Ackee (Blighia Sapida KD Koenig) – A Review of Its Economic Importance, Bioactive Components, Associated Health Benefits and Commercial Applications

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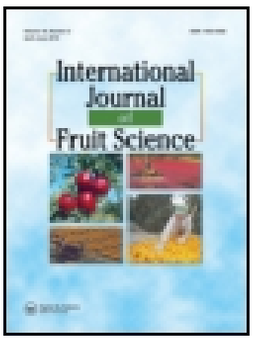

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Ackee (*Blighia Sapida* KD Koenig) - A Review of Its Economic Importance, Bioactive Components, Associated Health Benefits and Commercial Applications

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ABSTRACT

***Blighia sapida*:** (ackee) is the national fruit of Jamaica with origins in West Africa. It is considered an economically important crop to Jamaica with export earnings averaging about US $15 million annually. There is significant untapped potential for this fruit despite concerns regarding its consumption due to the presence of two toxins, hypoglycin A and hypoglycin B. Hypoglycin A decreases as the fruit matures whereas hypoglycin B is only present in the seeds which are discarded before the aril is prepared for consumption. Ackee is a particularly nutritious fruit due to it richness in bioactive compounds, vitamins, minerals, fats and proteins while being low in calories. These properties make it ideal for further commercialization and production of additional value-added products in the food, industrial and pharmaceutical sectors.

KEYWORDS
Ackees; hypoglycin; bioactives; commercial applications

Introduction

Blighia sapida or ackee as it is commonly known, is a native West African evergreen tree from the Sapindaceae family of angiosperms (Goldson, 2005; Lancashire, 2013). Although there is some uncertainty surrounding the introduction of ackees to Jamaica, several authors have stated that it was brought to the country by slave ships during the 18th century (Goldson, 2005; Mitchell et al., 2008; Lancashire, 2013). Since then, the fruit has become very popular among Jamaicans and has been declared the Country's National Fruit. A key ingredient in the Country's National Dish is saltfish which forms a part of the dish "ackee and saltfish" (Mitchell et al., 2008). Scholars believe that the name "ackee" may have origins in West Africa where the trees and fruits are referred to as "akye-fufuo", "ankye" (Goldson, 2005; Osei et al., 2014; Katibi et al., 2015; JIS, 2018). The ackee tree received its scientific name, *Blighia sapida*, in honor of Captain Bligh who brought samples of the Jamaican plant to the Royal Botanic Gardens in Kew, England in 1793 (Goldson, 2005; Mitchell et al., 2008; Lancashire, 2013). Ackees are widely grown in Jamaica with the main production areas being St. Elizabeth and Clarendon (Lancashire, 2013).

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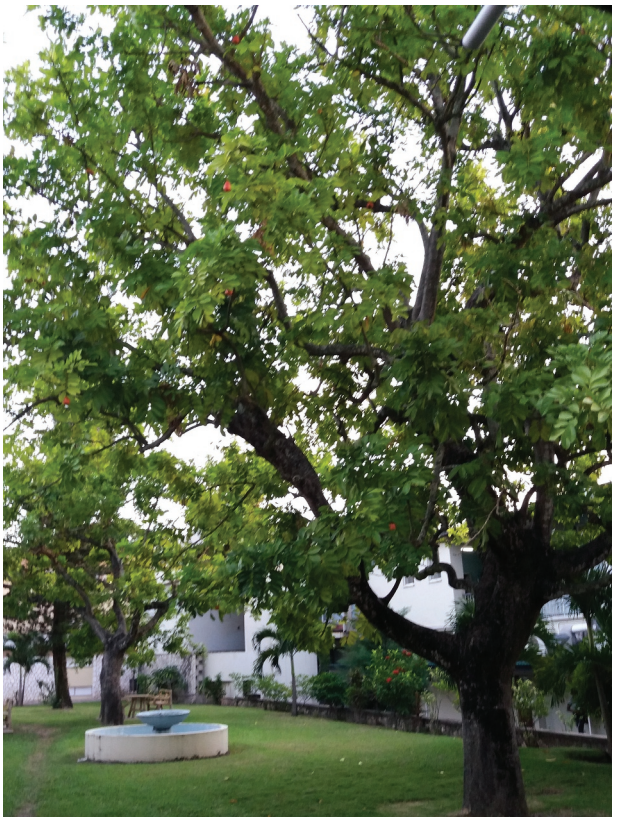


Figure 1. Ackee tree, University of the West Indies, Kingston, Jamaica.

