Chapter

A Review on the Cooking Attributes of African Yam Bean (*Sphenostylis stenocarpa*)

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Abstract

African yam bean, an underutilized legume usually cultivated for its edible tubers and seeds, is known for its nutrition-rich qualities; however, the crop's level of consumption is low. The underutilization of the crop could be attributed to several constraints, including long cooking hours of up to 24 hours. Cooking time is an important food trait; it affects consumers' choices, nutrients content, and anti-nutrient conditions. Additionally, foods requiring long cooking hours are non-economical in terms of energy usage and preparation time. The prolonged cooking time associated with AYB places enormous limitations on the invaluable food security potentials of the crop. Therefore, the availability of AYB grains with a short cooking time could lift the crop from its present underused status. To efficiently develop AYB grains with reduced cooking time, information on the crop's cooking variables is a prerequisite. This review presents available information on variations in cooking time, cooking methods, and processing steps used in improving cooking time and nutrient qualities in AYB. Likewise, the review brings to knowledge standard procedures that could be explored in evaluating AYB's cooking time. This document also emphasizes the molecular perspectives that could pilot the development of AYB cultivars with reduced cooking time.

Keywords: Seed hardness, Mattson Bean Cooker, GWAS, QTL, Cooking Time

1. Introduction

Food and nutrition security which is part of livelihood, is notably attracting the attention of stakeholders, spanning across nations, research organizations, the general public, academic institutions, and policymakers. At present, the world population is estimated at 7 billion; however, by 2050, the population is expected to reach 9.3 billion. As of 2017, the number of food-insecure people worldwide was estimated at 690 million [1]; however, by 2050, a 70–85% increase in food production will be needed to feed the projected 9.3 billion people [2, 3]. Notwithstanding, upscaling the adoption and utilization of sustainable crops offers considerable potentials in boosting food production amidst the prevailing challenges.

Grain-Legumes are sustainable, capable of surviving under harsh climate conditions. The grain legumes require minimal fertilizer inputs because of their ability to fix atmospheric nitrogen through symbiosis with soil *Rhizobia*. Also, intercropping legumes with other crops has improved soil fertility and crop productivity [4–6]. Importantly, legumes are a good source of food and feed for humans and animals, respectively; crops within the legume category are nutritionally rich; most significantly, they provide affordable sources of protein [7, 8]. The contribution of legumes as food and feed differs across types, while some legumes are known worldwide and considerably utilized (soy bean) (*Glycine max L*), common bean (*Phaseolus vulgaris* L), cowpea (*Vigna unguiculata* L.)) others are less known and underutilized (African yam bean (*Sphenostylis stenocarpa* Harms), lablab beans, (*Lablab purpureus* L) wing bean (*Psophocarpus tetragonolabus* L.). Adopting and accepting underutilized legumes such as African yam bean as a food crop is vital for their survival; nevertheless, AYB's adoption and utilization is intertwined with several factors, including cooking time, nutrient potentials, palatability, and value-added products.

1.1 African yam bean

African yam bean which, is commonly referred to as AYB, is one among the underutilized grain legumes of tropical Africa. The crop is grown for its edible seeds and tuberous roots. **Figure 1** presents AYB seeds harvested from a field evaluation in 2020. AYB seeds are enclosed in pods measuring about 3–15 cm long, such that a single pod can accommodate up to 30 seeds. The crop is a climber usually grown in mixed cropping with major crops [10–12]. AYB is locally adopted and has wide adaptability across diverse environmental conditions [13, 14]. Even though the crop is usually cultivated as an annual crop [15–17], some schools of thought consider it as perennial [18–20]. The cultivation of AYB majors among smallholder farmers across sub-Saharan Africa, of which Nigeria is one country prominent on the list [21]. The consumption of AYB is known to contribute to daily nutrition, food availability, and diet diversification to communities utilizing it; this date back to the Nigerian civil war of 1967–1970, where the crop's food and nutritional potentials were efficiently utilized in fighting malnutrition and hunger [15, 22–24].

The seeds of AYB provide an affordable source of protein when compared with other plant sources and animal extract. Aside from its rich protein content, its high carbohydrate content [25, 26] is comparable to the amount reported in grain cereals.

Figure 1.
Dried AYB seeds. (A) Non variegated seeds (B) Variegated seeds. Source: field evaluation (Shitta et al. [9]).

