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# Valorization of cashew apple bagasse in food application: Focus on the use and extraction of nutritional or bioactive compounds

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ABSTRACT

Cashew apple (CA) is one of the largest sources of residues produced by the cashew agronomic industry. However, its use is limited, due to its rapid degradation, which makes storage impossible. Cashew apple bagasse (CAB), a by-product of this apple after juice extraction, accounts for about 20% of its total weight. This by-product generates waste due to underutilization. Nevertheless, the bagasse presents a renewable and valuable reservoir of bioactive compounds. It appears as an alternative to the production of a wide variety of food products with high added value. In the present review, we discuss about valorization of CAB for food application by extraction of the bioactive compounds, fermentation of its compounds of interest and formulation of food products. This review found that in view of the evolution of food trends, the by-product of CA after juice extraction has favorable nutritional and sensory characteristics for new food formulation. CAB can be valorized using optimized new methods such as microwave assisted extraction and ultrasound-assisted extraction, for efficient and selective extraction of its bioactive compounds. Bagasse could be used as an ingredient in the development of functional, natural, fiber-rich foods to bring hope to nowadays consumer market.

## 1. Introduction

The cashew tree (*Anacardium occidentale L.*) is an important tropical tree that produces a fruit with two edible parts including the cashew nut and the CA, an enlarged peduncle. This tree is cultivated nowadays mainly for the cashew nut. World cashew production was estimated at 4.6 million tons for the 2022/2023 season (Tridge, 2023). Obtaining this nut creates a by-product, which is the CA. CA represents 9–10 times the weight of the nut (Akyereko et al., 2022; Soro, 2012) i.e. nearly 46 million tons of CA. This pseudo fruit is greatly underutilized, in most cases considered as waste product (Tamiello-Rosa et al., 2019).

The main causes that hinder the full utilization of CA are a short shelf life, poor storage and limited information on other uses (Pinho et al., 2011); lack of appropriate processing technologies and lack of farmer awareness of the potential economic benefits of harvesting (Rawson et al., 2011). The low interest in this biomass is also linked to its high perishability and its astringent taste, due to the richness of CA in polyphenolic compounds (Abreu et al., 2005). Various methods have been developed to improve the shelf life and sensory properties of whole CA.

A wide variety of preservation methods to overcome these drawbacks have been studied in the literature by the authors listed below. These methods range from chemical preservatives to high pressure processing, implementing physical, biochemical and chemical methods (Das & Arora, 2017; Fonteles et al., 2016; Soro, 2012).

CA is known to contain both medicinal and nutritional components such as vitamins, which are up to six times higher than orange juice, as well as other phytochemicals necessary for growth and development (primarily carotenoids, flavonoids, anacardic acid and tannins), minerals and dietary fibers (Das & Arora, 2017). The apple has found application in food systems as pure juice, juice blends, jam, syrup, pastries, ethanol, wine, and other value-added products in some advanced countries (Igbinadolor et al., 2017).

The main product of CA is juice (Santos et al., 2007) as observed in Brazil (Pinho et al., 2011). Thus, most of the research available in the scientific literature has been conducted on juice. CA is very juicy (85–90% of water), sweet (7–13% of carbohydrates), slightly flavored

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and acidic (Lautié et al., 2001). It is also very rich in vitamin C and polyphenols (Adegunwa et al., 2020). Clarification of apple juice impoverishes it compounds such as, vitamins, polyphenols and proteins (Soro et al., 2017). Antioxidant richness of CA juice could contribute to reduce of incidence of degenerative diseases such as accelerated aging, cancer, arthritis, arteriosclerosis, heart disease, inflammation, dysfunction of the brain, etc. (Feskanich et al., 2020).

The by-products of juice extraction of CA called CA bagasse, CA pomace (CAP) or CA fiber (CAF) are undervalued. CAB represents about 20% of the weight of the CA, so a significant value of bagasse is produced, which could be a great potential for its valorization. These products can also add value to CA after juice extraction for beverage. As lignocellulosic raw material, it appears as an alternative to ethanol production (Rocha et al., 2009) and a potential source of xylitol production (Kouassi, 2018). Pretreatment is also required to use CAB in bioconversion for the production of ethanol, which represents a promising alternative fuel to reduce waste and environmental problems (Rocha et al., 2009).

Studies have shown that CAB is used as nutritional supplement for animal feed in some countries, but it still remains discarded and treated as garbage, which has a negative impact on the environment (Esparza et al., 2020; Sucupira et al., 2020) and leads to important food (Guedes-Oliveira et al., 2016).

Indeed, Oliveira et al. (2020) carry out a technological prospection in the databases of patents and scientific articles mapping the applications of CAB and cashew gum. After analyzing patents and scientific papers, they showed that up to their article writing no patents have been found on the use of CAB. On the other hand, the first scientific article on bagasse was published in 2007 according to Oliveira et al. (2020). Until 2018, only researchers of three countries had published on the subject, distributed as follows: 25 publications for Brazil, 2 publications for China and 1 post for India. Regarding the research sectors, 9 publications concerned biotechnology, 7 agriculture, 7 engineering, 3 food technologies, 2 Pharmaceuticals (Medicine), 1 Energy and 1 Veterinary.

From 2020–2023, there has been growing interest in CAB (van Walraven & Stark, 2023). The main valuations of CAB are non-food but there remains a big food potential to determine which is the objective of this article.

In the literature, several researches have been done on CAB. However, few synthesis articles exist on CA by-products, including only one recent review, which focuses on the food sector (van Walraven & Stark, 2023). In this article, the authors talk about food waste and present a general overview of CA composition, composition of new formulations using CA and CAP and changes in physical properties of new products.

However, to our knowledge, a restricted description focused only on bagasse in the food sector and the extraction of its compounds based on nutritional potential are still not available in the literature.

Our objective is to propose a review article on the compounds of interest of CAB. We will focus on bagasse, which has been less developed, and present three of the most used and most promising valorization paths in the agri-food industry, which are of great importance. We will talk about its nutritional values, the extraction of some compounds and its use in food formulations.

## 2. CAB as food waste

The last decade has unveiled a prodigious advance in the food industry, making it one of the fastest growing segments across the world. Food safety and food waste management issues are the main challenges facing this sector. Food waste is mass produced and underused worldwide (Nirmal et al., 2023). CA is one of the major solid wastes generated by cashew nut producers and CA juice industries in several countries. It is discarded into the environment and thereby constituting environmental challenges. These wastes are currently less used for value-added processes due to limited research focusing on the possible conversion of cashew wastes into other valuable products. In some countries such as Côte d'Ivoire, they are dumped as solid wastes. Therefore, the research of new, environmentally friendly methods to manage this problem is a great concern (Prakash Maran et al., 2014). The management of this waste requires a nutritional approach such as knowledge of the nutritional composition (Kouassi et al., 2018), fermentation, extraction and elaboration of high value compounds. Due to their nutritional composition, thes valorization of CA waste into valuable products offers a great scope for utilization and would also create more income for farmers, and food processors. In fact, the nutrition composition highlights the potential for valorization by reducing environmental impacts of the waste (Prakoso & Mubarok, 2021).

## 3. Nutritional potential of cashew apple bagasse

The bagasse studied come either from the juice industries or from artisanal processes or from research studies. To obtain the CAB, the nut is first detached from the apple. Then, depending on the studies and the industrial-process, there are various treatments (Sucupira et al., 2020). The apples are either disinfected and/ or washed (Kouassi et al., 2018) or blanched (Akubor et al., 2014), treated with hot water, or washed with a saline solution followed by juice extraction using a blender or press (Ebere et al., 2015). Fig. 1 shows the process of obtaining fresh CAB and CAB powder (CABp).

The data in the literature relate either to fresh bagasse or dry bagasse, which is a way of stabilizing the conservation of CAB, which reduces humidity and shows an increase in composition (Table 1).

Different nutritional evaluations have demonstrated the rich composition of CAB in macro and micronutrients as well as in bioactive substances. Table 1 proposes an overview of its nutritional qualities. Several factors such as the growth region, climate, cultural practices factors, maturity at harvest, storage atmosphere and storage conditions (Drake et al., 2002) are known to affect the composition of CAB. This may justify the slight variations observed in the composition of the CAB analyzed in the different studies listed in all the tables below (Table 1–4).

The fresh CAB shows moisture contents between 58% and 78.76% and for the dry CAB between 3.55% and 9.29%. Carbohydrates composition of CAB ranges from 13.94% to 19.03% and from 27.68% to 77.5% for undried and dried CAB respectively. This is the main constituent of the CAB, whether dried or not. These carbohydrates are dominated by total dietary fiber in which the principal fraction is insoluble dietary fibers. Pectin, which varies from 8% to 11%, is widely used in the formulation of products in the pharmaceutical, and food sectors (Santos et al., 2020).

The second constituent is proteins content that ranges from 1.83% to 22.66% depending on the dry or fresh weight basis or if CAB is dried or not. These variations may be attributed to differences in the varieties of each CAB and samples pretreatment method.

Lipids come next varying from 0,38 to 12,06% depending on if CAB is dried or not. Lipids have a good fatty acid profile (Table 2). Lipid profile consist of free fatty acids, monoglycerides, diglycerides and triglycerides with contents of 44.06–57.11%, 1.55–3.71%, 19.77–26.84% and 23.73–29.29% respectively (Kouassi et al., 2018). Lipids are mainly unsaturated. According to the same author, this fraction represents 75.64–77% and the various fatty acids found in the lipids of the CAB are the same in olive pomace oils, *Cucumis amaris* seeds and *Hippophae rhamnoides L.* pulp. The fatty acid profile shows that oleic acid are the most abundant fraction in the CAB with 64.10–65%, which are many applications in food industry. In view of monounsaturated fatty acids composition especially oleic acid (ω-9) of CAB, its consumption would allow to decrease plasma triacylglycerol and cholesterol concentrations in healthy normolipidemic subjects (Sancho et al., 2015).

