African Pear (*Dacoryodes edulis* (G.Don) H.J.Lam) Physical Characteristics, Nutritional Properties and Postharvest Management: A Review

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Summary

African pear (*Dacoryodes edulis* (G.Don) H.J.Lam), is an underutilized tropical fruit tree, native to Central and West Africa. Its edible fruit has a high nutritional value; it is a source of protein, micronutrients, monosaturated fatty acids and high oil content, and thus has a high economic potential. There is ongoing research to select optimum varieties from the wild for cultivation in agroforestry system. The high perishability of African pear is also a major drawback to its exploitation. The increased demand at national and international level in the last decades has motivated researchers to search for solution to extend its shelf life and minimise postharvest loss. This review includes varieties identification challenges, nutritional composition and health benefits of fruit from different origins as well as some contribution on postharvest management of African pear.

Key words

African pear, monounsaturated fatty acid, morphological traits, postharvest, transformation, underutilized crop

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Introduction

The rising concerns for food security in the recent years have pushed governments and the research community to pay more attention to nonconventional and underutilized crops. Nonconventional crops can help increase the diversification of food production, adding new species to our diets that can result in better supply of particular nutrients, or increase access to sufficient, safe and nutritious food that fulfills the dietary needs for an active and healthy life (FAO, 2013). In addition, most of those crops provide economic and environmental benefits as they can be used to generate income and can be grown as part of crop systems to protect and enhance agro-biodiversity at the field level (Chivenge et al., 2015). African pear (*Dacryodes edulis* (G.Don) H.J.Lam) has been listed by FAO (2017) as one of the underutilized fruits contributing to biodiversity. In Cameroon, African pear trees are integrated within cocoa-coffee agroforests as a means of diversification (Rimlinger et al., 2018). It is an emerging economic fruit tree, with the potential to contribute to poverty alleviation in the countries where it is grown, if fully exploited (Noumi et al., 2014).

D. edulis is a tropical fruit tree that belongs to the family of Burseraceae. It is native to Africa and stretches along the Atlantic in five countries, namely Congo, Gabon, Equatorial Guinea, Cameroon and Nigeria (Todou et al., 2013). It has been domesticated in other African countries. It is an evergreen tree of 18-40m height, with alternate compound leaves consisting of 5-8 pairs of leaflets (Fig. 1) and yellow flowers (Mbagwu et al., 2008; Ajibesin, 2011). Flowering takes place from January to April and the fruiting season is between May and October (Owono et al., 2002; Ajibesin, 2011).

Figure 1. *Dacoryodes edulis* tree with immature fruits

The main use of *D. edulis* is its fruit. It is known as 'Safou' in French, 'African plum' or 'Atanga' in Central Africa, 'Ube (Ibo)' and 'Elemi (Yoruba)' in Nigeria. It can be eaten raw, boiled or roasted; when cooked it has a texture similar to butter and it is used in garnishing cooked Cassava, roasted maize or as butter in bread (Duru et al., 2012). Just like many other underutilised plants, African pear is a multipurpose tree. Other than fresh fruit consumption, the oil extracted from the pulp has been found to have good properties as frying oil (Ondo-Azi et al., 2014) and as substitutes to butter in baking (Akusu et al., 2019; Eyenga et al., 2020). Authors have also suggested the use of oil from the pulp and seed in pharmaceutical and cosmetic industries (Nwosuagwu et al., 2009; Amise et al., 2016; Enengedi et al., 2019), as well as biodiesel feedstock (Ogunsuyi, 2015). The leaves, the bark and root of the tree are used for medicinal purposes to treat various ailments such as wound, skin disease, dysentery, and fever (Omonhinmin, 2012; Miguel et al., 2017). The current review will focus mainly on African pear morphological diversity, nutritional value and postharvest management.