AYB's amino acid (histidine, isoleucine, lysine, methionine) profile is more in quantity than the amount observed in soybean [27–29]. Likewise, several authors have reported the presence of essential nutrients in AYB's seeds [25, 26, 30–36]. AYB tubers (**Figure 2**) contain considerable amount of magnesium (167 mg/100 g), potassium (1010 mg/100 g), protein (15–16%), and carbohydrate (67–68%) [34]. In addition to the crop's nutritional qualities, the crop is flexible for use in various diets; it can be utilized as a condiment, or as a whole meal, or as a snack. The contribution of AYB in feeds enrichment is an added advantage of the crop's food and nutrition attributes [37, 38].

Considering the enormous potential of AYB and its role in some African traditions [39–41]; the efficient utilization of AYB can reduce hunger and nutritional challenges in sub-Saharan Africa. Nevertheless, the food potential of the crop remains widely untapped, which can be attributed to several constraints such as long cooking hours of up to 24 hours [41–44], a long-maturity cycle of 9–10 months [16, 17, 45], and the abundance of anti-nutrition factors [35, 46–49]. However, the genetic variability reported in the crop [9, 50–53] provides a foundation for breeders to develop improved cultivars. In particular, the availability of AYB cultivars with reduced cooking time could boost the cultivation and consumption of the crop. Up-to-date information on cooking-related attributes is a prerequisite for improving cooking time trait. Keeping the above in view, the present review brings to knowledge cooking variables reported in AYB. Also, the review proposes the application of standard procedures and molecular technology for advanced studies. Furthermore, the present document is intended to stimulate more research interest towards improving cooking time in the crop.

Figure 2.
AYB tubers. Source: field evaluation (Shitta et al. [9]).

Seed thickness (mm)	Seed length (mm)	Seed width (mm)	100 seed weight (g)	References
—	8.90	6.90	24.70	[23]
6.99	8.69	6.80	29.79	[56]
6.66	8.57	6.77	28.80	[51]
6.30	8.21	—	20.83	[48]
6.22	8.06	6.31	22.42	[53]
6.20	8.40	6.35	25.30	[9]

Table 1.
Means of some physical properties reported in AYB seeds.

1.2 Structure of African yam bean seeds

Past research investigations have explained the relationship between seed properties, variety type, seed storage conditions, and cooking time [54, 55]. **Table 1** presents the physical properties reported in AYB seeds. AYB seeds are, dicot in nature and they can measure up to 10 mm in length and 7 mm in width and thickness[9, 50–53, 56]. The seeds of AYB differ in texture across germplasm; they could be rough, wrinkled, or smooth. The electron microstructure study of seeds revealed the presence of smooth starch granules exhibiting different sizes and shapes [57]. The cells were bounded by cell walls same as observed in other legumes [58, 59]. Likewise, the round undulating surface observed in the cotyledon is similar in structure to that of cowpea [59, 60]. For seeds subjected to milling, the cotyledon and cell components showed structural change. Equally, cell wall materials and protein matrix were reduced to flakes and particles; however, the structure of starch granules remained unchanged. The micrographs of cotyledon, flour, and starch showed the size of starch granules within the range of 4–40 μm for lengths and 4–25 μm for diameter [57].

2. Cooking quality in African yam bean

Preparing and cooking food is an integral part of daily living [61, 62]. For example most grain legumes are subjected to cooking before consumed; the cooking process converts raw food into a ready-to-eat product. Also, cooking facilitates the destruction of foodborne pathogens, thereby eliminating microbial hazards and achieving quality [63]. Moreover, the physical and chemical changes that occur during cooking increases the digestibility and availability of nutrient for use and storage in the body [64]; through processes including inactivation of antinutrient, starch gelatinization, proteins denaturation, leaching of polyphenols and solubilization of polysaccharides among other factors [59, 65, 66]. Despite the importance of cooking in food and nutrition the cooking culture is dwindling, especially in industrialized societies where individuals are exposed to a busy lifestyle with little time at their deposal. To cope with busy schedules, consumptions are choosing convenience food that requires less cooking time. Also, reports have shown that consumers are ready to pay more in exchange for long cooking hours [67, 68].