The ackee plant produces fruits twice per year during the months of January to March and June to August in Jamaica (Lancashire, 2013). The average height of the typical ackee plant ranges from 7 to 25 m tall and the tree is usually highly branched (Mitchell et al., 2008; JIS, 2018) (Figure 1). The leaves of the plant are alternate and pinnately compound with three to five pairs of elliptical leaflets which are 6 to 18 cm long and 5 to 7 cm wide (Dutta, 1999; Rashford, 2001; Dossou, 2014) (Figure 2). The inflorescence is usually 3 to 7 inches long and may be described as racemose or having clusters of greenish-white fragrant flowers (Rashford, 2001; Dossou, 2014) (Figure 2). These small flowers are usually male or bisexual and insect pollinated (Dutta, 1999; Dossou, 2014).

The fruit is described as a capsule with color changes from green to yellow or red as its maturity increases (Figure 3) (Mitchell et al., 2008). As the fruit matures, the pod which ranges in size from 7.5 to 10 cm, splits open to expose the aril and the shiny black seeds (Mitchell et al., 2008; Dossou, 2014; JIS, 2018) (Figure 4). The seeds (1–3 cm long) are poisonous and should not be eaten. The aril or the yellow flesh of the mature ackee can be safely eaten once the fruit has matured and is fully opened (Mitchell et al., 2008). The mature pod contains

Figure 2. Ackee leaves and inflorescence or flowers.

Figure 3. Ackee at different stages of maturity.

three pegs on average. Mitchell et al. (2008) has however recorded instances where the pod was shown to contain two, four or even five pegs (Figure 5).

Ackee Varieties

In Jamaica, the recognized varieties are classified according to the color and consistency or texture of the arilli (Mitchell et al., 2008; JIS, 2018). Butter ackee

Figure 4. Mature, open ackee fruit.

Figure 5. Mature ackee pod containing four pegs.

is described as having soft yellow arilli while the cheese variety has hard cream-colored arilli (Mitchell et al., 2008; JIS, 2018). Hybridization of butter and cheese ackees has resulted in new varieties, however, the cheese variety is still considered as the better variety due to the hard texture of the aril when cooked.

A review of the available literature has revealed that significant research has been conducted on the fruit, particularly within Jamaica where it is considered an economically important crop. Research has been conducted worldwide on its bioactive components, the toxicity of the immature fruit for human consumption, commercial applications and potential development of value-added products (Mitchell et al., 2008; Bowen-Forbes and Minott, 2011; Goldson et al., 2014; Dossou et al., 2014; Asiamah, 2017; Grande-Tovar et al., 2019). Recent publications have presented additional findings or confirmation of historical data. This review however seeks to present a summary of important

information as well as discuss the nutritional composition, health benefits and application of the fruit in the development of value-added products.

Phytochemical Screening

Phytochemical screening of oven-dried and freeze-dried ackee arilli revealed that both samples contained glycosides and tannins while saponins were only detected in oven-dried arilli (Dossou et al., 2014). Dossou et al. (2014) anticipated the presence of other phytochemicals such as anthracene and cyanogenic glycosides, flavonoids, alkaloids and triterpenes. Their absence provides a positive indication of the edibility of the fruits when fully mature (Dossou et al., 2014). The pods also contain saponins (Mazzola et al., 2011; Goldson-Barnaby and Williams, 2016). Three complex saponins, blighosides A, B and C have been isolated from the pods of the ackee fruit (Mazzola et al., 2011). Blighoside A was the most abundant and is a tetrasaccharide containing rhamnose, glucose and two arabinose sugar units. Fourier transform infrared (FTIR) spectroscopy of aqueous extracts of the pods confirmed the presence of triterpenoidal saponins (Goldson-Barnaby and Williams, 2016).