Fruit Morphology

The fruit is an ellipsoidal drupe, and the size varies approximately from 4- 9cm in length and from 2 to 5cm wide depending on the origin and the variety (Youmbi et al., 2010; Poligui et al., 2013; Kadji et al., 2016). The young fruit has a thin pink exocarp that turns blue-green, purple or shining black when mature; and the fruit pulp thickness varies between 1.6-9 mm (Youmbi et al., 2010; Kadji et al., 2016). There is not clear differentiation between African pear varieties or accessions (Fig. 2 and Fig. 3). Some authors (Ibanga and Okon, 2009; Poligui et al., 2013; Kadji et al, 2016; Djedje et al. 2020) have conveniently used the classification suggested by Okafor (1983), who identified two varieties based mainly on the size of fruit; *D. edulis* var. *edulis* (large fruit generally more than 5 x 2.5 cm, with a thick pulp about 3.5-9 mm) and *D. edulis* var. *parvicarpa* (fruit normally less than 5 x 2.5 cm, with a thin pulp about 2-3.5 mm). In a study by Youmbi et al. (2010, Cameroon), three main groups were defined by principal component analysis and hierarchical classification when analyses were done on morphological (~ 17) and physiological (colour, texture and taste) traits; the number of groups did not change when chemical characteristics (proximate analysis, phenols, amino acids) were included in the analysis. In an earlier study (Ndindeng et al., 2008), where physiological criteria such as the colour of the skin and the pulp, the uniformity of the colour of the skin at full maturity and the level of acidity were evaluated in addition to size, nine groups were defined. A similar study in Gabon revealed nine classes based on 3 morphological traits (mass, length and width) and chemical characteristics (proximate analysis and fatty acid composition) (Ondo-Azi et al., 2014). It is argued that the high level of tree-to-tree variation in fruit morphological traits is due to intra- and inter-specific variations found in other indigenous trees (Anegbeh et al., 2005; Youmbi et al., 2010). It is clear from these findings that more work is needed to classify African pear trees. Studies must be conducted using the most reliable criteria, such as genetic markers to confirm that the identified morphological and physio-chemical classes correspond indeed to varieties of *D. edulis*.

Figure 2. Accessions of *Dacoryodes edulis* found in Cameroon at different maturity stages

Figure 3. Cross section of different accessions showing pulp thickness; pulp length and seed size

Nutritional Composition of *D. edulis* Pulp

Proximate Analysis and Minerals

The chemical composition of African pear varies between countries (Table 1) and also within region, although the difference may not always be significant. The moisture content varies from 30-60%. Moisture in fruits is involved in several biochemical and physiological reactions and it also has a major influence on fruit shelf life (Arah et al., 2016; Yahaya and Mardiyya, 2019). The lipid content ranges from 18-62%. However, most studies reported a percentage above 30% which is considerably higher in comparison to that of avocado (Ikhuoria and Maliki, 2007; Enengedi et al., 2019). The protein and carbohydrate content varied from 2-19%, 1-23% respectively. Crude fibres and ash content were generally between 1-3%. Other factors such as the method of analysis, the maturity level of the fruit could contribute to the inconsistency of results in studies (Stadlmayr et al., 2013; Kadji et al., 2016; Ano et al., 2018). Duru et al. (2012) reported that with the development of dark colour in fruit exocarp or peel, a decrease in ash and crude fibers, and an increase in moisture and carbohydrate content was observed, while protein content remained relatively the same. In disagreement with the latter study, a decrease in water and carbohydrate content and an increase in oil, protein, ash and crude fibres was observed in the previous study by Nwosuagwu et al. (2009). Similar observations were made by other authors (Kinkéla et al., 2006; Fonteh et al., 2005).

Fruit chemical characteristics variability can also be explained by environmental factors such as soil type, climate, farming practices and fertiliser application. Youmbi et al. (2010) assessed fruit from five localities with different geographical coordinates and annual rainfall in Cameroon; they found that accession from Kekem had a significantly higher content of lipid (43.83%) compared to other localities (29-34%); the accession from Djombe had the significantly highest content in sugars (8.71%) in comparison to the four other localities (5.9-5.37%) and the accession from Makenene had the significantly highest content in protein (4.45%), while ,the protein content from other localities varied from 2.03 to 3.26%. In this study, variation between the moisture content percentage (28.14-31.00%) was minor with the exception Djombe (24.63%) that had the significantly lowest water content. According to the hierarchical classification, accession from the fifth location (Bomyebel, 650m latitude) appears to be closer to that of Djombe (80m latitude). It is to be noted that these two locations have similar annual rainfall (~ 2800mm) but differ in latitude.