Cooking time, an attribute of cooking quality is defined as the time from the beginning of cooking up to when the food becomes tender and suitable to eat [66, 69]. AYB, the same as most legumes is characterized by seed hardness, requiring long

Source	Cooking method	Cooking time (mins)	End product	References
Whole AYB seeds	Boiling	480	Flour	[70]
Whole AYB seeds	Boiling	228	Paste	[47]
Whole AYB seeds	Boiling	60	Porridge	[71]
Whole AYB seeds	Roasting	60	Flour	[47]
Whole AYB seeds	Roasting	10	Flour	[43]
Whole AYB seeds	Boiling	155	—	[43]
Dehulled AYB and maize flour	Frying	10	Kokoro	[72]
Dehulled AYB wet flour	Frying		Cheese	[73]
Dehulled AYB-wheat flour	Baking	20	Cookies	[74]
Dehulled AYB cowpea flour	Steaming	50	Moi-moi	[75]
Dehulled AYB wet flour	Steaming	60	Moi-moi	[71, 76]
AYB-maize-coconut fiber	Roasting	5	Flour blend	[77]
Whole grain	Roasting	45	Flour	[78]
Whole grain	Roasting	300	Flour	[79]

Table 2.
Source, cooking method, cooking time, end product, and references reported in AYB cooking experiments.

cooking hours of up to 24 hours (**Table 2**) in some scenarios [80]. Seed hardness has been identified as a heritable trait but also affected by seed composition, production, and, storage environment [54, 81, 82]. The mechanism by which seeds become hard-to-cook is categorized as a very complex phenomenon; it includes processes such as changes in the intracellular cell wall, middle lamella, polysaccharides, and other components. The hard-to-cook mechanism in seeds has been extensively reviewed by authors [83–85]. According to a particular study, an increase in calcium ion concentration led to a subsequent increase in seed hardness and a decrease in phytate concentration. It was also reported that a higher rate of leaching in phytate and peptic acid occurred in cooked and soaked hard-to-cook seeds than in fast-to-cook seeds [85].

Generally, grains with short cooking time are more preferred by consumers; because less time is invested in their preparation, and importantly less energy is spent when compared to energy requirements for grains with long cooking time. In addition, several studies have shown that nutrients such as minerals and proteins are conserved when grains are cooked over a short period. In contrast grains requiring long cooking hours usually lose a significant amount of nutrients [55, 86]. Cooking methods reported in AYB include boiling, steaming, roasting, and frying. However, advanced procedures including, sensory analysis: involving sensory panel [87, 88]; tactile method: [89] a method of compressing seeds within the thumb; texture analysis: [87] a method that measures the resistance of seed compression using a texture analyzer [90] have been investigated in major legumes.

2.1 Cooking method reported in AYB

2.1.1 Boiling

Boiling cooking method is a moist approach whereby the target food is submerged into a liquid. Cooking is achieved through the transfer of heat from the cooking equipment to the liquid in contact with the food. The food surface absorbs the heat and through conduction, the heat passes through to cook the food. The boiling method was experimented with selected AYB grains. The steps included boiling the grains in water for 480 minutes (**Table 2**) and thereafter oven drying for 24 hours before milling into flour [70]. In another report, AYB grains were boiled for 228 minutes. The analysis of the boiled seeds showed a reduction in phytate content and an increase in moisture content [47]. In addition, the boiling cooking method was reportedly used in preparing porridge. The procedure included presoaking seeds overnight and boiling them for 60 minutes. The porridge analysis showed an increase in carbohydrate, gross energy, fiber, lipid, water absorption capacity, oil absorption, bulk density, and gelation capacity however a decrease in protein and moisture content was observed [71].

2.1.2 Roasting

The roasting method is commonly used in preparing “roasted AYB grain,” a popular snack consumed in combination with other food in South-East Nigeria [19, 40, 43]. Roasting was effective in increasing the level of phosphorus and in-vitro protein digestibility of grains. An increase in phytic acid was also reported; however, the tannin level was shown to be at the barest minimum [43]. In the preparation of breakfast cereal from AYB grains in combination with maize and coconut fiber, the blends were roasted for 5 minutes at 280^0c temperature. The formulated blends revealed a protein content of 18.26%, moisture content of 4.20%, ash content of 7.36%, and energy content of 339.47% [77]. The roasting approach was likewise used in preparing AYB flour. The grains were subjected to roasting for 45 minutes (**Table 2**) using firewood as the energy source. Then, the roasted grains were dehulled and milled. The analysis of the roasted flour showed a decrease of about 0.27 mg/100 g in the level of the tannin content [78]. In a separate study, AYB grains were roasted in an oven at 120^0c for 300 minutes; and the roasted grains were dehulled and milled. The analysis of the dehulled flour showed a reduction in the emulsifying capacity, foam capacity, and stability of the flour, also the samples presented a high water and oil absorption capacity [79]. In a further experiment, researchers investigated the effect of roasting on the proximate, mineral, and anti-nutrient content of AYB grains. The study preceded the roasting of grains over firewood for 1 hour at 300^0c temperature condition. An increase was reported in the levels of calcium, potassium, copper, iron, manganese, magnesium, phosphorus, and sodium, and a drastic reduction in the percentage level of phytate, oxalate, tannins, hydrogen cyanide, and trypsin inhibitor was reported. On the contrary, there was no significant increase in the nutrient content [47].