Nutritional Composition and Bioactive Components

The ackee is widely consumed in Jamaica. It is normally prepared with codfish and seasoned with onions, tomatoes, escallion, salt and pepper. The meal may be served for breakfast or as a main course accompanied with ground provision or steamed rice. Nutritionally the ackee is a source of protein, carbohydrates and lipids (Tables 1 & 2). It also contains minerals and vitamins (Caribbean Food and Nutrition Institute (CFNI), 2000, Table 1). The fruit is unusual due to its high lipid content (Goldson et al., 2014). Additionally, it contains several bioactive components (Dossou et al., 2014; Goldson-Barnaby and Williams, 2017) and is low in calories.

Lipid Content and Fatty Acid Profile

The mature ackee fruit is a rich source of lipids (Goldson et al., 2014). There have been several reports on the fatty acid profile of the arilli of the fruit (Odutuga et al., 1992; Emanuel et al., 2013; Goldson et al., 2014; Grande-Tovar et al., 2019). Initial reports had cited linoleic acid as the primary fatty acid present (Odutuga et al., 1992). Subsequent studies from different researchers utilizing various analytical techniques have consistently detected oleic acid as the primary fatty acid present (Emanuel et al., 2013; Goldson et al., 2014; Grande-Tovar et al., 2019). Analytical techniques employed in analysis of the ackee aril oil which detected oleic acid as the primary fatty acid present were inclusive of gas chromatography, gas chromatography mass spectrometry,

Table 1. Nutritional composition of fresh and canned ackee (PAHO, 1998; USDA, 2019).

Nutrient	Fresh/100 g ([1]PAHO)	Canned/100 g ([1]PAHO)	Canned/100 g ([2]USDA)
Water (g)	57.6	76.7	-
Energy (kcal)	-	151	140
Energy (kj)	-	625	-
Protein (g)	8.75	2.9	4
Total Lipid (g)	3.45	15.2	9
Carbohydrate (g)	1.87	0.8	11
Fiber (g)	9.55	2.7	2
Sugars (g)	-	-	4
Potassium	-	270	-
Calcium (mg)	98	35	40
Iron (mg)	-	0.7	1.08
Sodium (mg)	-	240	125
Zinc (mg)	-	1	-
Thiamine (mg)	0.18	0.03	-
Riboflavin (mg)	3.74	0.07	-
Niacin (mg)	65	1.1	-
Folacin (µg)	-	41	-
Cyanocobalamin	-	0	-
Vitamin C (mg)	-	30	-
Vitamin A (IU)	-	-	500
Carotene (mg)	0.1	-	-
Fatty acids (g) (total saturated)	-	-	3.5

[1]PAHO: Pan American Health Organization.
[2]USDA: United States Department of Agriculture.

Table 2. Nutritional composition of oven dried and freeze dried ackees (Dossou et al., 2014).

Nutrient (%)	Oven Dried Arilli	Freeze Dried Arilli
Water	4.83 ± 0.02	5.20 ± 0.26
Energy	614.26 ± 1.61	590.67 ± 5.17
Protein	11.67 ± 0.37	10.94 ± 0.19
Total Lipid	56.66 ± 0.27	51.6 ± 2.23
Carbohydrate	14.41 ± 0.92	20.62 ± 3.61
Fiber	3.88 ± 0.14	3.63 ± 0.01
Ash	8.56 ± 0.44	8.01 ± 1.13

mass spectrometry, Fourier transform infrared spectroscopy and nuclear magnetic resonance spectroscopy (Emanuel et al., 2013; Goldson et al., 2014; Goldson-Barnaby et al., 2018). Other fatty acids detected in the arilli of the fruit included palmitic acid and stearic acid (Table 3, Goldson-Barnaby and Williams, 2017). Research conducted by Goldson et al. (2014) and Goldson-Barnaby et al. (2018) over different time periods and fruits from various locations across the island of Jamaica has consistently shown oleic acid as the major fatty acid present (Goldson et al., 2014; Goldson-Barnaby et al., 2018). Initial reports suggesting that linoleic acid was the primary fatty acid had sparked concerns that ackee may be a contributing factor to the high incidence of prostate cancer in Jamaica. Oleic acid, the major fatty acid present in the arilli is however associated with a decreased risk of prostate cancer (Goldson et al., 2014).

