210] or by pressurized liquid extraction (PLE) method with water and ethanol [211].

Other potential use of SCG is obtaining of valuable bio-sugars, such as oligosaccharides, manno-oligosaccharides and mannose, after its delignification and defatting, process which proved large-scale feasibility [212]. Peshev et al. [213] revealed utilization of SCG for obtaining

water extracts with sufficiently high caffeine concentration. Appliance of nano filtration to these extracts, by using a suitable membrane, conducted to valuable products, as permeate and retentate fractions. Permeate can be further used for soft and energy drinks, while retentate for coffee drink or as functional food ingredient.

### 3.9 Value Added Products from *Aframomum meleguta* (alligator pepper) Wastes and Byproducts

*Aframomum meleguta* (Alligator pepper) otherwise called 'grains of paradise' is a perennial herb from the family of Zingiberaceae which are a plant specie commonto the swampy regions on the West African coasts. Some common examples in that family incude *A. exscapum*, *A. danielli*, and *A. citratum*. It is popularly recognized for its hot, spicy, and aromatic seeds. Some parts of Africa call it mbongo spice, Afrika kakulesi, or Guinea pepper.

For ages, many parts of Africa and Asia used these seeds of alligator pepper among other ingredients and spices for many different applications whether tradomedicinal or sociocultural [214]. It has been used widely as treatment for ailments like diarrhoe, body pains, rheumatism, sore throat and catarrh. Current research shows that the plant possesses secondary metabolites like flavonoids, phenolic compounds, alkaloids, tannins, terpenoids, saponins, and cardiac glycosides which have been considered to have healing/medicinal and therapeutic purposes. Aside that, when the seeds are used to extract alcohol, they exhibit antibacterial and antiseptic properties and could act as an antidote for some infections [215]. Alligator pepper has active compounds which fall under natural occurring preservatives. Apart from is medicinal applications, it is often used as a snack together with bitter kola and kola nuts in some African customary rites like marriage and naming ceremonies (Sunil et al., 2018). It is reported that the seeds of alligator pepper are made up of calories of energy and substantial amount of iron, magnesium, and calcium [216]. Okunade et al. [217], documented that it contains, 13.01, 7.5, 4.78, and 2.84 g/100 g protein, dry matter of fat, crude fibre, and ash respectively. The fact that alligator pepper is used as an ingredient for culinary purposes like barbecue and peppersoup is no surprise. It can also be used to produce essential oils which are used for their flavor and perfumery in pharmaceutical and industrial applications. The

pulp and peels of this wild fruit can be used to produce pectin which can be used in the food industry as a gelling agent.

#### **4. CHALLENGES IN AGRO-FOOD WASTE AND BY-PRODUCT VALORIZATION IN CAMEROON**

The quest to recover the valuable compounds of food by-products industrially began a few years ago. Over the years, companies around the world adopted this technology and today, at least 50 companies recover valuable compounds from food waste. They transform them to food ingredients for processed food products (for example, functional compounds, natural preservatives in order to maintain shelf-life requirements), and these compounds work without having any impact on the flavor or texture of the original product [218]. This advancement caused the scientific community to multiply its efforts towards valorization of all sorts of by-products from food for the purpose of recovery.

Unfortunately, the process of industrialization and implementation of the “Universal Recovery Strategy” is not a day’s job as it involves lots of scientific research, need to protect intellectual rights, application to pilot plan and mass production full-scale, development of standard application techniques and the numerous problems which come with commercialization. For instance, most food wastes are seasonal and thus often available in large quantities; meanwhile they are prone to microbial spoilage. But if the collection process is managed properly, the waste can be treated by cooling and addition of preservatives.

Waste by-products often have broad contents and these possess as a serious problem, but these wastes can be modified by introducing a pretreatment step. Moreover, when changing from a batch to continuous processes, the issue of extending the time needed for heating and mixing, more stuff to handle, higher level of scrutiny and air incorporation arises. This causes an increase in cost of production because food ingredients recovered industrially are needed in higher concentrations. Subsequently, process cost is increased, as industrially recovered compounds are used in food formulations in higher concentrations compared to laboratory-recovered compounds [219-224]. Therefore, solving these issues are necessary in order to ensure the sustainability of the process, the

economic benefit and the perpetual establishment of the derived products in the market [218].

For a product which is commercially feasible to be generated, it must have a level of flexibility and other solutions can be applied in developing its methodology for example finding cheaper and faster methods in production. Though these methods often result in cruder products with small amounts of the target compounds, it is advisable to go with nonthermal methods, safer materials and green solvents to improve the efficiency of the final product. It is also important to come up with products that have precise applications to easily target a particular market. [225], e.g, producing natural antioxidants such as polyphenols preferably used fresh for lactating mothers and young children with distinct ingredients and a minimum shelflife under refrigeration of at most 3months. Besides, modern new products should aim at the fulfillment of consumer needs and the realization of consumer value rather than at the development of products or enabling technologies per se. This means that the developed products should meet the high expectations of the consumers in an increasingly competitive market, e.g., development of “green” “organic” and “Protected Designation of Origin” products. Unlike the needs to delight the consumer and minimize environmental impact, developers should also ensure that the final product and process meet particular specifications, e.g., provide clean-label ingredients without impacting flavor or texture. Currently, the manufacturer’s label typically provides only limited information about the origin and composition of the used extract in the final product formulation. A clearer label of the products containing recovered compounds would enable nutritionists and/or pharmacists to be more confident when recommending these products [226-237].

Also, it is important for legal authorities to regulate the manner in which companies advertise health benefits associated with their products. This is done by bringing out regulations which are going to have positive impact on the food industry and at the same time protecting consumers from doubtful claims [238-247]. Because proving health benefits in food is costly especially to small (startup) industries, there’s risk for the rejection of these claims especially those not properly done. At the moment, just a handful of compounds and products have been

cleared meanwhile a great number of health claims have been rejected by the regulatory bodies [248]. The legislation challenges regulating health beneficial dietary products are lying to the nature of the products, which have the characteristics of both food and biologically active ingredients. For instance, EFSA of EU has approved health claims for only a small number of compounds (e.g., hydroxytyrosol in olive oil) [218]. This means that if you recover hydroxytyrosol from OMW in order to fortify foods (e.g., bakery, meat products or even oils), it is not allowed to add the health claim on the label [249-259].

After taking all these challenges into consideration, we can conclude that food waste valorization is very interesting yet difficult to implement in many food industries when compared to valorization of non food waste [260-268]. Decision upon recovery or valorization strategy should always be taken account in relation to the substrate and industry's goals.

## 5. CONCLUSION

Large amounts of diverse agricultural-food wastes and their by-products are produced generally in Africa and in Cameroon in particular, which causes enormous environmental and economic problems. Biorefineries have the capacity of reducing the environmental and economic burdens of agro-food waste and by-products, at the same time, permit the production of value added biochemicals and products through application of appropriate process technologies. This work reviews agro-food waste and by-product production and provides inside on the quantity and quality of the waste as a renewable bioresources for the agro-food sector. It further highlights the current traditional methods of agro-food waste valorisation for the manufacture of environmentally friendly products with added value within the bioeconomy concept. In addition, the paper presents the exciting impending and challenges of bioeconomy and circular technology development in Cameroon, which largely rely on developing the current traditional process technologies for agro-food waste valorisation to ensure more sustainable production of quality value added products. To address such challenges, proposals on implementing bioeconomy concepts in the agro-food industry to ensure valorization of food waste as a route to innovation and wealth creation are indicated. More research and development should be carried out on traditional process technology for agro-food waste valorisation, which will

create the pathway to scale-ups and industrialisation.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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