Concerning the chemical composition of ashes, this fraction can contain minerals such as zinc, iron, manganese, copper, boron, magnesium, calcium, potassium, sodium and phosphorus (Table 2). The production and characterization of incineration ashes from the CAB showed

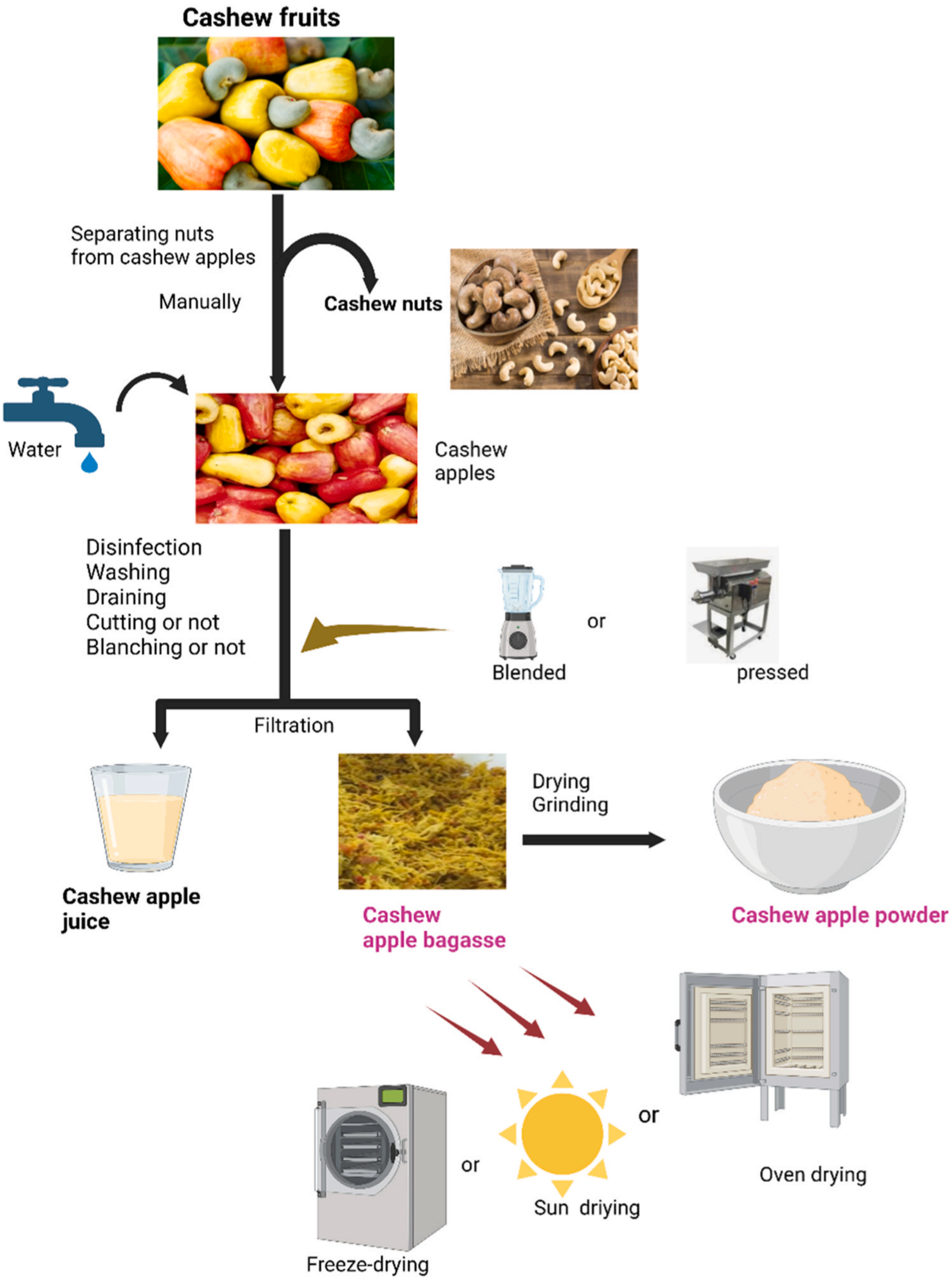

**Fig. 1.** Process of obtaining cashew apple bagasse powder (created with BioRender.com).

that these ashes represent only 3% of the incinerated material. The chemical elements of CAB shown by energy dispersive X-ray analysis are C, O, P, K, Mg, S, Na, Al and Si. X-ray diffraction and thermal analyzes indicated that the most significant crystalline phases are $KHCO_3$ (54.17%), $K_2SO_4$ (34.08%) and $MgKPO_46$ $H_2O$ (10.06%) (Sancho et al., 2015). These results indicate a possible use of this material as an imperishable source of potassium, phosphorus and magnesium. This material can have many applications in the food industry since its most abundant component is potassium bicarbonate, a compound with multiple uses (Santos et al., 2007).

Compared to other fruits, CAB has a high level of ascorbic acid and has an acid aspect (Table 2).

Regarding structural carbohydrates, cellulose and hemicellulose content in the CAB vary in a range of 14.25–34.93% and 8.20–51.65% respectively (Table 3). These variations could be explained by genetic differences, cultivation conditions, and even to the analytical techniques used (Cruz Reina et al., 2022). The relevance of this fraction is related to the fact that it can be hydrolyzed into fermentable sugars to produce xylitol (Narisetty et al., 2021), and organic acids (Bressani et al., 2020) for incorporation into food formulation. Cellulose and its derivatives are used in the food industry as food additives. Lignin can also be valorized and further used for obtaining substances such as vanillin, vanillin acid, muco-lactone, veratric acid, and others (Poveda-Giraldo et al., 2021).

Several studies investigated on the functional properties of CAB over the years (Table 4). Secondary metabolites such as phenolic acid, flavonoids, carotenoids are natural antioxidants found in CAB. These compounds have been applied in food science as coloring, flavoring, nutraceuticals and even active packaging (do Nascimento Silva et al., 2023).

CAB has a valuable wide range of biomolecules that potentially could be valorized into foods applications. Bagasse has a high nutritional value and can be considered as an excellent source of carbohydrates and

**Table 1**
Chemical composition of cashew apple bagasse.

| Components | Compositions | Unit | Type of bagasse | References |
|---|---|---|---|---|
| Moisture | 58.0 ± 00 * | % | Not dried | (Kuila et al., 2011) |
| | 71.04 ± 0.65 * | | | (Nurerk & Junden, 2021) |
| | 78.76 ± 0.41 * | | | (Matias et al., 2005) |
| | 3.55 ± 0.20 * | | Dried | |
| | 9.29 ± 0.07 * | | | (Cristina dos Santos Lima et al., 2012) |
| | 5.14 ± 0.48 * | | | (Sancho et al., 2015) |
| | 9.25 ± 0.38 * | | | (Guedes-Oliveira et al., 2016) |
| | 8.40 ± 0.01 * | | | (Silva et al., 2018) |
| | 6.5 ± 0.3 * * | | | (Medeiros et al., 2020) |
| | 8.26 ± 0.01 * * | | Dried mixture | (Kouassi et al., 2018) |
| | 9.27 ± 0.03 * * | | Dried R | |
| | 9.07 ± 0.06 * * | | Dried Y | |
| Carbohydrates | 13.94 ± 0.03 * | % | Not dried | (Nurerk & Junden, 2021) |
| | 26.79–47.41 * | mg/ 100 mg | Dried RV | (Nagaraja et al., 2007) |
| | 27.68–58.83 * | | Dried GAV | |
| | 44.5 ± 0.4 * * | % | Dried | (Medeiros et al., 2020) |
| | 77.5 ± 0.03 * * | | | (Akubor et al., 2014) |
| Sugars | 7.68 ± 0.63 * | mg/ 100 g | No dried | (Matias et al., 2005) |
| | 16.86 ± 0.28 * | | | |
| | 2.24 ± 0.09 * | % | Dried | (Guedes-Oliveira et al., 2016) |
| | 0.21–1.51 * | mg/ 100 mg | Dried RV | (Nagaraja et al., 2007) |
| | 0.17–2.89 * | | Dried GAV | |
| Reducing sugar | 7.25 * | % | Not dried | (Kuila et al., 2011) |
| | 6.84 ± 0.78 * | mg/ 100 g | | (Matias et al., 2005) |
| | 13.32 ± 0.30 * | | Dried | |
| | 0.56 ± 0.02 * | % | | (Cristina dos SantosLima et al., 2012) |
| | 36.00 ± 0.01 * | g/L | | (Sancho et al., 2015) |
| | 14.85 ± 0.27 * | | | (de Araújo Padilha et al., 2020) |
| Glucose | 0.25 * | % | Not dried | (Rodrigues et al., 2007) |
| | 9.29 ± 0.28 * | g/L | Dried | (de Araújo Padilha et al., 2020) |
| Crude fiber | 11.79 ± 0.16 * | % | Not dried | (Nurerk & Junden, 2021) |
| | 33.10 ± 0.75 * | | | (Matias et al., 2005) |
| | 11.64–18.30 * | mg/ 100 mg | Dried RV | (Nagaraja et al., 2007) |
| | 11.03–18.74 * | | Dried GAV | |
| | 41.53 ± 0.24 * | % | Dried | (Matias et al., 2005) |
| | 76.20 ± 0.10 * | | | (Guedes-Oliveira et al., 2016) |
| | 35.0 ± 0.1 * * | | | (Medeiros et al., 2020) |
| Soluble dietary fiber | 8.08 ± 0.21 * | % | Not dried | (Nurerk & Junden, 2021) |
| | 8.0 ± 0.4 * * | | Dried | (Medeiros et al., 2020) |
| Insoluble dietary fiber | 91.92 ± 1.22 * | % | Not dried | (Nurerk & Junden, 2021) |
| | 27.0 ± 0.01 * * | | Dried | (Medeiros et al., 2020) |
| Pectin | 9.28 ± 0.77 * * | % | Dried mixture | (Kouassi et al., 2018) |
| | 10.11 ± 0.48 * * | | Dried R | |
| | 8.56 ± 0.36 * * | | Dried Y | |
| | 11.2 ± 2.58 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 10.3 ± 1.80 * * | | Dried Y | |
| Starch | 15.09 ± 1.31 * | % | Not dried | (Preethi et al., 2021) |
| | 4.28 * | | Dried | (Kuila et al., 2011) |
| Proteins | 16.7 * | % | Not dried | (Rodrigues et al., 2007) |
| | 2.75 ± 0.08 * | | | (Nurerk & Junden, 2021) |
| | 1.83 ± 1.72 * | | | (Matias et al., 2005) |
| | 3.25 ± 0.31 * | | Dried | |
| | 22.66 ± 1.49 * | | | (Preethi et al., 2021) |
| | 9.9 ± 0.1 * * | | | (Medeiros et al., 2020) |
| | 10.09 ± 0.25 * | | | (Guedes-Oliveira et al., 2016) |
| | 18.73–31.11 * | mg/ 100 mg | Dried RV | (Nagaraja et al., 2007) |
| | 17.22–31.58 * | | Dried GAV | |
| | 16.31 ± 0.08 * * | % | Dried mixture | (Kouassi et al., 2018) |
| | 16.83 ± 0.05 * * | | Dried R | |
| | 18.20 ± 0.02 * * | | Dried Y | |
| | 8.69 ± 0.05 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 9.13 ± 0.05 * * | | Dried Y | |
| Lipids | 5.22 * | % | Not dried | (Rodrigues et al., 2007) |
| | 0.31 ± 0.12 * | | | (Nurerk & Junden, 2021) |
| | 0.38 ± 0.73 * | | | (Matias et al., 2005) |
| | 1.3 ± 0.39 * | | Dried | |
| | 2.49 ± 0.01 * | | | (Sancho et al., 2015) |
| | 1.72 ± 0.07 * | | | (Guedes-Oliveira et al., 2016) |
| | 2.2 ± 0.0 * * | | | (Medeiros et al., 2020) |
| | 7.59 ± 0.37 * * | | Dried mixture | (Kouassi et al., 2018) |
| | 10.47 ± 0.05 * * | | Dried R | |
| | 12.06 ± 0.02 * * | | Dried Y | |
| Ash | 1.07 * | % | Not dried | (Kuila et al., 2011) |
| | 1.62 ± 0.07 * | | Dried | (Correia et al., 2013) |
| | 1.41 ± 0.07 * | | | (Sancho et al., 2015) |
| | 0.74 ± 0.10 * | | | (Guedes-Oliveira et al., 2016) |
| | 1.08 ± 0.06 * | | | (Silva et al., 2018) |
| | 2.2 ± 0.1 * * | | | (Medeiros et al., 2020) |
| | 1.92 ± 0.04 * | | | (Preethi et al., 2021) |
| | 3.71 ± 0.11 * * | | Dried mixture | (Kouassi et al., 2018) |
| | 2.22 ± 0.06 * * | | Dried R | |
| | 2.20 ± 0.09 * * | | Dried Y | |
| | 1.510 ± 0.008 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 1.480 ± 0.016 * * | | Dried Y | |
| Volatile | 0.17 ± 0.05 * | % | Not dried | (Nurerk & Junden, 2021) |
| | 32.04 * | | Not dried | (Kuila et al., 2011) |
| | 65.65 ± 0.56 * | | Dried | (Silva et al., 2018) |