Table 3. Fatty acid profile (± SD; w/w) of ackee arilli and seeds (Goldson-Barnaby et al. 2017).

Fatty Acid	C:D	Aril	Seed
Palmitic acid	16:0	24.9 ± 8.1	4.5 ± 3.9
Stearic acid	18:0	11.2 ± 4.1	3.8 ± 1.9
Oleic acid	18:1	57.2 ± 8.8	13.7 ± 4.1
Linoleic acid	18:2	1.0 ± 0.2	ND
Arachidic acid	20:0	1.1 ± 0.5	28.7 ± 5.3
Gondoic acid	20:1	1.8 ± 1.3	48.4 ± 9.1
Behenic acid	22:0	ND	1.3 ± 0.3

Carotenoid Content and Antioxidant Activity

A study conducted on the carotenoid content and free radical scavenging activity of ackee aril oil found that it contained small quantities of carotenoids and exhibited free radical scavenging activity (Goldson-Barnaby et al., 2018). When the β-carotene content of ackee aril oil (21 ± 0.2 ppm) was compared to that of soybean oil (1.39 ± 0.1 ppm) and coconut oil (0.34 ± 0.1 ppm), two of the more popularly used oils within Jamaica, the ackee oil was found to be a better source of carotenoids as the others had only trace amounts (Goldson-Barnaby et al., 2018). Carotenoids are lipid soluble terpene derivatives which contribute to the yellow color and antioxidant properties of ackees (Goldson-Barnaby et al., 2018). Carotenoids are nutritionally significant as they are the plant form of vitamin A.

The free radical scavenging activity of the refined soybean oil with added antioxidants (100 %) was twice that of the unrefined ackee oil (48 ± 2.8 %). The activity of the ackee oil was however almost twice that of coconut oil (28 ± 7.1 %) (Goldson-Barnaby et al., 2018). Dossou et al. (2014) has conducted analyses on oven-dried and freeze-dried arilli and found that the antioxidant activity based on the DPPH inhibition method was 66.0 ± 6.8 and 29.4 ± 0.4 %, respectively. Although the reported amounts differ, both authors have proven that ackee contains antioxidants. It is possible that the variation in free radical scavenging activity is due to the processing methods – oil extraction, oven drying and freeze drying – as these may influence the quantity of bioactive compounds present in the finished product. In addition to the carotenoids present, the antioxidant properties of the ackee aril oil may also be due to the presence of phenolic compounds (Goldson-Barnaby et al., 2018). Methanolic extracts of the arilli and seeds of the fruit also exhibited free radical scavenging activity (arilli, 63.5% and seeds, 78.8 %, Goldson-Barnaby and Williams, 2017). It is therefore apparent that the antioxidant properties of the arilli are both from the aqueous and non-aqueous components within the fruit. Dossou et al. (2014) reported on the ascorbic acid and total phenolic content of oven-dried and freeze-dried ackee arilli. Freeze-dried arilli contained more vitamin C (35.7 mg/100 g) as compared to oven-dried arilli (29.6 mg/100 g). The

phenolic content of oven and freeze-dried samples was 5235 and 5174.4 mg GAE/100 g, respectively.

Carbohydrate Composition

Glucose, fructose, sucrose and short chain fructooligosaccharides were detected in the ackee arilli (Lopez and Benkeblia, 2017). FTIR analysis confirmed that sucrose is the predominant carbohydrate (Goldson-Barnaby and Williams, 2017). The seeds are rich in starch (Goldson-Barnaby and Williams, 2017). On a dry weight basis, the seeds contained 43.3% starch (Abiodun et al., 2015).

