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Potential for Development of Novel Food Products from *Azanza garckeana* Tree Fruit: A Review

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Abstract

Azanza garckeana is among the least utilized indigenous wild fruit trees of interest in the arid and semi-arid regions of Africa. The tree's fruit and seeds have found their importance as food while their barks and leaves as medicine because of their vast nutritional and functional components. This paper reviews the utilization of the fruit in food processing demonstrating the potential this species has in the preparation of novel foods. There are few reports on macronutrients and micronutrient composition of the fruit and the seeds, and their utilization in food processing. Some researchers have identified key functional ingredients in the fruits as well as their seeds that could be of benefit when incorporated in the production of value-added food products. This paper not only advocates for the production of value-added food products from this fruit, but also its integration into farming systems to enhance nutritional security and provide ready income for communities in the dry areas in sub Saharan Africa.

Keywords: Wild tree fruits; Value addition; Functional ingredients; Dryland resources

1 Introduction

Indigenous fruit trees for which research is limited in Sub-Saharan Africa have accumulated considerable interest for their role in poverty reduction (Akinnifesi, Ajayi, Sileshi, Kadzere & Akinnifesi, 2007; Awodoyin et al., 2015; Shumsky, Hickey, Pelletier & Johns, 2014; Simitu, Jamnadass, Kindt, Kimiywe & Kungu, 2009). Many countries in this region have vast numbers of these trees that are mostly underexploited. Simitu et al. (2009), reported that Kenya has some 400 such indigenous fruit plants. These trees show great potential for providing food, micronutrients as well as income for smallholder farmers and their families thereby advancing the fight against the existing micronutrient deficiencies and food insecurity among populations in most developing countries, in especially mothers and children (Kehlenbeck, Asaah & Jamnadass, 2013; Motlhanka & Makhabu, 2011; Simitu et al., 2009).

Among the most widely used indigenous wild fruit trees of interest is *A. garckeana* (Bélair, Ichikawa, Wong & Mulongoy, 2010; Legwaila, Mojeremane, Madisa, Mmolotsi & Rampart, 2011; Packham, 1993). It is also referred by its synonym, *Thespesia garckeana*. It is a semi-deciduous tree, producing fruits with a rough and hairy bark. The fruit is greyish brown in colour and fibrous with longitudinal fissures. The fruit is sweet and edible, containing 15-30 seeds with brownish and woolly floss. The ripe fruit is available from December to March mostly from eastern and southern Africa from Sudan to South Africa. The plant is common in dry areas with

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limited rainfall ranging from 600-800 mm (Jamnadass et al., 2013; Maundu & Tengnas, 2005; Michael, Onyia & Jidauna, 2015). The fruit, bark and leaves are considered to be of great importance (Ochokwu, Dasuki & Oshoke, 2015). For instance, the rural semi-arid areas of Kenya rely on these indigenous fruits to supplement their diets (Kehlenbeck et al., 2015; Shumsky et al., 2014; Simitu et al., 2009). In addition, marketing surveys have revealed that *A. garckeana* already has commercial potential as it is sold in local markets (Akinnifesi et al., 2007; Krog, Theilade, Hansen & Ruffo, 2005; Muok, Owuor, Dawson, Were et al., 2000). Similarly, in Sudan, the fruit is processed and marketed for household income (Abass & Ahmed, 2017). In Botswana, it is a valuable edible indigenous fruit widely distributed and used to supplement local food (Legwaila et al., 2011; Ochokwu et al., 2015) whereas, in South Africa, the ripe fruit carpels are widely used for food as well as food additives (Maroyi, 2017; Mojeremane & Tshwenyane, 2004). Moreover, in Nigeria, it has a high social and economic value (Jacob, Shehu, Danbature & Karu, 2016; Ochokwu et al., 2015) while in Malawi, the nutritional value of the fruit is highly valued (Saka & Msonthi, 1994). Thus, this tree can be a great resource for the people living in the range lands. Nevertheless, there is limited information on its composition as well as its utilization in value addition of foods.