(continued on next page)

**Table 1** (*continued*)

| Components | Compositions | Unit | Type of bagasse | References |
|---|---|---|---|---|
| Energy | 78.83 ± 0.32 * | kcal | Not dried | (Nurerk & Junden, 2021) |
| | 236.8 ± 0.8 * * | Kcal/ 100 | Dried | (Medeiros et al., 2020) |
| C | 50.49 ± 0.49 * | % | Dried | (Silva et al., 2018) |
| H | 5.73 ± 0.03 * | | | |
| N | 1.41 | | | |

* *In dry weight basis *Not in dry weight basis; R: Red; Y: Yellow; RV: Release Varieties; GAV: Germplasm Accessions Varieties; O: Orange

vitamin C (Costa et al., 2009).

## 4. Valorization of cashew apple bagasse by extraction of valuable compounds

Some researchers in their studies showed that CAB would be recoverable by extraction of the compounds of interest. Carotenoids, vitamin C and polyphenols are the compounds that attract the most interest from researchers in the agri-food field, although they are not the main compounds of CAB. Then come the other compounds such as sugars, pectin, proteins, etc.

### *4.1. Extraction process*

Investigations carried out on CAB compounds relate to extraction with solvents at a certain temperature for a given time for a defined number of compounds (Yapo & Koffi, 2013).

Reducing sugar extraction have been performed by aqueous extraction by varying liquid: solid, pH, incubation time and temperature (Kuila et al., 2011). Other compounds such as carotenoids have been extracted by maceration and press (Fernando Pinto de Abreu et al., 2013).

Conventional extraction techniques are difficult for the fruit because their bioactive compounds are buried in the innermost part of its cell walls (C. B. Da Rocha & Noreña, 2020). This is how current researchers are focusing directly on the use of new technologies such as ultrasound, microwaves, etc. for bioactive compounds extraction contained in the CAB inducing higher yield with less solvent, energy and time. Moreover, these emerging technologies have been considered as an alternative to conventional extraction techniques due to their cost-effectiveness and high extraction efficiency without degradation of thermolabile bioactive compounds (Fonteles et al., 2017).

Furthermore, the extraction of bioactive compounds from CAB using green technologies will be beneficial for industries in developing value-added food products. Optimizing the extraction process through the traditional "one factor at a time" approach is a laborious process. Therefore, various empirical methods based on statistical or/and artificial intelligence are used to overcome this problem (Patra, PP. 7 et al., 2022, 1631).

Response surface methodology (RSM) is a set of statistical performances for designing experiments, developing models, estimating the effects of factors and giving the optimal conditions (Desai et al., 2008). The experiment responses are fitted to the nonlinear regression equations by various design techniques such as rotating central composite design, box-Behnken design, etc.

Several articles propose an optimization of extraction of several CAB compounds at the same time based on a factorial design, as in the case of Patra et al. (2021). The objective of these authors was to develop a process with optimized conditions for the microwave-assisted extraction (MAE) of bioactive compounds (total polyphenols, tannin, ascorbic acid, antioxidant activity, proteins and minerals) from CAB with maximum yield using a Box-Behnken design of the RSM. The results obtained showed that all the process variables (microwave power, treatment time and bagasse/ solvent ratio) contributed, at different intensities, to the

**Table 2**
Fatty Acid composition, mineral content and organic acids in cashew apple bagasse.

| Fatty Acid composition of CAB | | | | |
|---|---|---|---|---|
| Components | Compositions | Unit | Type of bagasse | References |
| Myristic acid C14:0 | 0.4 * | % | Dried | (Sancho et al., 2015) |
| Palmitic acid C16:0 | 19.36–20.77 * * | | | (Kouassi et al., 2018) |
| | 34.0 * | | | (Sancho et al., 2015) |
| Stearic C18:0 | 1.98–2.56 * * | | | (Kouassi et al., 2018) |
| Arachidic acid C20:0 | 0.44–0.76 * * | | | |
| Behenic acid C22:0 | 0.80–0.95 * * | | | |
| Palmitoleic acid C16:1n7c | 1.29–1.45 * * | | | |
| | 0.5 * | | | (Sancho et al., 2015) |
| C18:1n7c | 3.65–3.94 * * | | | (Kouassi et al., 2018) |
| Oleic acid C18:1n9c | 64.10–64.69 * * | | | |
| | 65.0 * | | | (Sancho et al., 2015) |
| Linoleic acid C18:2n6c | 1.80–2.29 * * | | | (Kouassi et al., 2018) |
| Linolenic acid C18:3n3a | 1.75–2.43 * * | | | |
| Eicosenoic acid C20:1n9c | 2.20–2.65 * * | | | |
| Mineral content in CAB | | | | |
| Zinc (Zn) | 14.92 ± 00 * | ppm | Not dried | (Rodrigues et al., 2007) |
| | 0.01 ± 00 * | mg/g | Dried | (Sancho et al., 2015) |
| | 0.1 ± 0.02 * * | | | (Medeiros et al., 2020) |
| | 3.11 ± 0.40 * | | | (Preethi et al., 2021) |
| | 9.41 ± 00 * * | mg/kg | Dried O | (Cruz Reina et al., 2022) |
| | 9.87 ± 00 * * | | Dried Y | |
| Iron (Fe) | 49.72 * | ppm | Not dried | (Rodrigues et al., 2007) |
| | 0.02 ± 00 * | mg/g | Dried | (Sancho et al., 2015) |
| | 0.7 ± 0.02 * | | | (Medeiros et al., 2020) |
| | 17.96 ± 0.50 * | | | (Preethi et al., 2021) |
| | < 59.5 * * | mg/kg | Dried O | (Cruz Reina et al., 2022) |
| | < 59.5 * * | | Dried Y | |
| Manganese (Mn) | 14.82 * | ppm | Not dried | (Rodrigues et al., 2007) |
| | 0.02 ± 00 * | mg/g | Dried | (Sancho et al., 2015) |
| | 1.84 ± 0.03 * | | | (Preethi et al., 2021) |
| Copper (Cu) | 18.31 * | ppm | Not dried | (Rodrigues et al., 2007) |
| | 0.3 ± 0.04 * * | µg/g | Dried | (Medeiros et al., 2020) |
| | 41.92 ± 0.33 * | mg/g | | (Preethi et al., 2021) |
| | 33.9 * * | mg/kg | Dried O | (Cruz Reina et al., 2022) |
| | 26.1 * * | | Dried Y | |
| Boron (B) | 1.14 ± 0.08 * | mg/g | Dried | (Preethi et al., 2021) |
| Magnesium (Mg) | 8.13 * | ppm | Not dried | (Rodrigues et al., 2007) |
| | 1.03 ± 0.04 * | mg/g | Dried | (Sancho et al., 2015) |
| | 2.5 ± 0.1 * * | | | (Medeiros et al., 2020) |
| | 4.45 ± 0.25 * | | | (Preethi et al., 2021) |
| Calcium (Ca) | 0.34 ± 0.02 * | mg/g | Dried | (Sancho et al., 2015) |

(*continued on next page*)