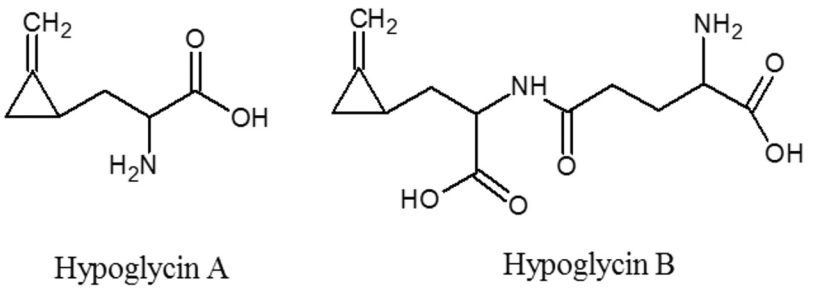
Ash and Mineral Content

Ackee arilli contained a higher percentage of ash (14.3 %) compared to the seeds (2.5 %) (Goldson-Barnaby and Williams, 2017) and is a source of the minerals, phosphorus, calcium, magnesium, potassium, sodium, iron and zinc (Dossou et al., 2014). A study conducted by Onuekwusi et al. (2014) quantified the minerals present in the seeds of the fruit. Potassium was present in the highest concentration, (16.6 ± 0.1 mg kg^{-1}), followed by sodium, (12.9 ± 0.5 mg kg^{-1}), phosphorus (7.1 ± 0.3 mg kg^{-1}) and zinc (3.1 ± 0.1 mg kg^{-1}).

Hypoglycin Toxicity

The toxicity of immature ackees is well documented (Gaillard et al., 2011). This characteristic feature of the fruit has been cited for its underutilization despite various articles speaking to the presence of other beneficial compounds which can be found in the mature fruit (Grande-Tovar et al., 2019). The toxic component of the fruit was first isolated in Jamaica by Hassall and Reyle (1955). The toxicity of ackees was attributed to the presence of two non-proteinogenic amino acids – hypoglycin A and hypoglycin B so named due to their ability to reduce blood glucose levels (Hassall and Reyle, 1955; Goldson, 2005; Mitchell et al., 2008). The structure of hypoglycin A was first elucidated by Carbon et al. (1958). Hypoglycin A is known as L-α-amino-β-methylene-cyclopropyl propionic acid while hypoglycin B is known as γ -L-glutamyl-α-amino-β-methylene cyclopropyl propionic acid or γ-glutamyl hypoglycin (Figure 6) (Bowen-Forbes and Minott, 2009; Gaillard et al., 2011; Goldson, 2005).

As the fruit matured the concentration of hypoglycin A in the arilli decreased from over 1000 ppm in the immature fruit to less than 0.1 ppm in fruits attaining full maturity (Brown et al., 1992). It has been postulated that hypoglycin A is translocated to the seeds of the fruit where it is converted to hypoglycin B (Bowen-Forbes and Minott, 2011). Ackee arilli with smaller seeds have been reported as having higher concentrations of hypoglycin



Hypoglycin A Hypoglycin B

Figure 6. Chemical toxicants found in ackee.

A (Dundee and Minott, 2012). The seed of the fruit contains the amino acids hydroxy-proline, glutamic acid, serine, glycine, threonine, alanine, histidine, arginine, tyrosine, valine, methionine, isoleucine, phenylalanine and lysine. Hypoglycin B is present in the highest concentration (106.0 ± 5.4 mg per 100 g) followed by histidine (44.5 ± 4.4 mg per 100 g) (Golden et al., 2002).