These fruits are excellent sources of both macronutrients and micronutrients. They have been reported to be high in fibre, total carbohydrates, protein level, ash and low in fat (Abass & Ahmed, 2017; Nkafamiya, Ardo, Osemeahon & Akinterinwa, 2016; Saka & Msonthi, 1994). Moreover, the amino acid profile presented by Nkafamiya et al. (2016) showed that *A. garckeana* can supply nine non-essential amino acids (alanine, arginine, aspartic acid, cysteine, glycine, glutamic acid, proline, serine and tyrosine) and eight essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine and valine). This shows that this fruit may be important in the fight against protein energy malnutrition (PEM). The fruits have been reported to have a variety of minerals including phosphorus, calcium, magnesium, iron, potassium, sodium, cobalt, copper, manganese and zinc (Abass & Ahmed, 2017; Danbature, Yirankinyuki, Magaji & Ibrahim, 2015; Jacob, Shehu et al., 2016; Nkafamiya et al., 2016; Saka & Msonthi, 1994; Suliman, Difa & Salih, 2012) as well as a vast amount of various vitamins, vitamin C (Danbature et al., 2015; Nkafamiya et al., 2016), vitamin A (Michael et al., 2015; Nkafamiya et al., 2016), vitamin B1, B2, and E (Nkafamiya et al., 2016). Furthermore, the fruit has been reported to have a remarkable composition of phytochemicals, including, alkaloids, flavonoids, tannins (Ahmed, El Hassan & El Hadi, 2016; Dikko, Khan, Tor-Anyiin, Anyam & Linus, 2016; Nkafamiya et al., 2016), steroids, terpenoids, saponins (Dikko et al., 2016), triterpenes and cumarins (Ahmed et al., 2016), most of which have a reported health effect. Furthermore, Michael et al. (2015) and Nkafamiya et al. (2016) reported *A. garckeana* seed to have 3.40% carotenoids and 75.00±0.23 mg/100 g Vitamin A, respectively. Therefore, their consumption has potential of preventing a wide range of deficiency diseases (Simitu et al., 2009). These results show the ability of this tree fruit to not only advance the fight against micronutrient deficiencies but also its ability to reduce PEM which has plagued the residents of sub-Saharan Africa and most developing countries around the world. Few researchers have tried to study the fruit's potential for application in the food industry. The production of juice has been attempted (Suliman et al., 2012) while its potential in the production of caramel colour has been demonstrated (Benhura, Mbuya & Machirori, 1999). Furthermore, its functional ingredients (Table 3) have been described showing a considerable array of nutrients (Ahmed et al., 2016; Danbature et al., 2015; Dikko et al., 2016; Nkafamiya et al., 2016; Ochokwu et al., 2015; Simitu et al., 2009) that are useful for supplementing food products, and also a range of antimicrobial constituents (Dikko et al., 2016) that are very useful and effective in food preservation. However, more research is needed to provide adequate nutrient databases to promote its utilization in food. According to Grivetti and Ogle (2000), the lack of adequate nutrient databases, due to limited and uneven compositional data, limits educational efforts to improve diets in many developing countries. Therefore, enhanced value addition and support of agroforestry is important. However, the promotion of wild trees for food has not been adequately fostered by countries and thus, as a consequence, they remain underutilized (Simitu et al., 2009). Farming *A. garckeana* will not only enhance the effort towards nutrition security but will also advance the battle against food insecurity through creation of value-added products as well as the creation of alternative sources of income for the people living in range lands. The aim of this review was to explore the nutritional value as well as value addition potential for *A. garckeana* in the food industry to guide efforts aimed at not only determining the quality characteristics of *A. garckeana* tree fruit, but also utilizing it among other edible wild fruit tree species in value addition of food products.