**Table 2** (*continued*)

| Fatty Acid composition of CAB | | | | |
|---|---|---|---|---|
| Components | Compositions | Unit | Type of bagasse | References |
| | 26.10 ± 6.05 * | | | (Preethi et al., 2021) |
| | 7.4 ± 0.4 * * | | | (Medeiros et al., 2020) |
| Potassium (K) | 83.5 0.1 * * | mg/g | Dried | (Medeiros et al., 2020) |
| | 4.92 ± 0.24 * | | | (Sancho et al., 2015) |
| | 15.60 ± 0.50 * | | | (Preethi et al., 2021) |
| Sodium (Na) | 0.25 ± 00 * | mg/g | Dried | (Sancho et al., 2015) |
| Phosphorus (P) | 1.28 ± 02 * | mg/g | Dried | (Sancho et al., 2015) |
| | 2.7 ± 0.1 * * | | | (Medeiros et al., 2020) |
| | 15.33 ± 1.16 * | | | (Preethi et al., 2021) |
| Organic acids in CAB | | | | |
| Oxalic acid | 64.2 ± 1.74 * * | mg/ 100 g | Dried O | (Cruz Reina et al., 2022) |
| | 74.9 ± 2.69 * * | | Dried Y | |
| Citric acid | 698 ± 60.6 * * | | Dried O | |
| | 1385 ± 269.8 * * | | Dried Y | |
| Fumaric acid | 58.2 ± 0.38 * * | | Dried O | |
| | 28.5 ± 1.03 * * | | Dried Y | |
| Lactic acid | 5177 ± 536.1 * * | | Dried O | |
| | 4803 ± 370.8 * * | | Dried Y | |
| Salicylic acid | 251.6 * * | | Dried | (Medeiros et al., 2020) |
| Vanillic acid | 19.4 * * | | | |
| Myricetin | 929.4 * * | | | |
| Quercetin | 50.8 * * | | | |
| Naringenin | 23.6 * * | | | |
| Hesperitin | 9.0 * * | | | |
| Chrysin | 8.8 * * | | | |

* *In dry weight basis *Not in dry weight basis; O: Orange; Y: Yellow

extraction of the bioactive compounds. The optimal conditions obtained for the MAE were a microwave power of 560 W, a treatment time of 110 s and a bagasse/solvent ratio of 1:30 (w/v). Additionally, compared to untreated extraction, microwave treatment resulted in a higher yield of bioactive compounds and minerals. Therefore, this study suggested that MAE can be used as a desirable technology to extract bioactive compounds from CAB with higher yield.

Ultrasound-assisted extraction (UAE) optimization using artificial neural network-genetic algorithm (ANN-GA) and RSM also allowed simultaneous extraction of ascorbic acid, total antioxidant and proteins in CAB (Patra, PP. 7 et al., 2022, 1631). UAE is a versatile, non-thermal and low-cost extraction method due to its ability to recover maximum compounds in less time, preserving the quality of the final product (Bhagya Raj and Dash, 2020; Meregalli et al., 2020).

Over the past two decades, ANN has been preferred for nonlinear multivariate modeling. It is a computational and mathematical modeling technique that predicts the responses based on data formed in the experimental range and studies the influence of input variables on the studied outputs through predictive modeling (Bhagya Raj and Dash, 2020). It is in this context that the studies of Patra, PP. 7) et al., (2022, 1631) are inscribed, which compares the performance of RSM and ANN-GA for modeling and optimization of the parameters of an UAE for CAB protein, antioxidant and acid ascorbic, by optimizing the process parameters (treatment time, ultrasonic amplitude and liquid/solid ratio). This optimization found as optimal conditions for RSM: 15 min of treatment time, 58% of ultrasound amplitude and 45 g/ml of CAB/solvent ratio. The optimum condition by ANN model was obtained at 15 min of treatment time, 53% of ultrasound amplitude, and 38 g/ml of

**Table 3**
Lignocellulosic composition of cashew apple bagasse.

| Components | Compositions | Unit | Type of bagasse | References |
|---|---|---|---|---|
| Cellulose | 14.25 ± 00 * | g/ 100 g | Not dried | (Kuila et al., 2011) |
| | 20.54 ± 0.70 * | | Dried | (Rodrigues et al., 2011) |
| | 18.31 ± 0.07 * | | | (Cristina dos Santos Lima et al., 2012) |
| | 20.56 ± 2.19 * | | | (Correia et al., 2013) |
| | 21.45 ± 0.31 * | | | (Medeiros et al., 2017) |
| | 20.56 ± 2.19 * | | | (Silva et al., 2018) |
| | 34.7 ± 0.2 * | | | (de Araújo Padilha et al., 2020) |
| | 19.21 ± 0.35 * | | | (Rodrigues et al., 2011) |
| | 19.19 ± 0.30 * * | | Dried mixture | (Kouassi et al., 2018) |
| | 18.00 ± 0.61 * * | | Dried R | |
| | 19.92 ± 0.36 * * | | Dried Y | |
| | 25.3 ± 0.26 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 26.6 ± 0.50 * * | | Dried Y | |
| Hemicellulose | 12.05 ± 0.37 * | g/ 100 g | Dried | (Rodrigues et al., 2011) |
| | 27,18 ± 0.01 * | | | (Cristina dos Santos Lima et al., 2012) |
| | 10.17 ± 0.89 * | | | (Correia et al., 2013) |
| | 10.96 ± 0.31 * | | | (Medeiros et al., 2017) |
| | 10.17 ± 0.89 * | | | (Silva et al., 2018) |
| | 17.6 ± 0.2 * | | | (de Araújo Padilha et al., 2020) |
| | 41.12 ± 0.24 * * | | Dried mixture | (Kouassi et al., 2018) |
| | 51.65 ± 0.11 * * | | Dried R | |
| | 51.10 ± 0.18 * * | | Dried Y | |
| | 28.4 ± 0.27 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 26.8 ± 0.54 * * | | Dried Y | |
| Lignin | 33.80 ± 1.30 * | g/ 100 g | Dried | (Rodrigues et al., 2011) |
| | 38.11 ± 0.08 * | | | |
| | 23,91 ± 0.02 * | | | (Cristina dos Santos Lima et al., 2012) |
| | 35.26 ± 0.9 * | | | (Correia et al., 2013) |
| | 35.39 ± 0.97 * | | | (Medeiros et al., 2017) |
| | 35.26 ± 0.90 * | | | (Silva et al., 2018) |
| | 41.4 ± 3.2 * | | | (de Araújo Padilha et al., 2020) |
| | 4.86 ± 0.23 * * | | Dried mixture | (Kouassi et al., 2018) |
| | 4.27 ± 0.41 * * | | Dried R | |
| | 3.65 ± 0.24 * * | | Dried Y | |
| | 15.2 ± 1.22 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 18.2 ± 1.40 * * | | Dried Y | |
| Extractives | 7.79 ± 0.60 * | g/ 100 g | Dried | (Correia et al., 2013) |
| | 9.51 ± 0.50 * | | | (Medeiros et al., 2017) |

(continued on next page)

**Table 3** (*continued*)

| Components | Compositions | Unit | Type of bagasse | References |
|---|---|---|---|---|
| | 6.5 ± 0.2 * | | | (de Araújo Padilha et al., 2020) |
| | 7.14 ± 0.51 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 7.52 ± 0.28 * * | | Dried Y | |
| Holocellulose | 32.41 ± 0.33 * | g/100 g | Dried | (Medeiros et al., 2017) |

* *In dry weight basis *Not in dry weight basis; R: Red; Y: Yellow; O: Orange

**Table 4**
Functional properties in cashew apple bagasse.

| Components | Compositions | Unit | Type of bagasse | References |
|---|---|---|---|---|
| Phenols | 20.70 ± 0.34 * | mg AGE/g | Dried | (Preethi et al., 2021) |
| | 13.20 ± 0.04 * | mg AGE/100 g | | (Sancho et al., 2015) |
| | 1.037.6 ± 22.5 * * | | | (Medeiros et al., 2020) |
| | 97.44 ± 6.65 * | | Not dried A | (Sucupira et al., 2020) |
| | 49.80 ± 0.22 * | | Not dried I | |
| | 293 ± 2.84 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 265 ± 3.88 * * | | Dried Y | |
| Proanthocyanidin | 62.2 ± 3.5 * * | mg PA2E/100 g | Dried | (Medeiros et al., 2020) |
| Anthocyanins | 2.46 ± 0.01 * | mg/100 g | | (Sancho et al., 2015) |
| Flavonoids | 46.9 ± 1.6 * * | mg CE/100 g | | (Medeiros et al., 2020) |
| | 0.45 ± 0.005 * | mg CE/g | | (Preethi et al., 2021) |
| Tannins | 0.073–0.412 * | mg/100 mg | Dried RV | (Nagaraja et al., 2007) |
| | 0.04–0.31 * | | Dried GAV | |
| | 299 ± 3.09 * * | mg TA/100 g | Dried O | (Cruz Reina et al., 2022) |
| | 288 ± 4.50 * * | | Dried Y | |
| Carotenoids | 4.5 ± 0.3 * * | mg/100 g | Dried | (Medeiros et al., 2020) |
| | 5.24 ± 0.37 * | | Not dried A | (Sucupira et al., 2020) |
| | 5.27 ± 0.04 * | | Not dried I | |
| | 1.71 ± 0.28 * * | µg/100 g | Dried O | (Cruz Reina et al., 2022) |
| | 4.72 ± 0.60 * * | | Dried Y | |
| Total antioxidant activity | 10.63 ± 0.02 * | mg AAE/g | Dried | (Preethi et al., 2021) |
| | 17.80 ± 0.05 * | % | | (Sancho et al., 2015) |
| Antioxidant activity ABTS | 8.06 ± 0.64 * * | TE/g | Dried O | (Cruz Reina et al., 2022) |
| | 7.17 ± 0.10 * * | | Dried Y | |
| | 49.76 ± 18.96 * | µM TE/g | Not dried A | (Sucupira et al., 2020) |
| | 32.68 ± 7.05 * | | Not dried I | |
| Antioxidant activity DPPH | 20.3 ± 0.7 * * | µmol TE/g | Dried | (Medeiros et al., 2020) |
| | 335 ± 3.75 * * | TE/g | Dried O | (Cruz Reina et al., 2022) |
| | 405 ± 19.4 * * | | Dried Y | |
| | 109.76 ± 13.66 * | µM TE/g | Not dried A | (Sucupira et al., 2020) |
| | 31.92 ± 2.31 * | | Not dried I | |
| Oxygen radical absorbance capacity | 131.7 ± 11.9 * | µmol TE/g | Dried | (Medeiros et al., 2020) |
| Ascorbic acid | 2.0 ± 0.3 * * | mg/100 g | | (Medeiros et al., 2020) |
| | 65.25 ± 1.74 * | | | (Preethi et al., 2021) |
| | 30.49 ± 0.06 * | | | (Sancho et al., 2015) |
| | 188 ± 3.81 * * | | Dried O | (Cruz Reina et al., 2022) |
| | 204 ± 4.26 * * | | Dried Y | |
| | 901.2 ± 74.88 * | | Not dried A | (Sucupira et al., 2020) |
| | 20.3 ± 0.02 * | | Not dried I | |

* *In dry weight basis *Not in dry weight basis; A: Artisanal; I: Industrial; O: Orange; Y: Yellow; RV: Release Varieties; GAV: Germplasm Accessions Varieties;

CAB to solvent ratio. In these optimal conditions antioxidant activity extracted using RSM were 90.98% and 94.97% with ANN-GA (Patra, PP. 7 et al., 2022, 1631). Similar studies have shown that extraction of bioactive compounds from grape juice residue through MAE and UAE methods would preserve thermolabile compounds and minimize environmental impact (C. B. Da Rocha & Noreña, 2020).