Table 1. Proximate analysis of African pear (*Dacoryodes edulis*) pulp from different origins

Origin	Moisture content (%)	Lipid (%)	Protein (%)	Ash (%)	Crude fibre (%)	Carbohydrate (%)	References
Gabon	41.47	35.95	3.32	2.95	2.72	13.61	Djedje et al., 2020
Nigeria	32.1	31.5	8.25	2.6	2.1	23.14	Duru et al., 2012
Nigeria	45.99	30.14	15.48	1.2	–	6.18	Onuegbu et al.,2008
Nigeria	51.77	33.46	2.18	0.79	3.45	8.6	Odo and Ibiam, 2013
Nigeria	44.45	35.6	3.03	2.76	1.57	12.56	Omogbai and Ojeaburu, 2010
Nigeria	44.4	34.44	3.37	2.59	1.45	11.73	Ogwu et al., 2016
Cameroon	59.1	38.46	7.76	4.26	–	–	Fonteh et al., 2005
Cameroon	41.85	63.64	8.615	–	4.75	18.8	Eyenga et al., 2020
Average	45.43±8.59	37.40±10.62	6.59±4.45	2.45±1.15	2.67±1.26	13.51±5.81	

A similar observation was made by Ondo-Azi et al. (2014), who reported a high tree-to tree chemical characteristics variation after assessing 213 trees from home gardens in Franceville, Gabon. Contrary to these authors, Kadji et al. (2016) found no significant difference between fruit collected from three localities in the south-east of Côte d'Ivoire. The above studies also imply that the chemical composition may also be influenced by genetic makeup of each tree. The high protein and carbohydrate content suggest that African pear can significantly contribute to reducing protein malnutrition and it is a good source of energy. Accessions with high oil content will be more economical if processed as vegetable oil or used as alternative for butter in baking (Akusu et al., 2019; Eyenga et al., 2020)

African pear is rich in micronutrient and minerals (Table 2). Just like with the proximate analysis the concentration of each mineral varies from one study to another. In some studies (Odo and Ibiam, 2013; Omogbai and Ojeaburu, 2010) phosphorous was found to have the highest concentration while it was not detected in others. Calcium is reported to be the most abundant mineral by several authors. Sodium and potassium are also present in relatively high concentration; other micronutrients include magnesium, zinc, iron and copper. These minerals are important to health and when present even in trace are important for physiological functions of tissues and regulate many biochemical processes. A deficiency in phosphorus and potassium can cause muscle weakness and high risk of kidney stones respectively (Fairweather-Tait and Cashman 2015). Calcium is used in the body to build bones, teeth, blood and nervous system (Pravina et al., 2012). Iron deficiency can lead to anemia and increased maternal and infant mortality (Celep et al., 2017). Copper helps maintain bone structures and contributes to wound healing, while deficiency in zinc causes growth retardation and skin lesions (Fairweather and Cashman, 2015). A comparison study revealed that African pear had a high oil and carbohydrate content and high concentration of most minerals and a slightly lower content in protein and crude fibres than avocado (Table 2). The concentration of vitamin C and E in African pear is relatively high and comparable to that of avocado (Ngozi-Olehi et al., 2012; Odo and Ibiam, 2013).

