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Review

Digitaria exilis (acha/fonio), *Digitaria iburua* (iburu/fonio) and *Eluesine coracana* (tamba/finger millet) – Non-conventional cereal grains with potentials

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Traditional African cereal grains, acha (*Digitaria exilis* Stapf), iburu (*Digitaria iburua* Stapf) and tamba (*Eluesine coracana*) though poorly studied have received an increasing attention by scientists within the last decade as revealed from the literature. They have potential to contribute significantly to whole grain diets, wellness, economic status improvement, and play important role in food security in developing economy. They are considered as health grains in the sense that they are often consumed whole and are gluten-free. Studies have shown that sprouting and fermenting tamba (finger millet) with fungus adds value for effective utilization and provides scope for development of functional food. Like other emerging ancient grains, these cereals with excellent culinary and nutritional properties have potential in new product development as they are believed to represent the highest quality of vitamins, minerals, fibre and the sulphur containing amino acids. Food industry may look into their use as ingredients in product formulation considering growing awareness of a healthy diet and challenging cost of health care. Value addition and exploitation of these cereal grains require concerted and collaborative efforts in terms of infrastructure, funding, innovation, purposeful policies from governments, international donors, academia, food industry, the private sector if the growing population in the sub-Saharan region is to experience the full benefits of cereal grains for active and healthy life; hence this review.

Key words: Cereal, wholegrain, *Digitaria* spp., acha, iburu, *Eluesine* spp., tamba, raji, finger millet.

INTRODUCTION

The world population, and in particular countries in Africa, will continue to depend on cereal grains (Wrigley et al., 2004). With an estimate of 30% of the total population of Africa suffering from chronic hunger and malnutrition, looking into ways of salvaging food crisis remains a challenge to all stakeholders in and outside the region. It is encouraging that three non conventional indigenous cereal grains, acha (*Digitaria exilis* Staph), iburu (*Digitaria iburua*) and tamba (*Eluecine coracana*), (Jideani et al., 1996) have continued to receive increasing attention within the last ten years as revealed by the work of the following researchers: Mbithi-Mwikya et al. (2002), Morales-Payan et al. (2002), Kuta et al. (2003), Cruz (2004), Adoukonou-Sagbadja et al. (2006, 2007), Lasekan (2004), Lasekan et al. (2001, 2010), Shewry (2002), Lasekan and Feijao (2002), Obilana (2003), Ayo and Nkama (2006), Ayo et al. (2008), Kolawole et al. (2006), Gigou et al. (2009), Wadikar et al. (2006), Philip and Itodo (2006), Dury et al. (2007), Koreissi et al. (2007), Ndiaye et al. (2008), Balde et al. (2008), Akinhanmi et al. (2008), Taylor (2008), Agu et al. (2008a, 2009), Chukwu (2009), Echendu et al. (2009), Anuonye et al. (2010), Ayo et al. (2010), Balasubramanian and Viswanathan (2010), Coda et al. (2010), Tunde-Akintunde (2010), Dansi et al. (2010), Muazu et al. (2010), Chandrashekar (2010), Srimathi (2010), Venkateswaran and Vijayalakshmi (2010), Ogaji and Famoriyo (2010), Ntui et al. (2010), Fanou-Fogny et al. (2011), Philip and Atiko (2012), Singh and Raghuvanshi (2012) and Cabral (2012).