2.1.3 Steaming

The steaming approach involves the use of steam as the cooking medium; the steam is mostly generated from vigorously boiling water. Unlike reported in boiling method, the steaming procedure does not require submerging the food directly into the water; in steaming, the target food gets cooked as the result of the steam or vapors generated from the boiling water. Steam is considered a good heat conductor, nevertheless, the temperature release from steam does not exceed that of boiling water except in the pressure system [91]. Steaming was reported to have minimal effects on chlorophyll, soluble protein, sugar, vitamin c, and glucosinolates [92]. The steaming process helped preserve antioxidant properties and maintained the lowest biogenic amine content in bean varieties [93]. In AYB, the steaming approach was reportedly used in preparing a traditional snack called “Moi-Moi”. The procedure involved dehulling and wet milling of the grains accompanied by spicing. For the Moi-Moi to get cooked, it was steamed for about 60 minutes [71, 76]. The analysis of the AYB Moi-Moi showed a lower gelation capacity, higher water absorption capacity, lower oil absorption capacity when compared to Moi-Moi made from cowpea. The sensory analysis of AYB Moi-Moi showed no significant difference in color and flavor from Moi-Moi made from cowpea (cowpea is the most common grain for preparing Moi-Moi). Additionally, the acceptance level of the AYB Moi-Moi was similar to Moi-Moi constituted from cowpea [71]. Some researchers utilized the steaming cooking method in making Moi-Moi from AYB and cowpea blends, they reported a total steaming time of about 50 minutes [75].

2.1.4 Frying

Frying is one of the ancient and well-known cooking methods used for food preparation; the procedure is known for its ease, speed, and unique flavor and taste [94]; in addition, frying gives an attractive color, texture to food. The frying process involves the use of fat or oil which serves as the medium of direct heat transfer with the food [63, 95]. The transfer of heat, oil, and air during the frying process brings about changes like loss of moisture, oil uptake, starch gelatinization, aromatization, denaturation of protein, and changes in the color of the food. The changes in food and oil are largely dependent on the food property, the quality of oil, heating process, length of immersion, the rate at which air mixes with the oil, temperature, and the quality of the frying medium [96]. Frying could lead to the release of toxic products through oxidation, which usually occurs when oil is continuously used under high temperatures and atmospheric air [97]. The frying method of cooking was reportedly used in the preparation of traditional snacks commonly known as “akara” or “beans ball”, a snack widely eaten in Nigeria. The grains were soaked overnight and dehulled before wet milling (paste) and spicing. The frying medium (groundnut oil) was heated to 185-190^{0}c, and the total frying time was about 5 minutes (**Table 2**). The end product (akara) showed an increase in carbohydrate, gross energy, water absorption capacity, oil absorption capacity, bulk density, and gelation capacity. Meanwhile, no significant difference was reported in accepting the AYB akara from the usual cowpea akara [71]. In like manner, the frying method was used in preparing Kokoro a popular snack in South-West Nigeria. The Kokoro process involved deep-frying the paste constituted from the AYB-Maize blend for about 10 minutes. The proximate analysis conducted on the Kokoro showed an increase in protein, sugar, ash, moisture, potassium, and calcium as the proportion of AYB flour increases. On the contrary, a decrease in fat and starch was observed with an increase in AYB flour [72]. Furthermore, the frying process was used to produce AYB cheese, using palm oil as the frying medium. The sensory evaluation indicated a general acceptance of the AYB cheese [73].

2.1.5 Baking

The baking process is a method whereby the raw dough is transformed into crumb and crust texture, under the influence of heat. During baking, the changes that occur include the crust formation, yeast inactivation, coagulation of protein, volume expansion, starch gelatinization, and moisture loss [98–100]. The baking approach was used in producing cookies from AYB-wheat composite flour. The cookies were baked for 20 minutes using an oven mark of 180^{0}c. The nutritional analysis of the cookies showed an increase in protein content from 8.59 to 9.35% fat from 3.84 to 4.63%, ash from 4.84 to 5.21%, and crude fiber from 3.84 to 4.22%. An increase in mineral content corresponding to a percentage increase in the level of AYB flour was also observed [74].