Fig. 2 summarizes the different methods used to extract the compounds of interest from the CAB. As for Fig. 3, it shows the process of extraction of compounds from CAB under the optimization conditions described above, using ultrasound-assisted extraction as an example method.

### 4.2. *Antioxidants extraction*

CAB is a potential, abundant and inexpensive source of bioactive compounds such us polyphenols, carotenoids and ascorbic acid. Ultrasonic treatment can be applied to release these antioxidant compounds improving the nutritional value of this residue. It is in this mind that Fonteles et al. (2017) directed their studies towards developing an ultrasonic-based process for CAB that would enable the use of this fruit residue as a nutrient raw material in the food industry. After the extraction of the bioactive compounds, the water content appeared as the most significant variable. However, all the variables studied (bagasse/water ratio, ultrasound power intensity and treatment time) in the process contributed at different levels to the improvement of their extraction. Sonication, in contrary to conventional heat treatment, gave a higher yield of bioactive compounds. The optimal conditions obtained after this study were 6 min of sonication time, 226 W/cm$^2$ for ultrasonic power intensity, and a bagasse/water ratio of 1:4.

A study of Colombian CAB with a view to use their knowledge for the development of new functional food products showed the highest levels of ascorbic acid (Contreras-Calderón et al., 2011). In several studies, ascorbic acid (vitamin C) has been taken as an index of the nutritional quality of foods (Fonteles et al., 2016). Ultrasound is a technology that would have a minimal effect on the quality of foods containing heat-labile vitamins (Golmohamadi et al., 2013).

#### 4.2.1. *Carotenoids*

CAB is a source of carotenoids, which is one of the most important pigment groups for food fortification and/or dietary supplements and used as natural colorants in food (Fernando Pinto de Abreu et al., 2013). Carotenoids are known for several biological functions such as its antioxidant and pro-vitamin A properties. Because of these properties carotenoids have been associated with reducing the risk of several degenerative diseases, including cancer, cardiovascular diseases and cataracts (Azeredo et al., 2006; Feskanich et al., 2020; Ramel et al., 2012; PP. 111).

Carotenoids are usually extracted with organic solvents. However, many of these solvents are known to have negative impacts on human health and the environment. The emission of polluting and/or carcinogenic gases by these solvents has motivated researchers to replace this type of extraction with "cleaner" processes, which are ecological and do not promote health damage (Azeredo et al., 2006). The carotenoids

AGE: Acid Gallic Equivalents; PAC2: Proanthocyanidin A2 Equivalents; CE: Catechin Equivalents; TA: Tannic Acid; TE: Trolox Equivalents.

could be extracted, for example, by maceration of the tissues in an aqueous medium followed by pressing. Abreu (2001) set up a process for the extraction of carotenoids from CAB by sequential aqueous extraction. The process includes a CAB humidification step (water/fiber ratio varying between 1/1 and 3/1, at a pH between 3 and 7) followed by several successive pressing cycles (continuous screw press). The residual fibers contained in the final extract are eliminated by sieving at 0.3 mm. Finally, the product is concentrated by evaporation under vacuum at 50–65 °C. However, the efficiency of the different extraction steps and the impact of bagasse pre-treatments have not been quantified. The main limitation of the aqueous extraction of carotenoids concerns their very low solubility in water (Azeredo et al., 2006).

Some authors have implemented processes to overcome the limits of the aqueous extraction of compounds with low polarity. Among these methods is enzymatic extraction due to the fact that carotenoids are contained in cell walls with complex structures.

The action of enzymes with mixed activities (mainly cellulase, hemicellulase and pectinase) hydrolyze the structural polysaccharides of the cell walls of tissues and allows the release of their content (Delgado-Vargas & Paredes-López, 1997).

Pre-freezing tissues can also increase the efficiency of extraction, because it leads to disruption of cellular structures facilitating the release of their contents. It is with this in mind that Azeredo et al. (2006), evaluated the impact of freezing CA to improve the extraction of carotenoids from CAB and added pectinase to increase efficiency of sequential extraction steps by pressing. They combined 4 extraction methods. The result of their studies showed an extraction of 29.57%; 46.72%; 20.97% and 35.91% carotenoids respectively for maceration in enzymatic solution, freezing followed by maceration in enzymatic solution; maceration in water and finally freezing followed by maceration in water. With a significant difference between the different treatments, the combination of CAB freezing followed by maceration in enzymatic solution was found to be more efficient for carotenoids extraction. Fernando Antonio Pinto de Abreu (2012) made an aqueous extraction of carotenoids, which is carried out by pressure and entrainment with water after enzymatic maceration. Then the crude extract was concentrated and purified by micro and diafiltration with 6 cycles of pressing. The extraction conditions were set as follows: maceration 60 min at 55 °C with 500 mg/kg of pectinase and without AMG, water/CAB ratio 1:1, screw rotation speed 30 rpm and force applied 2500 N. The final extract obtained has a carotenoid content of 70 mg/kg. Their results are in the same order of magnitude as those obtained by (Stoll et al., 2003), who described a process for recovering a functional food ingredient rich in carotene from carrot pomace and obtained a concentrate with a final carotenoid content of about 64 mg/kg. In the study of Fernando Pinto de Abreu et al. (2013) pressing using a continuous helicoidal type press followed by microfiltration of the CAB yielded an aqueous extract. The extract was characterized by an intense yellow color due to carotenoid pigments. The carotenoids content increased from 10 to 54 mg/kg in the concentrate. They also analyze the carotenoid profile and results showed 11 carotenoids. Most of the CAB carotenoids identified by HPLC-DAD-MS are xanthophylls present in an esterified form. Auroxanthin and β-cryptoxanthin account for approximately 50% of total carotenoids, they are the main carotenoids and together they are responsible for the bright yellow color of the extract and the concentrate (Abreu et al., 2013).

With growing scientific interest in the influence of ultrasound on the nutritional quality of the food matrix. Fonteles et al. (2017) implemented for the first time an ultrasound-based process for CAB. The parameters likely to influence the process were optimized using a statistical experimental design approach. They obtained an almost 60% increase in β-carotene when a power intensity of 226 W/cm$^2$ and a CAB/water ratio of 1:4 for 6 min were applied, with a final