The presence of other bioactive compounds (β-caroten, sterols, flavonoids, caffeine and squalene) in this fruit has been reported (Duru et al., 2012; Ene-Obonga et al., 2019) The levels of anti-nutrients such as cyanides (0.004-0.05 mg/100g), oxalates (4.9-13.4 mg/100g), phytates (1.41-1.58 mg/100g), tannins (0.76-3.10 mg/100g) in African pear pulp have been found to be lower in comparison to those of many other crops including peanuts, chick peas, beans, nightshades (Ibanga et al., 2009; Omogbai

Table 2. Prominent minerals element of African pear (*Dacoryodes edulis*) pulp from different origins (mg·100 g^{-1})

References	Calcium (Ca)	Potassium (K)	Sodium (Na)	Magnesium (Mg)	Iron (Fe)	Manganese (Mn)	Zinc (Zn)	Phosphorous (P)	Copper (Cu)
Kadji et al., 2016	130.77	55.24	10.80	7.20	0.85	2.63	13.33		
Omogbai and Ojeaburu. 2010	350.24	546.45	168.31	285.80	3.50		3.76	667.14	0.42
Ene-bong et al., 2019	10-88	392-1013	10-21		2.6-7.5		0.64-4.58	8-36	0.62-1.5
Eyenga et al, 2020	125.00	819.00	3.00	135.00	2.26	1.04	0.99	12.60	1.78
Odo and Ibiam. 2013	82.83	86.42	246.83	249.43	N.D	5.90	1.80	510.25	1.80
Ajayi and Adesanwo. 2009	4.97	195.21	298.07	240.30	ND	3.88	8.08	35.43	6.24

and Ojeaburu, 2010, Duru et al., 2012; Popova and Mihaylova, 2019). Antinutrients are known to interfere with the absorption of nutrients and may reduce nutrient digestion and utilization; their presence in high concentration may elicit harmful biological responses (Popova and Mihaylova, 2019).

Fatty Acid Composition

Palmitic acid, stearic acid, oleic acid, and linoleic acid are the principal fatty acids found in African pear pulp and constitute more than 90% of the oil (Table 3). The variation between samples or accessions cannot be emphasized enough, but generally, palmitic acid (15-48%) and oleic acid (13-40%) are the most abundant, followed by linoleic acid (17-28%) and stearic acid (2.1-15%). Saturated fatty acids such as palmitic acid and stearic acid influence cholesterol and triacylglycerol biosynthesis, lipoprotein assembly and metabolism as well as inflammation process. Thus, they play important roles in cellular and tissue metabolism and function, but if present in excess, increase the risk of cardiometabolic diseases (Calder et al., 2015). Monounsaturated fatty acid (oleic acid) has been shown to lower blood pressure and may also improve glucose control and insulin sensitivity, and lower the risk of cardiovascular events (Schwingshackl and Hoffmann, 2014; Calder, 2015). Ikhuoria and Maliki (2007) found that African pear had more oleic, palmitic, and linoleic acids than avocado. Similar observation was made by Kapseu (2009), with the exception that oleic acid was lower in African pear samples compared to avocado. It is to be noted that palmitoleic acid is one of the major fatty acids in avocado while it is only found in traces in Africa pear, and stearic acid is absent in avocado. The overall percentage of saturated and unsaturated fatty acids in African pear is estimated to ~ 42.5 and ~57.5%, and in avocado ~28 and ~72%, respectively (Ikhuoria and Maliki, 2007; Kapseu, 2009). The fatty acid composition makes both oils more attractive as vegetable oils and display greater oxidative stability due to the high content in oleic acid (Kapseu, 2009; Flores et al, 2019).

Postharvest Management and Value Added Product

A major setback in the commercialization of most fruits is the perishability within a short period (Fig. 4). African pear has been commercialized beyond the borders of Central African countries and in specialised market in Europe. Although no recent economic study could be found, studies estimated 11,000 tonnes worth US$7.5 million sold to domestic and export markets in Cameroon (Owona, 2002), and export to Europe (France, Britain and Belgium) from Central African countries and Nigeria was estimated to over 326 tonnes, with a value of over US$2 million in 1999 (Tabuna, 2000). Although researchers have made progress in the last decade, scientific information on African pear postharvest management is still limited. Its softening starts from about three to five days after the fruit have been detached from the tree (Noumi et al., 2006; Djedje et al., 2020). Postharvest losses of African pear of up to even 50% have been reported (Silou et al., 2007; Mayele, 2010).