Research has shown that methylenecyclopropane acetyl CoA (MCPA-CoA) , a metabolite of hypoglycin A is the cause of ackee poisoning, Jamaican Vomiting Sickness or Toxic Hypoglycemic Syndrome (Goldson, 2005; Mitchell et al., 2008). Ackee poisoning occurs when the amine group of hypoglycin A is removed by the process of deamination to form methylene-cyclopropyl-alanine or MCPA which loses its carboxyl group by the process of oxidative decarboxylation to form MCPA-CoA (Goldson, 2005). Once formed, this metabolite inhibits the activities of coenzyme A dehydrogenase thereby causing a rapid reduction of the body's glucose content resulting in hypoglycemia or low blood sugar as coenzyme A dehydrogenase is essential for gluconeogenesis (Goldson, 2005).

The disease progressed around the 1880s and afflicted persons exhibited symptoms such as abdominal pain, nausea, vomiting, hypoglycemia with glycogen depletion within the liver, coma and death in extreme cases within 6 to 48 hours after ingestion (Goldson, 2005; Mitchell et al., 2008; Katibi et al., 2015). Treatment is usually through the administration of a sugar solution as well as providing symptomatic relief (Goldson, 2005; Katibi et al., 2015). With the rapid onset of the disease, it is important that the methods available for its detection be selective, specific and rapid. As such, there have been several improvements in the extraction and quantification of hypoglycin A and B since the compounds were first isolated.

Current methods of analysis are based on the aqueous extraction of hypoglycin A followed by derivatization with phenylisothiocyanate (PITC) or O-phthalaldehyde (OPA) at room temperature (Sarwar and Botting, 1994; Ware, 2002; Goldson, 2005). This results in the formation of the phenylthiocarbamyl or o-phthalaldehyde derivatives of hypoglycin A which allows for detection and analysis of minute quantities of the amino acid by reverse phase

high performance liquid chromatographic (HPLC) techniques (Sarwar and Botting, 1994; Ware, 2002; Goldson, 2005). Ion exchange chromatography has been utilized in the purification of hypoglycin B (Bowen-Forbes and Minott, 2009).

Local Ackee Industry

The major processing technique utilized for ackee is canning. Ackee processing facilities and orchards are located across the island of Jamaica. More orchards are needed to meet current export demands. For each acre, 72 trees can be planted yielding 144 boxes of canned fruit with each containing 24 tins (8 oz) of canned fruit. The ackee industry provides significant employment for the local population (Lambie, 2000). Currently it is estimated that the number of persons employed by the local industry is 90,000 (Lambie, 2000). Mature ackee fruits are harvested and delivered to processing facilities. Upon receival, the ackees are inspected, sorted and compared to the Ackee Maturity Index Chart that was published by the Bureau of Standards Jamaica in 2006 and which can be found affixed to the walls in the receival areas of many ackee processors throughout the country (BSJ, Bureau of Standards Jamaica, 2016). Mature unopened ackees which meet the acceptance criteria are racked and those which do not open within three days of racking are discarded by processors. The racking process allows the fruit to ripen and open naturally, thereby leading to lower levels of hypoglycin A due to its conversion to hypoglycin B in the seeds. The seeds and raphe (pink membrane) which attaches the aril to the capsule or pod is removed from ackees selected for processing. Arilli are washed in glacial acetic acid solution (0.1%), rinsed with potable water (residual chlorine, 3 to 5 ppm), drained, blanched, packed into cans of the desired size and filled with hot brine before seaming and retorting. The cooled cans are subsequently coded and labeled before storage or sale.

Within Jamaica, canned ackees are designated as a "prescribed food". Set standards must be adhered to when the food is being processed for export or sale on the domestic market. The mandatory Jamaican Standard Specification for processed ackees (JS 276:2016), states that the finished product shall be commercially sterile at 35°C and 55°C (BSJ, 2016) and that the concentration of hypoglycin A shall not exceed 150 ppm. Heavy metals such as tin, lead or arsenic which may be detected in the product should be less than or equal to 250, 2 or 1 ppm, respectively (BSJ, Bureau of Standards Jamaica, 2016). Currently, canned ackees with hypoglycin levels below 100 ppm are allowed entry into the United States of America. Those with 150 ppm or less can enter the Canadian and European markets.