2 Fruit Composition

2.1 Macronutrients

There is limited research on the macronutrients composition of this fruit as shown in Table 1. Nevertheless, the fruits have been reported to be high in fibre, total carbohydrates, protein level, ash and low in fat. These values are comparable to other wild fruits; *Strychnos spinosea, Detarium microcarpum, Diospyros mespiliformis, Dialium guineese*, and *Gardenia ternifolia* whose moisture contents ranged between (6.17-10.70%); crude fat (2.04-8.85%); crude protein (5.16-6.80%); crude fiber (7.23-19.65%); Ash (3.46-5.56%); and carbohydrate (57.77-69.79%) (Jacob, Mann, Adeshina & Ndamitso, 2016). Nevertheless, despite the great variability, *A. garckeana* can provide more dietary fiber (36.0 - 45.5% dry weight), (Abass & Ahmed, 2017; Nkafamiya et al., 2016; Saka & Msonthi, 1994). The fibre content is also higher than that of baobab (*Adansonia digitate* L.) fruit pulp, another commonly consumed wild fruit, with a crude fibre of 8.68% (dry weight) recorded in Kenya (Muthai et al., 2017). Moreover, the amino acid profile presented by Nkafamiya et al. (2016) showed that *A. garckeana* can supply nine non-essential amino acids (alanine, arginine, aspartic acid, cysteine, glycine, glutamic acid, proline, serine and tyrosine) and eight essential amino acid (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine and valine). In their work, they reported a very high level of protein (12%). Therefore, *A. garckeana* has potential to advance the fight against PEM which has plagued the sub-Saharan Africa for generations (Bain et al., 2013). Most populations in these regions rely on highly deficient sources of food that has resulted in high and increasing prevalence of deficiency diseases (Harika, Faber, Samuel, Mulugeta et al., 2017). *A. garckeana* fruit can significantly contribute to reduced PEM by contributing significantly to the protein content and quality of the daily diets.

2.2 Micronutrients

The fruits have been reported to have a variety of minerals including phosphorus, calcium, magnesium, iron, potassium, sodium, cobalt, copper, manganese and zinc (Abass & Ahmed, 2017; Danbature et al., 2015; Jacob, Shehu et al., 2016; Nkafamiya et al., 2016; Saka & Msonthi, 1994; Suliman et al., 2012) as shown in Table 2. In addition, the fruit has also been reported to have a vast amount of various vitamins including vitamin A (Michael et al., 2015; Nkafamiya et al., 2016), ascorbic acid (23.664mg/100g) (Danbature et al., 2015), and vitamin B_1, B_2, C and E at 1.28±0.97, 1.18±0.45, 319.09±0.45 and 3.08±0.55 mg/100 g, respectively (Nkafamiya et al., 2016). Furthermore, Michael et al. (2015) and Nkafamiya et al. (2016) reported *A. garckeana* seed to have 3.4% carotenoids and 0.075% Vitamin A, respectively. Both mineral and vitamin analysis shows that *A. garckeana* could contribute a considerable amount of both micro and macro elements to human nutrition. The results show that the fruit has potential to help in the battle against the prevalence of vitamin A deficiency, as well as mineral deficiencies in sub-Saharan Africa. Based on RDI values (Joint FAO/ WHO expert committee, 2005), 100g of the fruit is able to supply sufficient levels of Vitamin B1, B2, and C to infants, adolescents and adult males and females per day. According to Jamnadass et al. (2013) consuming 100 g of *A. garckeana* fruit pulp can contribute approximately 50% of the vitamin C daily requirement of

Table 1: *Azanza garckeana* Fruit Macronutrient Composition

Region	Wet (W)/ Dry (D) basis	Moisture %	Dry matter %	Ash %	Crude protein %	Fat %	Fiber %	Total CHO %	Total Sugar %	Reference
Malawi	D	-	52.8	6.3	12.0	1.1	45.3	35.2	-	Saka and Msonthi (1994)
Sudan	W	13.542	-	7.3	10.05	1.04	45.524	22.444	-	Suliman, Difa and Salih (2012)
Nigeria	*	6.50	-	6.7	12.00	1.1	45.30	28.40	-	Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Sudan	D	-	84.92	4.04	6.65	1.81	36.00	87.65	61.39	Abass and Ahmed (2017)
Sudan	W	15.07	-	3.43	5.65	1.55	30.58	74.44	52.02	Abass and Ahmed (2017)
Average**	D		68.86±22.71	5.68±1.43	10.22±3.09	1.34±0.41	42.20±5.37	50.42±32.42	-	
	W	14.31±1.08	-	5.37±2.74	7.85±3.11	1.30±0.36	38.05±10.57	48.44±36.77	-	

* Not specified, ** Average was obtained from the values available in the respective columns.