In terms of traditional storage, in Cameroon farmers usually spray in fruit a monolayer on a dry surface in a room with enough ventilation or usually insert lemon fruit in African pear basket to extent the shelf life (Noumi et al., 2006). The increase in shelf life of African pear mixed with citron can be related to antimicrobial properties of essential oils in lemon peels (Ndindeng et al., 2007;

Table 3. Common fatty acid found in African pear (*Dacoryodes edulis*) and avocado pulp oil from different origins

	Country of origin	Palmitic acid (%)	Stearic acid (%)	oleic acid (%)	Linolenic acid (%)	References
African pear	Gabon	42.84	2.85	19.84	0.77	Ondo-Azi et al., 2014
	Benin	9.06	15.46	30.85		Ikhuoria and Maliki. 2007
	Nigeria	17.18	14.84	40.45	23.17	Ajayi and Adesanwo. 2009
	Nigeria	48.75	4.96	28.57	1.65	Ezekkwesili and Eneh, 2014
	Nigeria	47.5	2.1	31.3	17.5	Dzondo-Gadet et al., 2005
	Congo	48.8	2.6	20.6	1.7	Kinkela et al., 2006
	Congo	44.5	_	33.5	18.5	Dzondo-Gadet et al., 2005
	Cameroon	43.74	2.21	22.62	1.37	Noumi et al., 2014
	Cameroon	39	3.7	31	24.9	Kapseu, 2009
	Mean ± SD	35.95 ± 14.72	5.73 ± 5.8	28.063 ± 6.24	12.71 ± 11.05	
Avocado	Benin	7.22	12.86	22	24.79	Ikhuoria and Maliki., 2007
	Cameroon	24.8		53.6	14.5	Kapseu., 2009
	Chilie, Australia. Mexico, New Zealand, United states	13.7-25.63	_	42.59-67.4	10.64-20.87	Flores et al., 2019

Figure 4. Fruit deterioration due to poor pre- and post– harvest management

Moosavy et al., 2017). In the Democratic Republic of Congo, the fruits are stored in basket and covered with leaves (e.g. *Maprounea africana* Müll.Arg) and can be kept for five days, while in Gabon fruits and leaves of African pear are mixed in the basket (Poligui et al., 2013). However, there is limited scientific evidence supporting the application of these methods.

Modern methods have also been explored to reduce African pear postharvest losses. Kengué (2006) suggested that fruits could be preserved for more than a week if stored at 4°C. Fruit softening started after 7-8 days after harvest when the fruit were kept in air-conditioned room (16-20°C) in comparison to 2-3 days at ambient temperature (Silou et al., 2007). This finding was further supported by Ijabo et al. (2012) who suggested 20°C as the best temperature for African pear storage. Dossou et al. (2012) conducted a detailed study on factors affecting African pear postharvest preservation; the factors included fruit size, ripeness stage, picking mode, packaging mode, and storage temperature. They found that ripeness stage and picking mode did not significantly affect fruit softening. Storage temperature and packaging mode had the most significant effects on African pear texture. Fruits stored without packaging and those stored in perforated packaging exhibited similar softening patterns, reaching the highest peak after 4 and 6 days at 28°C and 36°C respectively, and after 8 days at 18°C. Fruits stored in sealed packages showed a significant increase in softening from two days of storage at 28°C and 36°C and those stored at 18°C also maintained a good texture up until 8 days. This study suggests that African pear can maintain its firmness for longer when stored without packaging or in perforated packaging at temperatures below 20°C. Sealed packaging accelerates post-harvest spoilage, which is probably due to the accumulation of ethylene following the restriction of free movement of gas through the package (Doussou et al., 2018; Yahaya and Mardiyya, 2019). In the latter study it was also found that larger fruits soften faster in comparison to the smaller ones. This finding was supported by the recent study done in the same laboratory (Doussou et al., 2018); but is contradictory with the study of Ijabo et al. (2012) where no significant difference was found between fruits of different sizes.