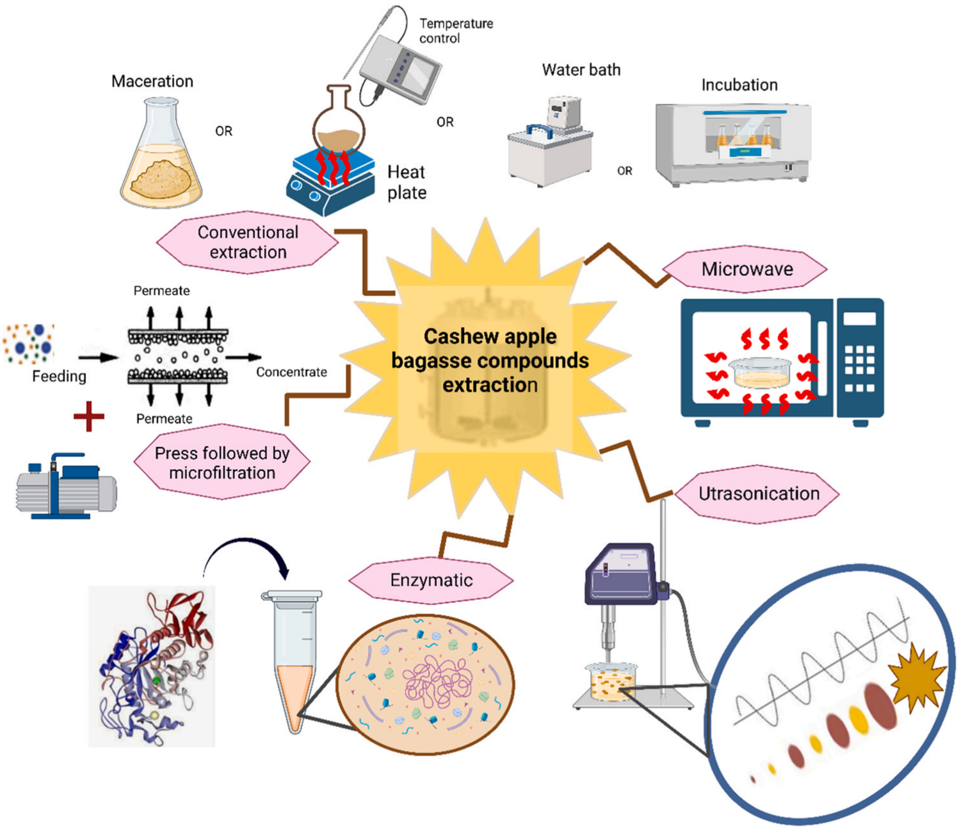

**Fig. 2.** Methods for extracting compounds from CAB) (created with BioRender.com).

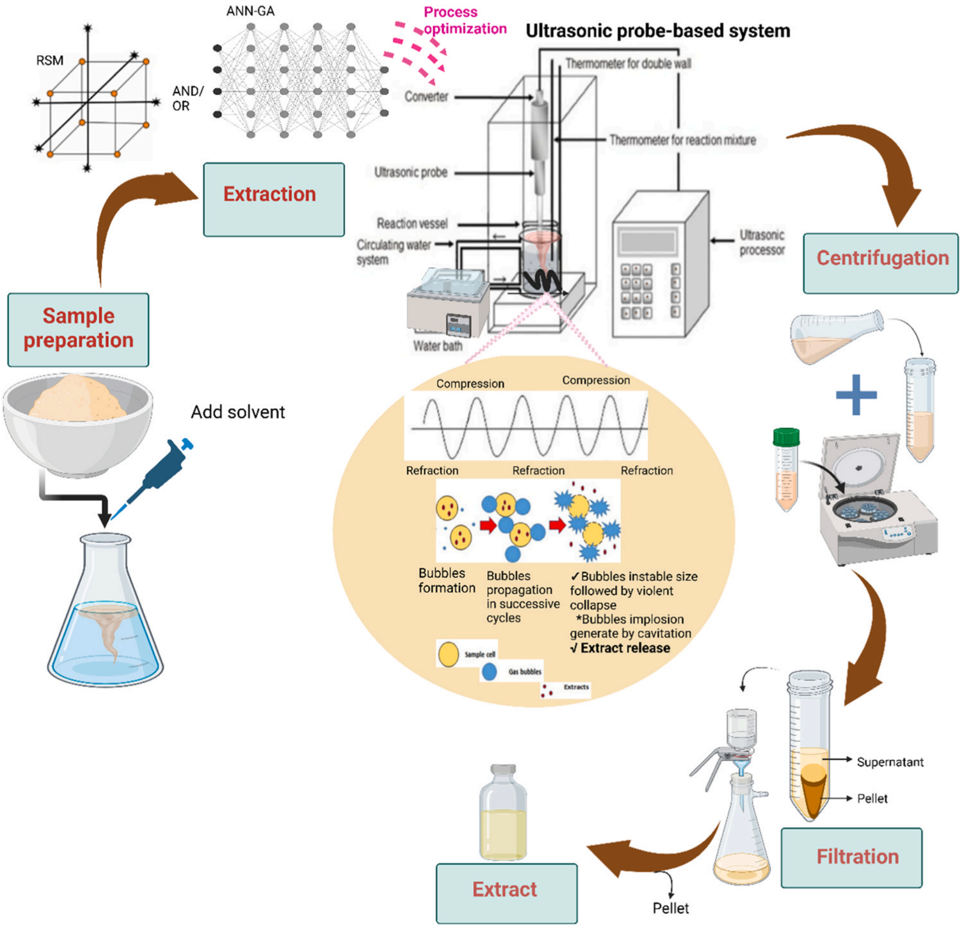

**Fig. 3.** Example of process for extracting compounds from CAB with some optimization methods: case of ultrasound-assisted extraction (Patra, PP. 7 et al., 2022, 1631) (created with BioRender.com).

concentration of 12.38 mg/100 g DW (Dry Weight).

In view of all the above, CAB can be considered as an innovative and interesting product containing nutritionally important carotenoids, which could make it usable as a dietary supplement. According to Fernando Pinto de Abreu et al. (2013), from this abundant and cheap raw material, the analyzes made it possible to define and validate a new realistic process for obtaining concentrated and purified carotenoid extracts. The results are very encouraging both in terms of the efficiency of the process and in terms of the quality of the finished product. They make it possible to envisage a future implementation of the process on an industrial scale. The purified concentrated extracts obtained correspond to products with high added value. They can be used directly as food colorings or, more generally, as sources of carotenoids (Fernando Antonio Pinto de Abreu, 2012).

### 4.2.2. *Polyphenols*

Phenolic compounds represent one of the most diverse families of compounds found in plant matrices, there are known for their important role in the sensory and nutritional quality of fruits and vegetables (Arruda et al., 2018). These secondary plant metabolites have several interesting properties including antioxidant, antimutagenic, anti-allergic, anti-inflammatory and antimicrobial (Martins et al., 2011).

CAB is a potential, abundant, and low-cost source of phenolic compounds, with this in mind Fonteles et al. (2016) developed an ultrasound-based process for the CAB that would allow the use of this bagasse as a nutritious raw material in the food industry. Their study showed that sonication provided a higher yield of polyphenol compared to CAB without ultrasound treatment. Fonteles et al. (2017) studied the effect of each parameter on the extraction and the optimal conditions that led to the maximum amount of phenolic compounds were: sonication time of 6 min, power intensity of 226 W/cm$^2$, and CAB/water ratio of 1:4. Microwave technology, which utilizes the electromagnetic wave of frequency from 300 MHz to 300 GHz, is another rapid, energy-efficient, green, and emerging technology for bioactive compound extraction.

Patra et al. (2021) successfully extracted the phenolic compound from this by-product by modeling and optimizing MAE using RSM.

Besides the experimental design, certain parameters such as solvent, temperature, and time are the most common factors known to affect the extraction of polyphenols from CAB (Patra et al., 2021; Silveira et al., 2021).

Indeed, for food application when extracting phenolic compounds from plants using UAE, by recommendation, ethanol should be an environmentally friendly and non-toxic food grade organic solvent (Chen et al., 2015). The recovery of phenolic compounds from CAB by UAE was carried out evaluating the effect of extraction time and ethanol concentration as process variables and the antimicrobial potential of extract against food pathogenic bacteria and phenolic profiling by UPLC-QTOF was analyzed from extraction optimized condition by RSM (Silveira et al., 2021). They optimized parameters for a total phenolic extract of 750 mg AGE/100 g were 42.16% ethanol (v/v) and extraction times of 37.34 min in an ultrasonic bath. Indeed, the phenolic profile of the extracts was conducted using an ultra-performance liquid chromatography, a total of 15 compounds including quercetin and myricetin derivatives, gallic acid, and anacardic acid were identified. The extracts displayed effective action against *Staphylococcus aureus* and *Listeria monocytogenes*. The extracts were effective against foodborne pathogenic bacteria thus demonstrating their potential to be a good natural alternative to synthetic additives in the food industry.

Phenolic compounds are sensitive to light, oxygen and moisture (Ballesteros et al., 2017) so it is necessary to combine the extraction of these compounds with those that protect and stabilize them. de Souza Lima et al. (2022) proposed the extraction and encapsulation of phenolic compounds from CAB by freeze-drying and using maltodextrin and gum arabic as encapsulants. This methods enabled the preservation of phenolic compounds and as such, their potential use by the nutraceutical or food industry as a food additive to enrich the compound content and antioxidant activity. They have also shown a good effect of encapsulants on the simulated gastrointestinal digestion of these phenolic compounds and the antioxidant activity of the extracts.

#### 4.2.3. Global antioxidant activity

From what we have seen of the constituents, which have just been detailed above, a significant global antioxidant activity can be anticipated. In Sucupira et al. (2020) studies, the CAB analyzed showed considerable antioxidant activity and can be considered a good source of natural antioxidants such us carotenoids, ascorbic acid and polyphenols as developed in the previous points, which can be used for industrialization in order to obtain new food products or to enrich them.

The increase in phenolic compounds and the high final amount of vitamin C contributed to the improvement of antioxidant activity in sonicated CAB samples (Fonteles et al., 2016). The positive correlation indicates that phenolic compounds are the main contributors to the antioxidant properties of this product. A significant and positive correlation has also been reported for phenolic compounds and antioxidant activity by other authors (Contreras-Calderón et al., 2011; Rufino et al., 2010).

The antioxidant activity of exotic fruits from Colombia was studied by Contreras-Calderón et al. (2011), they reported that banana passion fruit, arrayana and CAB showed the highest antioxidant activities among other fruits. The high antioxidant activities in the CAB could be linked to the presence of bioactive compounds easily recoverable from this biomass, such as ascorbic acid, and carotenes (Contreras-Calderón et al., 2011).

Components of bioaccessibility facilitators, for example, ascorbic acid are readily found in fruits like CAB, and it increases the absorption of non-haeme iron and depressant components such as tannins, phytates, and calcium oxalate. In addition, phenolic compounds and ascorbic acid contribute very positively to the bioaccessibility percentage of the total antioxidant activity, which in turn may possibly contribute to the protection against several diseases in relation to its antioxidant potency (De Lima et al., 2014).

Antioxidant activity is related to the type and properties of polyphenols, which can interact differently with free radicals, as reported by Villaño et al. (2007).

### 4.3. Proteins

Several authors analyzed and discussed the protein content of CAB without extracting them and found variability in the protein contents. Very little data exists on protein content and on the extraction; there are only two at the time of writing (mentioned above).

The extraction and characterization of CAB proteins could partially replace some expensive proteins such as egg and soy proteins (Patra, PP. 7 et al., 2022, 1631).

### 4.4. Carbohydrates

#### 4.4.1. Sugar

Optimization of aqueous extraction of reducing sugar from CAB has been investigated by (Kuila et al., 2011) using RSM based Box Behnken Design, to obtain the best possible combination of liquid/solid ratio, pH, extraction time and extraction temperature for maximum reducing sugar extraction. The optimum extraction conditions were as follows: liquid/solid ratio 3.26 (ml/g), pH 6.42, extraction time 6.30 h and temperature 52.27 °C. Under these conditions, the experimental yield was 56.89 (g/100 g dry substrate), which was well matched with the predictive yield 57.64 (g/100 g dry substrate). Further analysis of sugar was done by HPLC, which revealed glucose (34.28 g/100 g dry substrate), fructose (18.57 g/100 g dry substrate) and arabinose (3.42 g/100 g dry substrate). The study show that CAB is a potential low cost substrate (Kuila et al., 2011) in food application.

#### 4.4.2. Pectin

The extraction of pectin from CAB by Yapo and Koffi (2013) used water acidified with 1 N HNO3 at three different extraction strengths (pH 1.0, 1.5 and 2.0), with a solid/liquid ratio of 1:25 (w/v), temperature 75 °C for 90 min. This demonstrated that CAB is a commercially viable raw material for the eventual production of low-methoxy pectin needed for the manufacture of low calorie gelling agent food products. The pectin content orientates the valorization of this bagasse towards gelling, texturizing, thickening, emulsifying and stabilizing agents in food processing as well as in the cosmetic and pharmaceutical industries (Kouassi, 2018).

### 4.5. Synthesis of extraction process and application of CAB bioactive compounds in food industry

The cashew nut industrialization process generates large quantities of co-products that are difficult to preserve due to their chemical and physicochemical properties. Due to their nutritional composition, several compounds with high added value could be identified through an appropriate conversion process. To gain the benefits of the large amount of potentially valuable compounds they contain, these CAB compounds could be transformed into marketable products as ingredients for the development of new food products. Compounds of interest from CAB were reported to be used in various food applications. This use is made possible by optimizing the extraction process parameters that would be essential to quickly and easily extract the compounds of interest from CAB with a high yield. The extractions are performed from simple to combinated processes that allow to improve and preserve the nutritional, functional and nutraceutical characteristics of the CAB compounds. The extraction process of carbohydrates is thereby less important compared to other compounds (vitamin, polyphenols, carotenoids, proteins…) which by their sensitivity (Ballesteros et al., 2017), availability and complex structure make extractions more complex. For example, the extraction of bioactive compounds from CAB are made possible by MAE and UAE methods which could preserve thermolabile compounds and minimize environmental impact. Whatever the compounds, by adapting the extraction process, extracts that were quite competitive for their antioxidant content were obtained. It is therefore possible to have good extraction results with CAB but the right process has to be chosen and the right process is not necessarily the same for each of the compounds. For carotenoids, for example, research has shown that combined methods need to be applied (Fernando Antonio Pinto de Abreu, 2012) as explained above.