Table 2: *Azanza garckeana* Fruit Mineral Composition

Region		Minerals (μg/g)										Reference
	P	Ca	Mg	Fe	K	Na	Co	Cu	Mn	Zn		
Malawi	D	1476	95	1453	84	26190	202	-	-	-	-	Saka and Msonthi (1994)
Sudan	D	-	560	-	60	13600	600	-	-	-	-	Suliman, Difa and Salih (2012)
Nigeria	D	300	1270	96250	120	-	-	0.2	4.5	0.2	120.2	Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Nigeria	D	-	40	1833.33	120	-	-	-	-	84.33	-	Jacob, Shehu, Danbature and Karu (2016)
Sudan	D	965	293	218	40	1860	52	-	4.3	4.3	-	Abass and Ahmed (2017)
	W	820	204.9	185	340	1808	44	-	3.7	3.7	-	Abass and Ahmed (2017)
Average*	D	913.7±589.7	451.6±500.8	24938.6±47545.9	84.8±35.7	13883.3±12167.5	284.7±283.2	-	4.4±0.1	29.6±47.4	-	

* Average was obtained from the values available in the respective columns.

an adult man. In addition, the fruits may contribute significantly to the daily requirements of both vitamins A and E. Nevertheless, the results indicate a wide variation in fruits composition, possibly because of the varied regions from where these studies were carried out as well as the possibility of analysis being carried out on fruits at different stages of maturity. Furthermore, the range of data determined for each one of the studies is also highly varied. There is therefore the need for more research on the composition of fruits of different regions, at similar harvesting or maturity periods for ease of comparison. Optimization of the harvesting period to facilitate the selection for and extraction of various fruit constituents is also important.

2.3 Functional components

Functional foods contain physiologically active constituents that provide an additional health benefit beyond basic nutrition. This may include some plants products containing proven and well documented physiologically active compounds that may improve human health and reduce the risk of chronic diseases (Choudhary & Tandon, 2009; Goldberg, 2012; Hasler, 2000; Milner, 1999; Reynolds & Martirosyan, 2016). These compounds with physiological activity are called phytochemicals (Johnson & Williamson, 2003). The fruit (flesh and seeds) of *A. garckeana* have been reported to have significant content of a variety of these substances (Table 3). Most researchers have reported presence of alkaloids, flavonoids and tannins in the fruit extracts (Ahmed et al., 2016; Dikko et al., 2016; Nkafamiya et al., 2016). In addition, steroids, terpenoids and saponins (Dikko et al., 2016), triterpenes and cumarins (Ahmed et al., 2016) have also been identified. Various researchers have reported their importance. For instance, alkaloids are used in the design of modern medicine as natural or modified compounds due to their proven enzyme inhibitory effects as well as their anticancer, anti-inflammatory, and antimicrobial activity (Aniszewski, 2007; Wansi, Devkota, Tshikalange & Kuete, 2013). In addition, tannins' antimicrobial activity on fungi, yeasts, bacteria, and viruses has been well documented. Tannins have also been reported to accelerate blood clotting process, reduce blood pressure, decrease the serum lipid level, and in modulating immune responses (Chung, Wong, Wei, Huang & Lin, 1998). On the other hand, steroids possess many documented medicinal, pharmaceutical and agrochemical activities like anti-tumour, immunosuppressive, antibacterial, as well as cytotoxic activity (Patel & Savjani, 2015). Generally, most of these phytochemicals have found great application in the design and manufacture of medicines (Adamu, Ushie, Lawal & Oga, 2013; Maroyi, 2011). Besides their application in medicine, in the food industry, these substances with antimicrobial effects can be utilized to achieve preservation in food products. According to Chung et al. (1998), the tannic acid has antimicrobial property and can therefore be used in food processing to increase the shelf-life of foods such as catfish fillets.