2.2 Technological gap in the evaluation of AYB cooking time

In AYB, the majority of the cooking time investigations were conducted using basic approaches like firewood, gas, and kerosene stove. No information is documented on the use of standard equipment such as texture analyzer and Mattson bean cooker; however, the use of Matson bean cooker and texture have been reported in several legumes.

2.2.1 Mattson bean cooker

One standard method of measuring cooking time in pulses is to evaluate using a Mattson bean cooker [101]. The equipment is easy to use, cost-effective, and generates unbiased data compared to other methods [90]. The use of Mattson cooker is recommended in grain genetic improvement for evaluating new varieties [66]. Mattson first developed the Mattson bean cooker, having 100 plungers [102], but was later redesigned to have 25 plungers [103]. The usage of the equipment involves placing individual presoaked seeds on each of the saddle on the rack such that the tip of each plunger comes in contact with the surface of the seed. The weight of each plunger can be optimized to suit the size of the target grain by adjusting the number of lead buckshot inside each plunger. To initiate the cooking test, the lower part of the cooking rack is immersed in a boiling water bath up to half of its height. When a seed reaches tenderness, the plunger penetrates that particular seed and drops a short distance through the hole in the saddle. The top of a plunger that has dropped (penetrated a seed) will be lower than the top of the plungers which are yet to drop. The scenario makes it visibly easy to identify the plunger that has penetrated its seed [66, 90]. The cooking time for a set of seeds (25) has been explained differently by researchers; the cooking time was defined as the time required for 100% of the seeds to get penetrated [104]. In an additional study, the cooking time was recorded as the time 92% of seeds got penetrated [105]. Operating the Mattson cooker requires the uninterrupted attention of the user; the user manually records the time each plunger penetrates a seed the situation becomes more critical when multiple plungers penetrate at the same time. To overcome the bottleneck of manual recording several researchers have reported the use of an automated Mattson cooker where the cooking time is automatically recorded [66, 90, 106].

2.2.2 Texture analysis

The texture is an important trait of food characterized by its mechanical, geometrical, surface, and body attributes detected by senses of vision, hearing, touch, and kinesthetics [107, 108]. The mechanical attributes have to do with the qualities of the food under stress conditions; like hardness, cohesiveness, elasticity, and adhesiveness. In contrast, the geometrical attributes are related to the size, shape, and structural arrangement of the product. The surface attribute has to do with the sensations produced (in the mouth) around or in the surface of the product by moisture and fat or either of the two; similarly, the body attributes are related to the feelings produced in the mouth and how the moisture and fat or both are released [109]. Of recent, instrumental texture analysis has proven to be efficient in evaluating the mechanical and physical qualities of the raw and finished product, of which the application of texture analyzer is a well-established protocol. A texture analyzer is used for evaluating the hardness, fragility, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience of food [54, 88]. The instrument is easy to operate; it eliminates subjective judgment, as may be found in sensory evaluations [109]. The selection of a probe for use during analysis is dependent on the type of test, which could be a compression test, penetration (puncture) test, traction (tension). The different texture analysis test types were previously reviewed [109]. The texture analyzer has been applied in several texture studies in legumes, fruits, vegetables, meat, milk, among others [109, 110].

3. Methods of reducing cooking time in AYB

Several studies have reported a significant decrease in cooking time after seeds were subjected to processing methods like presoaking, dehulling, frying, steaming, and blanching [43, 71, 111, 112].

3.1 Presoaking of seeds

Presoaking is a long-age traditional practice used in homes to reduce cooking time, especially in grain legumes. The approach is flexible, simple, and common both at the domestic and industrial levels. The process involves the imbibition of water through the outer cuticle, the seed coat, and then into the cotyledons; [69, 113]. The first step in imbibition is the penetration of water by the seed, and the process can be through the seed coats since the seed coat has high fiber content and thus high-water holding capacity. Water inhibition can also occur through the micropyle or hilum; when the water reaches the cotyledons, the seed starts to absorb water and swell until the seeds attain their maximum water uptake capacity. Presoaking of seed before cooking enables the easy identification of unhydrated seeds, which can be discarded to achieve uniform cooking time. The procedure reduces cooking time because the hydrated seeds acquire a soft texture and thereby speeding up the cooking process and shortening the cooking time [114]. Also, soaking aid the easy identification of hydratable seeds and improves the nutrient quality of foods since the soaked content is usually discarded. Soaking grains before cooking is a good practice used traditionally in increasing food safety especially in situations when consumers have no idea of the storage preservatives used for the target grain.