Extraction with CAB makes it possible to have enriched extracts that can be more easily incorporated into food processing products, as is already the case for the extraction of bioactive compounds from avocado seed (R. G. Araújo et al., 2020), carrot pomace (Stoll et al., 2003) and *Citrullus Lanatus* fruit rinds (Prakash Maran et al., 2014).

CAB are rich sources of many bioactive compounds, such as dietary fiber (pectin, cellulose, hemicellulose, and lignin), vitamins, minerals, organic acids, phenolic acids, carotenoids. Numerous health benefits have been linked to these bioactive substances, including antioxidant, antibacterial, anti-inflammatory, anti-hypertensive, neuroprotective, and antiallergenic activities. The creation of several products employing CAB extracts is gaining interest in the food industry. CAB can be used for food fortification and food preservation.

#### 4.5.1. Food fortification

CAB can be used in food items as a cost-effective, low-calorie bulking agent to replace some of the sugar, fat, or flour (Aderiye et al., 1992). It frequently improves food functionality by enhancing emulsion stability and water and oil retention (Lima et al., 2017, 2018). For example, apple pomace in meat could make up for the lack of fiber in our diets. researchers developed several high-fiber, functional baked (Muniz et al., 2020) and extruded snacks. CAB improved the aroma and flavor of baked goods. Pectins are now used as thickeners, water binders, and stabilizers and texturizing fat replacer to mimic the mouth-feel of lipids in low-calorie foods (Kouassi et al., 2018; Nirmal et al., 2023). Among other uses, it has been considered in the class of dietary fibers known to have a positive effect on digestive processes and to help lower cholesterol (Chen et al., 2016; Nurerk & Junden, 2021).

Beyond fulfilling fundamental nutritional needs, bioactive substances have positive health effects on the host. Due to the GRAS (Generally Recognized as Safe) status of extracts, they can be added to a variety of food products (Nirmal et al., 2023). The prebiotic capacity of CABs is one of their characteristics that is sought-after in food applications. Incorporating CAB powder or extracts into a food formulation such as patties improves the water-holding capacity, cooking yield, meat emulsion stability, and textural qualities, such as firmness, toughness, and toughness (Guedes-Oliveira et al., 2016; Sucupira et al., 2020).

#### 4.5.2. Food preservation

Bioactive compounds such as phenolics are the most important group of chemicals with antimicrobial activity (Nirmal et al., 2023). CAB extracts are high in phenolic compounds and can thus be an effective method for enhancing the lipid stability of food cooked. On the other hand, mango seed biowaste has been characterized by a high concentration of bioactive components, including phenolic compounds, carotenoids, and vitamin C. Various mango peel extracts were evaluated for their antibacterial effects against Gram-positive Staphylococcus aureus and Gram-negative Pseudomonas fluorescens. Different levels of antibacterial activity were present in the extracts against both (Nirmal et al., 2023). Considering that CAB has a similar concentration of bioactive compounds, its extracts could also be able to preserve food against these bacteria.

Based on what we have presented on the extraction processes, extracts with high potential can be obtained since they are of the order of other extracts which have proven themselves industrially in food applications. The extraction and use of CAB compounds could help food industries generate a new source of food, reduce waste and minimize environmental problems (Cristina dos Santos Lima et al., 2012; Silva et al., 2018).

The food industry is one of the industries that uses various extracts derived from co-products, mainly in response to consumer demand for new products low in synthetic preservatives generated by sustainable and eco-efficient techniques. The use of CAB as a source of bioactive compounds and as an ingredient in food formulations has now become an attractive field. Nevertheless, this procedure requires interdisciplinary research, which may include food chemistry, food technology, biotechnology, molecular biology or toxicity (Nirmal et al., 2023).

## 5. Valorization of bagasse by fermentation way

Some investigations have shown that CAB can be valorized by fermentation to produce several compounds of interest such as enzymes, ethanol, biosurfactants and others. This aspect has been reviewed by Sharma et al. (2020), where the authors present cashew shell liquid, testa, CA and CAB. They showed the importance of these by-products for the industry through transformation into several bioactive compounds, polymers and other products, thus making the process and products economical, environmentally friendly and sustainable.

CAB is presented as a product rich in organic nature and could be a potent source of lignocellulosic material for the production of bioethanol and other microbial products through biological processes (Rodrigues et al., 2011; Silva et al., 2018; Valderez et al., 2011). Most articles are focused mainly on the non-food plan, which will not be discussed in detail in this review. There are very few scientific papers concerning the food domain, which is our field of interest in this review article. If CAB fermentation can be valorize for biosurfactants and bioethanol, it also could be valorize in food industry.

Indeed, CAB by fermentation in the presence of certain microorganisms has made it possible to produce enzymes, which have a key role in the food industry. Tannase is important enzyme that is widely use in food industry, particularly for tea clarification and the production of pharmaceutically important compounds, such as gallic acid. Gallic acid, a tannin product, is the substrate for chemical synthesis of propyl gallate and trimethoprim, which are important in food and pharmaceutical industries, respectively (Pinho et al., 2011). Tannase is also used in the treatment of tannery effluents for the stabilization of malt polyphenols, clarification of beer and fruit juices, for the prevention of phenol-induced maderization in wine and fruit juices, and for the reduction of antinutritional effects of tannins in animal feed (Adachi et al., 1968; Pinto et al., 2001).

Rodrigues et al. (2007) showed in their study that CAB is a promissing substrate for the production of this enzyme; *Aspergillus Oryzae* was used for solid-state fermentation with CAB as the substrate. The physicochemical parameters that influenced enzyme production were: water content (60 ml), tannic acid supplementation (2.5% [w/w]) and nitrogen source supplementation (2.5% [w/v] ammonium sulphate). Increasing the concentration of ammonium sulfate in the medium improved the enzyme productivity when 2.5% was added. Supplementation of the medium with phosphorus (NaH2P04·H20), ammonium nitrate, peptone and yeast extract had no influence on tannase production.

The investigation of Rodrigues et al. (2008) on the optimization of tannase production by solid state fermentation of CAB demonstrated that temperature and inoculum concentration play an important role in the production. Indeed, the optimal conditions for enzyme production were an inoculum concentration of $10^7$ spores/g and an incubation temperature of 30 °C coupled with supplementation of the substrate with starch and sucrose as carbon sources. They showed that tannase is an adaptive enzyme, low levels of inoculum were not sufficient to induce microbial growth and enzyme liberation.

## 6. Valorization of bagasse by elaboration of food products

Several researchers have made investigations in the formulation of food products in the context of the valorization of CAB. It reported that CAB can be used for various application like substitutes of meat-based product like chicken patties (Guedes-Oliveira et al., 2016) and hamburger (Pinho et al., 2011; Barros et al., 2012; Rosa and Lobato, 2020). Some authors have successfully developed vegetarian burgers with good acceptance (Lima et al., 2017, 2018; Maciel, 2022) and fish burger (Marques, 2018). Many researches have been conducted on bakery products such as biscuits (Akubor, 2016), cupcakes (Morais et al., 2018), cakes (Aderiye et al., 1992; Akubor et al., 2014; Adegunwa et al., 2020) and cookies (Matias et al. (2005); Uchoa et al. (2009); Ebere et al. (2015); (Araújo et al., 2021) in order to substitute wheat flour (Wf) with CAB powder (CABp) in their formulation.

In recent years researches have been directed towards new CAB-based food formulations such as yogurt (de Lima Mendes et al., 2019), cereal bar (Muniz et al., 2020), plant-based products (Portela, 2022; Saldanha, 2022; Sucupira et al., 2020), cereal-based extrudates (Preethi et al., 2021) and jam (Nurerk & Junden, 2021).

The main studies relate to the field of pastry products because children and adults consume these products all over the world. Indeed, health-conscious consumers are therefore looking for functional, natural and fiber-rich products.

The first attempt at valorization was the elaboration of cake with a

CAB fermented for 96 h (Aderiye et al., 1992). These authors, in order to know the nutritional significance of the composite flour made with CABp, have used this biodegraded CAB in cake formulations. They show that CAB at 10% of Wf did not harm the baking characteristics and sensory qualities. The final product obtained had a changed physicochemical composition improving the nutritional aspect with an increase in fiber from 1.5% to 7.5%; proteins from 5.2% to 11.5% and a decrease in carbohydrates from 43.2% to 19.2% (Aderiye et al., 1992). Similarly, other authors have been interested in adding nutritional values to new formulation such as Muniz et al. (2020), who changed the processing of the CAB by proposing a solid-state fermentation of CAB using *Saccharomyces cerevisiae* yeast concentration of 3% for other food formulations.

Over the years, other authors have proposed cake formulations with different processes that have given different results in terms of sensory and biochemical analyses. Cake with substitution at 0%, 5% and 10% maximum of CABp in relation to Wf content had a higher preference than the traditional Wf cake and did not show a difference between them (Akubor et al., 2014). By pushing further the analyzes on the inclusion of CAB in pastry to enhance the nutritional and functionality, Adegunwa et al. (2020) found in their study that substituting Wf with CAB decreased the pH (3.59–5.40), oil absorption capacity (67.26–71.45%) and the pasting characteristics (except pasting temperature) of the composite fours. An increase in Ca (3.36–22.80%), Mg (11.72–87.90%), P (10.27–40.38%), Zn (4.31–57.97%) and Fe (5.01–44.82%) showed that the composite fours would be useful in tackling micronutrient deficiencies. According to the same authors, bulk density (0.63–0.78 g/ml) decrease would make them suitable in the formulation of complementary foods. In addition, Wf substituted with 5% and 10% of CAB are recommended for the application of cakes and other similar products, which confirms the studies carried out by Akubor et al. (2014). In fact, the increasing rehydration index and water absorption capacity of the composite fours with CAB is an indication of their usefulness in the production of baked and other similar food products that require hydration.