2.4 Microbial quality

Research has revealed the potential of *A. garckeana* fruit extracts to act as antimicrobials. In a recent study, methanol and ethyl acetate extracts containing flavonoids, steroids, terpenoids, saponins, alkaloids, reducing sugars and tannins were found to inhibit methicillin resistant *Staphylococcus aureus, Staphylococcus aureus, Pseudomonas aeruginosa, Candida krusei* and *Escherichia coli* (Dikko et al., 2016). Pathogenic ubiquitous microorganisms such as S. aureus have been attributed to many infections and intoxications involving many food products. Chung et al. (1998), reported that tannic acid could be used in preservation to increase the shelf-life of foods such as catfish fillets. Therefore, utilization of this fruit in food has potential to keep the food unadulterated or contaminated with pathogens. This has great potential in extending shelf life as well as enhancing food safety. Nevertheless, there is need to study the effectiveness of these antimicrobial substances in whole fruits as well as whole fruit formulations to determine their activities. Moreover, the characterization of the microbial profile of these fruits is required.

Table 3: Functional ingredients in *Azanza garckeana* tree fruit

Phytochemicals	Reference
Alkaloids*+	Adamu, Ushie, Lawal and Oga (2013), Ahmed, El Hassan and El Hadi (2016), Dikko, Khan, Tor-Anyiin, Anyam and Linus (2016), Michael, Onyia and Jidauna (2015), Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Tanninss*+	Adamu, Ushie, Lawal and Oga (2013), Ahmed, El Hassan and El Hadi (2016), Dikko, Khan, Tor-Anyiin, Anyam and Linus (2016), Michael, Onyia and Jidauna (2015), Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Steroids*	Dikko, Khan, Tor-Anyiin, Anyam and Linus (2016), Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Terpenoids*	Adamu, Ushie, Lawal and Oga (2013), Ahmed, El Hassan and El Hadi (2016), Dikko, Khan, Tor-Anyiin, Anyam and Linus (2016), Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Saponinss*+	Adamu, Ushie, Lawal and Oga (2013), Ahmed, El Hassan and El Hadi (2016), Dikko, Khan, Tor-Anyiin, Anyam and Linus (2016), Michael, Onyia and Jidauna (2015)
Cumarins*	Ahmed, El Hassan and El Hadi (2016)
Flavonoidss*+	Adamu, Ushie, Lawal and Oga (2013), Ahmed, El Hassan and El Hadi (2016), Dikko, Khan, Tor-Anyiin, Anyam and Linus (2016), Michael, Onyia and Jidauna (2015), Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Cardlac glycosides*	Nkafamiya, Ardo, Osemeahon and Akinterinwa (2016)
Phenolss*+	Adamu, Ushie, Lawal and Oga (2013), Michael, Onyia and Jidauna (2015)
Cyanogenic glucosides+	Michael, Onyia and Jidauna (2015)
Carotenoidss+	Michael, Onyia and Jidauna (2015)

*+ Reported in both fruit and seeds; + reported only in seeds

3 Protein energy malnutrition and Micronutrient deficiencies

Due to the vast levels of macro and micronutrients in wild fruits (Grivetti & Ogle, 2000), their role in value addition to deficient foods cannot be underestimated. The fruit is highly nutritious with high reported levels of beta carotene and iron. Some of these nutrients are deficient in the diet for most of the population that live in the arid and semi-arid areas of sub-Saharan Africa. According to Harika, Faber, Samuel, Kimiywe et al. (2017), in women aged between 15–49 years and pregnant women in Kenya, Ethiopia, Nigeria and South Africa, the prevalence of iron, zinc, iodine, folate and vitamin A deficiencies are very high. Moreover, high prevalence of anaemia, vitamin A, zinc, and iodine deficiencies are of public health significance in children living in these areas. The fruit was reported to contain a vast amount of ascorbic acid (28.5 mg/100g) (Jacob, Shehu et al., 2016) which is important in the fight against scurvy. The utilization of these fruits in food processing with the aim of providing deficient nutrients in processed food has potential in alleviating malnutrition especially PEM which is a major problem in developing countries (Bain et al., 2013). The amino acid profile presented by Nkafamiya et al. (2016), shows that the fruit's protein profile contains all essential amino acids except Tryptophan as well as 9 non-essential amino acids including alanine, arginine, aspartic acid, cysteine, glycine, glutamic acid, proline, serine and tyrosine. Nevertheless, since the addition of substances in the processing of foods may impact on the functionality of the various components of the food, more research is needed on the potential of utilizing this fruit in food formulations.