The effect of presoaking in shortening the cooking time of AYB's seed was reported by several authors. Presoaking AYB seeds in distilled water over a varying time of 6, 12, 18, and 24 hours reduced cooking time by 50%. The process also reduced the level of tannin and phytate, in addition to improving in-vitro protein digestibility. Soaking for 12 hours was the most effective in reducing cooking time, tannin, phytate, and in-vitro protein digestibility; however, soaking for 24 hours before dehulling was observed to significantly increase crude protein level by 16% [43]. In a similar study, AYB seeds were presoaked each in 0.20%, 0.40%, 0.60%, 0.80% and 1.00% of akanwu (sodium sesquicarbonate), and common salt (sodium chloride) and water for a duration of 6, 12, 18, 24, 30, 36 hours. Seeds soaked for 6 hours in 0.060% akanwu and 1.00% common salt showed a 50% decrease in cooking time, while seeds soaked in tap water achieved a 50% reduction in cooking time after 24 hours of presoaking. Meanwhile, seeds presoaked in tap water took about 180 minutes to get tender [112]. According to a study, a 50% reduction in cooking time was achieved when seeds were presoaked for 12 hours in either 1% potash or 4% common salt. Seeds soaked for 12 hours in 4% common salt reached tenderness after 45 minutes of cooking however seeds that were not soaked remained hard even after 60 minutes of cooking [111]. In a similar experiment, presoaking seeds in a different medium (water, alkali, brine, alkaline-brine) reduced the cooking time to a considerable level; the most effective medium was alkaline-brine, with a maximum cooking time of 100 minutes as against 210 minutes reported for cooking dry raw seeds [115]. In a separate study, AYB grains soaked overnight reached tenderness after 60 minutes of cooking [71]. Notably, aside from reducing cooking time, presoaking is also effective in investigating nutrient and anti-nutrient content [15, 43, 116–119].

3.2 Dehulling

Dehulling is a procedure through which seed coats or testa are removed either mechanically or using a machine. In most traditional setting, the process is carried out using either mortar and pestle or grinding stone, depending on the available option. Dehulled seeds have a good appearance in texture, cooking quality, palatability, and ease in digestibility. The approach reduces cooking time in grains legumes because during the dehulling process impermeable seed coats which usually prevent water uptake are removed [120]. Dehulled AYB grains showed the shortest cooking time of 35 minutes as against 80 and 150 minutes reported for whole seeds and soaked seeds, respectively [121]. The dehulling approach was observed to have a significant effect on the functional properties of AYB flour; a higher bulk density (0.93 g/cm^3) was reported as against the bulk density (0.59 g/cm^3) in cowpea and pigeon pea (0.70 g/cm^3). Similarly, the swelling index (5.9 g/cm^3) of dehulled AYB flour is more than the observed value in cowpea (3.7 g/cm^3) and pigeon (4.1 g/cm^3). The water absorption capacity (2.8 ml/$h_2$0/g) in dehulled AYB flour was also higher than the observed in cowpea (1.2 ml/$h_2$0/g) and pigeon pea (2.4 ml/$h_2$0/g) [122]. In a further experiment, a higher water capacity of 71 ml/g was observed for dehulled AYB than the value of 60 ml/g reported for raw samples [71].

About 80–90% of the total amount of potential anti-nutrient factors (polyphenols) in grain legumes are found in the seed coats, and thus dehulling has proven to be effective in reducing anti-nutrient contents especially those found in the seed coats [123, 124]. Authors reported a drastic reduction in oxalate, phytate, saponin, trypsin inhibitor, and tannin content of dehulled AYB flour [122]. Similarly, an increase in protein but a decrease in calcium and iron was reported for dehulled AYB flour [43]. In a separate study, the proximate analysis of dehulled AYB flour showed high protein content, high carbohydrate concentration, and sufficient level of amino acid [125].