On the other hand, for the application in croquette type plant-based product with soy protein, the substitution can go up to 40% of CAB (Saldanha, 2022).

The evaluation of the physicochemical composition and the sensory acceptability of a cupcake prepared with a partial substitution of Wf by CABf did not show any significant difference between the sensory analysis criteria (appearance, aroma, flavor, texture and overall acceptance), except for the appearance of product without CABf, which was assigned the highest average among the tasters. Cupcakes made with CAB had a higher amount of fiber compared to cupcakes without CAB thus adding nutritional value to the formulated product (Morais et al., 2018).

Enriched cookies were also prepared by adding 5%, 10% and 15% of CAB. Appearance, color, odor, taste, and texture were the sensory attributes assessed for enriched and unenriched cookies. Particle size analysis determined that the most suitable particles to add were between 65 and 100 mesh. Indeed, cookies enriched with CAF at 10% showed a high rate of acceptability with respect to flavor (Matias and al., 2005). Uchoa et al. (2009) proposed others formulations of cookies with CABf at15 g/100 g substitution levels that gave a "very good'' global appearance ("most liked").

CABf was used as a source of fiber in cookies and the chemical composition of the cookies analyses showed that protein and carbohydrates decreased with the increase in CABf substitution levels (Ebere et al., 2015). At 10% of CABf, Akubor (2016) found an higher carbohydrate content than the 100% Wf biscuit contrary to the results found by Araújo et al. (2021). Microbiological analysis was also carried out on CAB cookies and a nonsignificant presence of microorganisms was detected (L. B. A. de Araújo et al., 2021).

Concerning the application of CAB in meat-based product, CAB from washed CA was used as a fat substitute in chicken meat patties (Guedes-Oliveira et al., 2016). The substitution of lipids with CAB aimed to reduce the total lipid content and overall energy value of the product because lipid content and energy value are correlated (Pinho et al., 2011). Guedes-Oliveira et al. (2016) found in their study that washed CAB added to chicken patties increased the cooking yield and did not negatively affect shortening and shear force values. Furthermore, appearance, texture, flavor, juiciness, and overall impression values of washed CAF added chicken patties were not different from control counterparts. In addition, the fiber-washing step eliminated the water-soluble tannins, thus canceling their negative effects. The purchase intent test, which assessed the consumer's willingness to purchase the product, showed that at least 70% of consumers would buy the formulated chicken patties. The substitution of fats by CAB did not negatively influence the physicochemical and sensory parameters of the chicken patties.

CABp was used to produce hamburgers with partial substitution of the meat. It was reported that the total dietary fiber value was between 0% and 7.66%, with a higher content of insoluble dietary fiber (Pinho et al., 2011). Rather et al. (2018) used CAB powder as a fat replacer in meat emulsions and it resulted in significantly higher emulsion stability, crude fiber content and oxidative stability.

Thus, CAB is a promising example of a tropical fruit that would be very interesting for commercial applications in the meat industry without forgetting that the use of CAB is economical (Rodrigues et al., 2008; Cristina dos Santos Lima et al., 2012).

Sucupira et al. (2020) analyzed the bioactive compounds of artisanal and industrialized CAB cooked using different cooking methods. The processing methods evaluated in their research demonstrated that frying is the best cooking method in terms of retaining the bioactive constituents after formulation of CAB "meatball"(CAB without meat).

CAB has been successfully used for jam formulation, by adding CA juice. Several formulations were tested but the formula with 5% CA juice had favorable sensory qualities. The study of the physical and chemical properties of the formulated product helped to promote CAB jam in the market (Nurerk & Junden, 2021).

The formulation of yogurt by adding CAB as a source of bioactive compounds has been studied. The results after the chemical, physical, physicochemical and sensory properties showed that the incorporation of 10% or 20% CAB extract gave a product accepted by the consumer (de Lima Mendes et al., 2019).

CAB, due to its beneficial nutritional potential, has been used as a biofortifying agent during the preparation of cereal-based extrudates. Enrichment of cereal extrudates was done by supplementing rice flour with CABf at 5–15%. The incorporation of CABf as an ingredient in the cereal based extrudates significantly improved their biochemical properties (Preethi et al., 2021). The treatment applied to the raw CAF before incorporation into the formulation of traditional dish allowed a reduction in acidity. The formulation with 10% and 15% of these CAF were the most accepted and were similar to the control food (traditional vatapá) (Portela, 2022).

Finally, the use of CAB reduces calories (Aderiye et al., 1992; Maciel, 2022). CAB provides a low calorific food, which is good enough for diabetic persons who require food with a low sugar content (Aderiye et al., 1992). Formulation with CAB decreased the pH, this acidity provided greater stability to the formulated products (Adegunwa et al., 2020; L. B. A. de Araújo et al., 2021; Maciel, 2022), making it difficult for microorganisms to grow, although this does not completely prevent food spoilage by fungi or bacteria during food processing.

The final product can also present an decreased lipid content (Guedes-Oliveira et al., 2016) and an increased amounts of ash, protein (Aderiye et al., 1992; Akubor, 2016; Preethi et al., 2021), starch, overall mineral content excluding phosphorous and boron content, flavonoids, phenolic, vitamin C (Preethi et al., 2021), carotenoid (Maciel, 2022), antioxidant activity (Maciel, 2022; Preethi et al., 2021), and crude fiber (Aderiye et al., 1992; Uchoa et al., 2009; Ebere et al., 2015; Akubor, 2016; Morais et al., 2018; Araújo et al., 2021).

Indeed, texture analyses showed that high dietary fiber content increased the product hardness and cohesiveness (Marques, 2018; Muniz et al., 2020). This crude fiber contains both soluble and insoluble dietary fiber. The soluble fibers have the function of keeping food in the stomach for a longer time due to a short transit of these foods in the small intestine. This phenomenon leads to slow absorption of nutrients, which is good for a person with diabetes and high cholesterol blood levels. While the insoluble fibers contained in these formulation will help the human digestive system (Chen et al., 2016; Nurerk & Junden, 2021).

However, fortification or making products from CAB should be carried out with caution, although it is a food rich in fiber and antioxidant compounds. Studies have shown that, lipid metabolism was impaired by integral CAF consumption, resulting in hyperlipidemia, hyperleptinemia, and increased abdominal fat in normal mice fed an isocaloric diet (Carvalho et al., 2018). According to these authors, to improve the physiological quality of CAF in order to use it as a functional food with potential health benefits, low molecular weight metabolites should be extracted. Another CAF consumption test without low molecular weight metabolites in normal mice with an isocaloric diet showed no changes in the animals lipid profile, in the abdominal adiposity and in leptin hormone. The results also showed a reduction in blood glucose, insulin and ghrelin hormone levels.

CAB, although it has beneficial effects on food formulations with important functional properties, also negatively influences the physical and structural properties of the final product (Preethi et al., 2021).

The incorporation of CABp in some formulation produced slightly darker products (Uchoa et al., 2009). Depending on the objectives to be achieved after the formulation of the feed, the quantity of CAB to be incorporated as well as the treatment before incorporation must be considered. For example, where the functional properties are of major concern, 20% or more incorporation of CAB is suggested, which will not be the case for the biochemical, physical and structural properties. In the latter case the quantity of CAB must be reduced and adapted because the nutritional composition of the formulated product could decrease with an increase in the amount of CAB (Ebere et al., 2015; Portela, 2022) and caloric value can also increase with increasing CAB (Morais et al., 2018).

Similarly, washing CAB will reduce the tannin content and astringency but will remove beneficial water-soluble bio compounds (Lima et al., 2017, 2018; Sucupira et al., 2020; Preethi et al., 2021; Maciel, 2022; Portela, 2022; Saldanha, 2022).

By-products of CA juice processing have the potential to be used as a vital source of nutritional and functional components in the composition of food products. That is an interesting alternative for the integral use of this fruit, allowing the growth of new food products and reducing processing waste. The product formulated with CAB is therefore hopeful for the consumer market.

## 7. Conclusion

All of the studies reviewed here highlight the nutritional potentials of the by-product of CA juice extraction that creates a lot of waste worldwide. CAB could contribute to meeting the nutritional challenges faced by today's world, by using it in new food formulations.

Different authors have found optimized methods to extract some compounds in CAB. These new technologies used to successfully extract CAB compounds are more rapid, with better extraction quality and efficiency. These techniques demonstrate an innovative and sustainable approach from a nutritional, environmental and economical point of view. In addition, the food applications of this by-product should be widely studied with caution because of the richness of several compounds, which are not necessarily beneficial for consumption.

Valorization of CAB to compensate its underutilization could lead to a wide variety of high value-added products. CAB has potential but also limiting factors that are slowing down its valuation. Notably the short shelf life of CA from which CAB comes, its acidity, its astringency, the deficiency of knowledge on CAB potential use in the food industry and the lack of simple and cost-effective strategies.

### 7.1. Future trends and research need

By 2020, the global nutraceutical market is expected to grow by 8% per year and reach a value of USD 263 billion (Jiménez-Moreno et al., 2020). The CAB could respond to these prospects. However, the use and application of CAB in the food industry will depend on several parameters, including the mode of addition of CAB in the food matrix (raw CAB or CAB extracts), the amount of CAB or bioactive component extract. The impact of external factors, such as heat, light, pressure must be considered during food processing.

Promising processing, efficient and selective extractions as well as quantification of its compounds is an innovative trend in food technology. The use of new sustainable extraction technologies such as extraction assisted by microwave, extraction with supercritical fluid, ultrasound-assisted extraction, extraction by homogenization, pressurized fluid extraction can be used for the selective extraction of a diverse range of bioactive compounds as food ingredient. Indeed, future research should be conducted to find the best extraction procedures to meet the requirements for food fortification and other applications. Nevertheless, before advertising and employing the CAB bioactive component for consumer use, the extracts must undergo an in vivo analysis to validate their bioactivity, stability, safety, and bioavailability. Specifically it would be interesting to include technologies ensuring the safety of formulated food products in the value chains with a view to avoiding toxic or allergic reactions in consumers due to the presence of tannins, alkaloids and unknown substances (Cruz Reina et al., 2022). However, these novel technologies are conjoined with an array of challenges, among which the two major remain the higher cost and the difficulties in scaling up to industrial standards (Jiménez-Moreno et al., 2020).

## Declaration of Competing Interest

The authors declare no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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