4 Food processing

4.1 Production of caramel colours

Controlled heat treatment of carbohydrates produces caramel, which can be utilized in various applications. Caramel colours have application in processed foods such as baked products and drinks (Sengar & Sharma, 2014). The mucilage from *A. garckeana* fruit can be extracted with water and the extract utilized in various ways. According to Benhura et al. (1999), the extract can be heated in the presence of ammonium salts causing the sugars present to form colours depending on the initial concentration of the mucilage. The result is a soluble caramelized material that can be used to impart colours ranging from pale golden to dark brown to liquids and semisolids. This has potential for wide application in juices, baked foods as well as in gums and candies not only for the colour but also the taste and nutritional composition. The utilization of caramel colours will reduce the utilization of synthetic ones which are associated with many complications (Sengar & Sharma, 2014). Furthermore, according to Benhura et al. (1999), the insoluble material obtained when mucilage from *A. garckeana* fruit is heated can be used to impart shades of brown colours to powders.

4.2 Production of sweets

A. garckeana fruit has been used in the manufacture of sweets with promising results. According to Abass and Ahmed (2017) it was used to produce a Turkish delight (Lokum) type sweet, a product made from starch and sugar. Owing to its ability to produce caramel colours (Benhura et al., 1999), the mucilage can be used in sweet formulations to achieve the desirable caramel colour and flavour.

4.3 Production of juice

Studies to determine the suitability of this fruit for juice production have been successfully done with promising results. According to Suliman et al. (2012) this fruit was successfully used to make juice having a pH value, total soluble solid and ascorbic acid contents of 5.48, 4.5% and 21.13 mg/100 g, respectively. In their research, sensory evaluation revealed that the overall acceptance was notable for *A. garckeana* fruits juice while moulds and yeasts were absent in the juices. However, despite the promising results, the total bacterial count found in the juice ranged from 1.20×10^7 to 1.72×10^6 CFU mL^{-1}. This calls for strict methodologies for processing to enhance safety as well as the shelf life of the product. As there is limited data on the utilization of this for juice making, more research inclined towards quality as well as safety of *A. garckeana* fruits drink is needed. In addition, more research is required on the microbial quality and safety of the resulting product.

4.4 Production of pectin

Pectins are naturally occurring biopolymers that can be used in various food applications. They have gelling, emulsifying, and film forming properties that are ideal for various processing systems and applications such as in the making of jams. The yield of pectin from *A. garckeana* fruits both dried and wet samples were in the ranges of 4.65 to 24.38 % and 9.82 to 26.75 %, respectively (Joel, Barminas, Riki, Yelwa & Edeh, 2018). Compared to other fruits such as *Adansonia digitate* L whose highest pectin content in fruits was reported as 2.56 %, *A. garckeana* fruit has very high levels. This makes it suitable for the production of pectin for commercial use. The addition of this fruit to jam formulations has the potential to enhance the gelling properties of such formulations as well as the nutritional quality of these products. In addition, being resistant to degradation in the upper gastrointestinal tract, it may be ideal for use in enhancing the growth of probiotic bacteria in the body as a prebiotic (Gomez, Gullon, Yanez, Schols & Alonso, 2016). Therefore, *A. garckeana* fruit can be ideal in the design of symbiotic products.

5 Integration into farming systems

Despite their wide natural occurrence in dry areas, *A. garckeana* trees can be integrated into farming systems to support the nutritional security and income of communities (Simitu et al., 2009). This is because these trees have potential for domestication. In Nigeria, an attempt has been made to integrate this plant into farming systems (Ochokwu et al., 2015). However, the promotion of wild trees has not been adequately fostered by agricultural and forestry institutions and thus, as a consequence, they remain underutilized (Simitu et al., 2009). Thus, there is need to promote the domestication and commercialization of under-utilized tree products (Leakey, 1999). The domestication of *A. garckeana* trees for agroforestry has potential for not only poverty alleviation but also environmental rehabilitation in sub-Saharan Africa. However, this will largely depend on the expansion of the market demand for its value-added products. Hence, the need for value addition of *A. garckeana* tree resources.