3.3 Other processing methods in AYB

3.3.1 Fermentation

Fermentation increases the bioaccessibility and bioavailability of nutrients and sensory quality in addition to shelf life [126, 127]. The process involves the biochemical modification of food by microorganisms and their enzymes [128]; the process is capable of disrupting the activities of pathogens [126, 129]. The fermentation process was explored for the preparation of “tempeh” from AYB grains; tempeh is a traditional food usually made from fermented soybean or soybean already broken down by microorganisms. The procedures for making AYB tempeh included: cooking presoaked grains for 45 minutes at 100^0c and inoculating the cooked grains with spore suspension to initiate fermentation. The inoculated grains were allowed to ferment over 42 hours. The final product showed significant changes in crude protein and carbohydrate. An increase in protein and amino nitrogen content was reported whereas a decrease in carbohydrates was observed. The quality of the AYB tempeh was acceptable to a large number of sensory panelists [130]. Meanwhile, some authors reported the minimal effect of fermentation on calcium, iron, magnesium, and zinc contents. However, they reported about a 34% reduction in phytate level and only tannin traces were detected [43]. Further research investigated the solid (3 days) and liquid (62 days) state fermentation approaches in making sauce from AYB grains. The prepared sauce revealed an increase of 11.94%, 4.85%, and 16.75% in ash, protein, and carbohydrate contents respectively. The sensory evaluation showed the acceptability of the AYB sauce was not significantly different from the level of acceptance of the commercial soy sauce in terms of color, aroma, and flavor [131].

Other studies used the fermentation process to formulate a yogurt-like product from dehulled and whole AYB grains. The process involved: the extraction of milk from grains which was followed by inoculation with a starter culture. For fermentation to occur, the inoculated milk was kept undisturbed over a time frame of 12 hours. The analysis of the formulated AYB yogurt presented a high total viable and *Lactobacilli* counts. As storage time increases, a decrease in the microbial load of the yogurt was observed [132]. In a similar experiment, raw AYB grains fermented for 48 hours showed an increase in protein and oil content [70]. "Dawa-Dawa" a traditional condiment was reportedly prepared through fermentation. The grains were boiled in water laced with "potash", the boiled grains were later dehulled and allowed to ferment at room temperature for 72 hours. The proximate analysis of the "Dawa-Dawa" showed an increase in crude protein from 22.00 to 32.80% and crude fibers from 5.70 to 7.77%, ash content increased from 3.20 to 4.60%, and lipid from 1.20 to 1.38%. Nevertheless, a decrease in carbohydrates from 74.20 to 57.21% was observed in the product [133].

3.3.2 Germination

Germination is a complex process that involves a mature seed to make an immediate change from maturation to the germination-driven stage and prepare for seedling growth [134]. The stages of germination include uptake of water by the seeds (imbibition) and the second phase is the reinitiating of metabolic processes followed by the emergence of the radicle through the seed envelopes. The germination process was used to prepare flour from AYB grains. The grains were soaked in water at room temperature for 48 hours. After soaking, the grains were allowed to sprout for 96 hours and subjected to oven drying. The dried grains were further dehulled and milled into flour. The germinated AYB-wheat composite flour showed an increase in protein; for every increase in the percentage of AYB flour [74].

4. Molecular perspectives for shortening cooking time in AYB

4.1 Seed hardness attribute

Seed hardness is an important quality of grain legumes; the trait acts as a barrier against seed coat pathogens and seed damage. Likewise, it affects germination, seed processing, and cooking time [82, 135]. Seed hardness is heritable but can also be influenced by environmental conditions at production and storage time [81, 82]. The genetic factors responsible for seed hardness are not well understood; however, the roles of a few genes have been documented [82]. The influence of the environment on seed hardness is reflected in the hard-to-cook phenomenon, which is not also independent of genetic influence [82, 84]. Understanding the genetic basis of cooking time in AYB is a necessity for improving the trait. It is noteworthy that genetic architecture in cooking time is yet to be reported in AYB; thus, no molecular approach has been documented in studying AYB's cooking time. Molecular techniques like GWAS and QTL could locate loci that controlled cooking time and thereby facilitate the identification of fast cooking lines. Likewise, new breeding techniques, including ZFNs, TALENS, and CRISPR/Cas9, have provided researchers the flexibility to insert desired traits precisely and quickly.

4.2 DNA technology

Previously, it would require about 7–10 years to transfer a target trait from a species to an adapted cultivar. The conventional process requires, handling a large number of progenies and several cycles of field evaluation. However, with molecular biology, a gene can be transferred in a single experiment, and within 5–6 years the new cultivar could exhibit a stable gene expression [136]. Presently, advances in plant molecular biology have provided processes and platforms through which the genetic architecture of traits can be well understood, manipulated, and transferred from different backgrounds [136, 137]. In addition, through DNA technology, gene sequences and functions can be accessed. Similarly, specific region (s) on the chromosome can be identified, molecular markers can be developed and genetic maps can be constructed, among many other possibilities. Genetic manipulation using physical, chemical, and biological mutagenesis presents added advantages with an enormous contribution to crop improvement. Among the widely used DNA technology reported in crop improvement programs are Genome-Wide Association Study (GWAS), Quantitative Trait Loci (QTL) Mapping, and Genome Editing.