Other Value-added Products

Despite concerns regarding hypoglycin A, there remains an untapped potential for the growth of the ackee industry. Freeze dried ackees are now commercially available and can be purchased via E-commerce. A visit to local supermarkets has shown that frozen ackee arilli are sold in vacuum packed pouches. Ackee patties (a pastry) may also be purchased from local fast food entities. Additionally, within the last 5–10 years, there has been the development and subsequent marketing of ackee wines on the domestic market. The ackee fruit therefore has potential for the development of other value-added products.

Proximate analyses of the ackee with a view toward the development of potential products such as flours made from arilli and seeds, oils made from arilli, chips from the arilli and lubricants from the seeds are being evaluated (Mitchell et al., 2008; Essuman et al., 2016; Famuwagun and Gbadamosi, 2016; Aloko et al., 2017; Goldson-Barnaby et al., 2018). This shows that researchers are actively seeking ways to capitalize on products that can be developed from the ackee. The data put forward by these researchers supports the commercialization of these products as a way of tapping into various markets and harnessing the nutrients and bioactive compounds that can be found in this fruit. They have also shown that if the fruit is harvested at the right maturity and properly processed then the value-added products that can be developed are endless.

Nonfood Commercial Applications

The ackee tree is resistant to termites. The wood therefore has the potential to be utilized to create furniture for use in areas that are prone to infestations (Mitchell et al., 2008). Additionally, research could be conducted on the properties of the fruit that imparts this insecticidal function with a view toward isolation and commercialization of a natural pesticide. The fruit has been shown to contain saponins which cause the fruits to foam or lather when placed in water (Mitchell et al., 2008; Goldson-Barnaby , 2016). This property of the fruit could be exploited for the creation of natural soaps which would be beneficial to the cosmetics and pharmaceutical industries. In Africa the pods are utilized in the laundering of clothes. The pods of the fruit also contain antioxidants and exhibit free radical scavenging activities (Goldson-Barnaby and Williams, 2016).

Ackee Exportation

Ackees are commercially significant in Jamaica. The country has been exporting canned ackees from the 1950's to Europe, Canada and the United States of

America (USA) (Mitchell et al., 2008; Goldson-Barnaby et al., 2018). Data from the Statistical Institute of Jamaica has shown that the country earned an average 15.5 USDmillion annually between 2012 and 2017 from the export of ackees (STATIN, 2018). The country recorded its highest export of approximately 21 USD million in 2016 and its lowest export of 12 USD million in 2014 (STATIN, 2018). An article published by the online edition of the Jamaica Observer dated Sunday June 4, 2017 predicts that the export of ackees will continue to grow within the coming years with export figures expected to increase to 29.25 USD million by the year 2020 (Bennett, 2017). Registered agro-processors whose plants are Hazard Analysis Critical Control Points (HACCP) certified can export canned ackees to the USA without automatic detention of the products at the ports of entries. Additionally, the advent of the Food Safety Modernization Act means that more stringent guidelines will be in place to prevent the entry of unsafe foods into the United States of America.

Conclusion

Ackees are an integral part of the Jamaican diet. This has given rise to the exportation of canned ackees to many areas populated by the Jamaican diaspora. It is however underutilized in other regions of the world due to concerns about the presence of hypoglycin A. Proper harvesting and preparation of the fruit is necessary prior to consumption to avoid any ill effects. Another challenge faced in Jamaica is the lack of adequate quantities of the fruit for processing. This may be addressed by the planting of more ackee orchards across the island. The Rural Agricultural Development Authority of Jamaica (RADA) has documented guidelines for the effective planting and management of the ackee tree which includes adequate weed control, fertilization and pruning of the tree. Based on the associated health benefits of ackees, steps can be taken to reduce its hypoglycin content by only utilizing mature fruits. Increased production of value-added products can be obtained from this underutilized crop. These products will have potential applications in the food, industrial and pharmaceutical sectors.

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