6 Recommendations and future prospects

Millions of people in especially the developing countries depend on food from wild tree species to supplement their diets. Thus, wild tree species contribute significantly to human nutrition. However, many of these tree species are still unknown or underutilized despite their potential for value addition and commercialization. With the increasing world population, more sources of human food are required. One important source is the wild fruit trees that have not been utilized or commercialized. Besides food security, nutrition security is also a global problem that will require the exploration of new sources of food nutrients. Listed below is a summary of the challenges and way forward in enhancing utilization of *A. garckeana* tree fruit:

- Few studies have been launched to characterize the edible wild tree products to determine their commercial potential. Thus, there is lack of adequate nutrient database for *A. garckeana* tree fruit. The data on fruit composition is very minimal and highly variable and influenced by the region. Researchers who have analysed this fruit targeted certain nutrients. As a result, data on other nutrients is highly limited or unavailable. Thus, there is need to analyse the fruit from different regions to provide sufficient data to inform the probable fruit nutritional quality. Furthermore, to obtain uniform data for ease of comparison, the period of harvest or maturity has to be taken into account during sampling of fruits.
- The development of any tree fruit occurs gradually with many physiological changes taking place. As a result, the concentration of different fruit components also changes gradually over time with each component reaching its highest concentration at a particular time. The optimal time for extraction of these components may therefore not be the same. The determination of the ideal time for harvesting and processing is also important in the extraction of different components. A study targeting the extraction of these functional substances and determining the optimal harvesting time for highest yield for each one is therefore important.
- Despite the promising nutritional and functional quality of the fruit, minimal research exists on value added products containing these fruits. Moreover, the potential for consumption of *A. garckeana* fruit seeds as well as tree leaves has received minimal attention. Only production of juice has been attempted although potential for use as a colouring agent has been demonstrated. In addition, there were no studies found on enrichment of food despite the vast nutrient composition reported. Utilisation of this fruit in many processes in food will inform on the functionality of the various nutrients during processing. Furthermore, some of the constituents that have functional properties may be investigated to determine their

mechanisms of action and safety in food products. This information may be useful for advancing research studies on application of *A. garckeana* fruit in other food products. Discovering new avenues for utilization of this fruit will not only help in the fight against food and nutrient insecurity but also help in improving the livelihoods for actors in the fruit value chain through increased household incomes.

- The contribution of wild food tree species including *A. garckeana* to human nutrition among the rural poor in different developing countries should be quantified. There is need to determine the contribution of these tree species to daily nutrient intake to better determine their potential in reducing food and nutrition insecurity.

- Despite the usefulness of wild fruit trees as sources of nutrition for millions of people in the developing countries, many of these tree species are still harvested from the wild, with little attempts on on-farm management. Despite its usefulness, limited attempts have been made towards domestication of *A. garckeana*. Furthermore, many of these tree species are only known locally in their respective regions with minimal utilization and commercialization. Thus, there is need for increased public awareness on wild fruit trees that can potentially influence the lives of people living in these arid and semi-arid areas. Research targeting food tree domestication is therefore encouraged. On-farm management and improvement of these wild tree species has potential for enhanced utilization and quality of these tree resources. Furthermore, they may contribute significantly to increased plant cover on earth as well as in soil conservation, which are important in climate change adaptation and mitigation.

7 Conclusions

Clearly, there is limited information on *A. garckeana* tree fruit despite its potential for utilization in the food industry. Currently published research on the *A. garckeana* fruit shows promising results as some of the nutrients identified may be useful in the battle against food and nutrition insecurity in the developing countries. Further research is required to characterize *A. garckeana* fruit to unravel its utility as a source of important food nutrients and functional constituents useful in the food industry.

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