4.2.1 GWAS

Over the years, GWAS has been implemented across a wide variety of crops such as soybean, maize, common bean, sorghum, and rice [55, 138–141]. GWAS identifies genetic variants across the genome and associates the variants with the target phenotype. The commonly used GWAS approach involves identifying single nucleotide polymorphism (SNPs) markers and testing each marker for evidence of an association between the marker and the trait of interest. The marker-trait association approach relies on linkage disequilibrium (LD) between markers and causal polymorphisms [142, 143]. To minimize false genotype–phenotype association that may arise from population structure, a linear mixed model analysis option is usually implemented. The application of GWAS has contributed significantly to identifying candidate genes; identified markers can be mapped to reference genomes, and thereafter candidate genes can be identified [143]. Once genomic regions of a target trait and the corresponding alleles at each locus are identified, the allele can be incorporated into another variety through crosses. The resultant progenies with the desired allele combination can be subjected to marker-assisted selection. GWAS in combination with marker-assisted breeding offers great gains for improving quantitative traits with low heritability [136].

4.2.2 QTL mapping

QTLs are phenotypically defined regions on the chromosome that contribute to allelic variation for a biological trait [144]. QTL technique has become a popular approach [144, 145] used to study complex traits [146, 147]. The application of QTL analysis in crop improvement was reported by several authors [82, 148]. Regions on the chromosomes that significantly affect variations of quantitative traits are identifiable through QTL mapping. The ability to locate chromosomal region (s) is important in identifying target genes and in understanding the genetic mechanism of genetic variation. Majorly, QTL mapping reveals information on QTL's having a significant effect on trait variation, and also answers the question to what extent is the variation due to additive, dominant, and epistasis effects of the QTL? The mapping of QTL also shows the genetic correlation of different traits and also answers the question does the QTL interact with the environment? [149]. The ability of QTL mapping to unravel and, at the same time provide answers to genetic questions makes it a powerful technique in crop improvement.

4.2.3 Genome editing

The discovery of genome editing technologies has revolutionized plant and animal research. Through genome editing, researchers can introduce sequence-specific modifications into the genome of different cell types and organisms. The site-specific nucleases (SSNs) have successfully been used in precise gene editing. The SSNs create double-stranded breaks (DSB) in the target DNA. The DSB is repaired through non-homologous end joining (NHEJ) or homolog-directed recombination (HDR) pathways resulting in insertion/deletion (INDELS) and substitution mutations in the target region (s), respectively [150, 151]. The technology produces defined mutant; also, the edited crops typically carry the desired trait [152]. Gene editing has been reported in plants including Arabidopsis [153], rice [154], and other crops, The genome editing techniques include meganucleases, zinc finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), clustered regularly interspaced palindromic repeats (CRISPR/Cas9). These techniques have been extensively reviewed [151, 155].

5. Conclusion

Despite the unique attribute of AYB as a seed and tuber producing crop, the crop is underutilized due to identified limitations, including long cooking hours and the abundance of anti-nutrition. Different cooking hours have previously been reported for AYB grains; the lengthiest cooking duration was 24 hours. The cooking hours were observed to be dependent on the cooking methods used, the energy source, and the germplasm considered. The boiling cooking method presented the most prolonged cooking hours (24) while roasting gave rise to the least cooking time of 5 minutes. The diverse cooking methods experimented within AYB effectively reduced the level of anti-nutrient content in the grains. Nevertheless, processing methods such as presoaking and dehulling were observed as the most effective in improving both cooking time and nutritional contents. Fermentation and germination likewise showed positive effects in enhancing the nutrient quality of AYB food products.

Furthermore, the application of recommended equipment like the Mattson bean cooker and texture analyzer could efficiently evaluate cooking time and seed hardness across AYB germplasm. The adequate phenotyping of cooking traits using basic and standard equipment will provide definite baseline information that breeders could use to select parental materials for hybridization and genetic improvement of cooking traits. Additionally, DNA technology which has proven to be effective in providing solutions to complex problems could be exploited through GWAS, QTL mapping, and genome editing for the improvement of AYB's cooking attributes. Conclusively, the present review is targeted at stimulating researchers' interest in developing AYB cultivars with reduced cooking time.

Conflict of interest

The authors declare no conflict of interest.

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