The application of fungicide treatment and ethylene inhibitor has also been explored to minimise postharvest loss in *D. edulis*. Ndindeng et al. (2007) found that the application of 1-methylcyclopropene (1-MCP) at 500-625 ppb helped maintain the quality of the fruit for up to 8 days of storage at room temperature, and combining 1-MCP and benomyl minimised fungal growth to 5% compared to 15% with 1-MCP (alone) after two weeks of storage. Other factors such as maturity stage and the harvesting method have also been found to have significant influence on African pear shelf life. Fruit semi-ripe seems to exhibit a longer shelf life compared to ripe fruit (Ndindeng et al., 2007; Doussou et al., 2012). Fruits harvested with pedicel remain firmer longer that those with detached pedoncule (Ndindeng et al., 2007; Doussou et al., 2012), which is also true for other fruits such as avocado (Vijay et al., 2012).

Drying is one of the most common methods used to extend the availability of perishable food particularly in less developed countries. Ndindeng et al. (2012) reported that drying big and thick slices (1500 mm^2) at 60°C stored better compared to smaller and thin slices (40 mm^2) of African pear as smaller slices rancid faster and tent to lose their flavour during drying. African pear pulp dried at 50 °C to water content of ~6% and stored in polyethylene packages maintained its chemical characteristics and the oil quality up until 12 months (Noumi et al., 2014). The transformation of African pear pulp into readily available marketable product has received limited attention. A study by Ndindeng et al. (2012) revealed that partial substitution of butter with African pear flour (46% butter: 54% African pear) in baking did not affect the level of biscuits' acceptability by customers. A similar study by Eyenga et al. (2020) shows that the fortification of rice biscuits with African pear increases the protein, essential amino acid, and mineral contents of the biscuits with very appreciable taste.

Future Perspectives

A lot of potential efforts still remain towards the selection of top accessions based not only on the morphological traits but also on other traits such as the yield, the fruit organoleptic characteristics, as well as tree and fruit resistance to pathogen (Poligui et al, 2013; Dossou et al, 2018). There is a wide gap of scientific information on African pear postharvest management; from defining product quality standard, fruit shelf-life extension and supply chain. The quality of fruits is the combination of characteristics significantly influencing the degree of acceptability of the product to a user (Prasad et al, 2018). The colour, the size and the acidity level have been suggested to play a major role on the marketability and the shelf life of African pear (Ndindeng et al, 2012; Doussou et al., 2018). With the raising health and environmental concern on the use of chemical fungicide to reduce postharvest losses (Sapper and Chiralt, 2018), researchers should focus on developing cost-effective natural products from the rich biodiversity of Central and West Africa to extend fresh fruit shelf life. Notably, the lack of infrastructure (transport system and cooling facilities) is significantly contributing to the postharvest losses in the region. Therefore, the design of insulated containers that can maintain low temperature and minimise abrasion or injury during transportation should be explored. There should be continuous efforts to establish cold chain facilities to significantly increase the export of fresh fruit. African pear physico-chemical characteristics are similar to those of avocado; currently more than 250000 tonnes of avocado are exported from various African countries to Europe (PPECB, 2021), so much can be learned from avocado success. Drying fruit may help extend its availability during off season and may increase export; however fresh fruit is still consumers' first preference.

Conclusion

D. edulis fruit could serve the dual purpose of being a source of protein, fatty acids, micronutrients and minerals to human nutrition and as a raw material for industries, if properly harnessed. It can be consumed fresh, dry as a snack, and after processing (oil extraction, butter, ketch-up sauce). However, the lack of adequate and consistent data is hampering its full exploitation. A combination of molecular, morphological and physio-chemical studies is needed to clearly define cultivars/varieties, facilitating the domestication of cultivars with the desire of consumers and food industry. Efforts should be made to include other physiological characteristics such as moisture content and chemical composition to delimit maturity/ripening stage, in addition to the change in skin colour from pink to blue-black to help improve quality standard. Developing value added product from African pear or its use for nutrients fortification is a great alternative to minimise postharvest losses. However, more studies are needed to promote its use both at national and international level; this will lead to the increase in demand, increase in production and boost of rural economies.

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