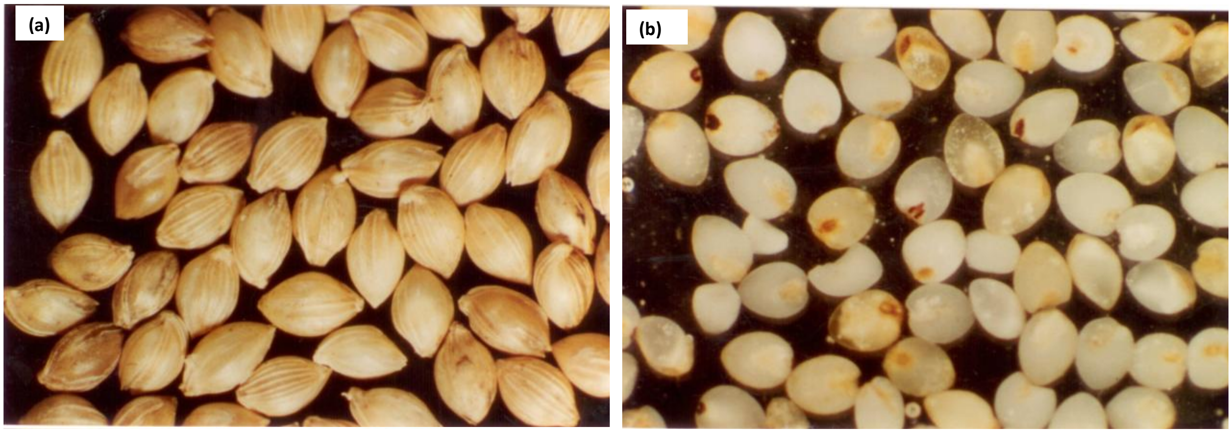

Figure 1. Acha (*Digitaria exilis*) grains, (a) hulled, (b) dehullled (Courtesy F. O. Flint, Magnification, approx. 12x).

The global food crisis with its severe impact on food security in Africa has been attributed to various factors including: rising prices of food, energy and oil, declining outputs, growing scarcities worldwide, civil unrest, loss of agricultural land due to draught, floods, storms and erosion resulting from climate change, increasing world population and decline in arable land, little investment in agricultural sector, very low spending on agricultural research and development, rapid migration from the countryside to cities, lack of purchasing power, and lack of appreciation of traditional indigenous foods (Mwebaza, 2008; Clarke, 2009). On the contrary, there is enormous potential for growth in Agriculture in sub-Saharan Africa as well as abundant natural resources (Clarke, 2009) like cheap labour, favourable climatic condition, etc.

To address the threatening situation, it would require countries in sub-Saharan Africa looking inwards to indigenous foods especially those neglected due to influx of western foods into the continent. It is with this understanding, perhaps with the good prospects and abundant resources, that this review is focusing on these three cereal grains that could be exploited in an attempt to have sufficient food grains, and to develop and market healthier foodstuff, for active and healthy life by the growing population in the region. It is predicted that sub-Saharan Africa's population grows from 770 million in 2005 to 1.5 to 2.0 billion in 2050. It is also important to add to the call for "concerted structural and purposeful policy" improvement in the food challenge facing sub-Saharan Africa by scientists, the food industry, governments – policy makers, international donors and the private sector (Clarke, 2009). A deliberate policy of increased fonio productivity is needed from policy makers to set these cereal grains at par with convectional cereal grains like rice and maize. The applications of science and technology within the food system have allowed production of foods in adequate quantities to meet the needs of society (Jideani, 2002; Floros et al., 2010). The factor to making scientific breakthroughs realisable is political will, such that only governments, acting on behalf of humanity, have the power and authority to do what science says (Rudin, 2012).

ACHA (*DIGITARIA EXILIS*) AND IBURU (*DIGITARIA IBURUA*) CEREAL GRAINS

Acha (white fonio) and iburu (black fonio) (Kone, 1993; Jideani and Akingbala, 1993; Dendy, 1995; Carcea and Acquistucci, 1997), also known as *fundi, findi*, hungry rice, and Asian millet (NRC, 1996) are similar in shape, size (Figures 1 and 2) and nutritional composition, except for the differences in morphological characteristics of the kernel (Irving and Jideani, 1997). Increased popularity and attention on fonio grains led to the European Fonio project, managed by the French Agricultural Research Centre for International Development (CIRAD, 2011).

Acha and iburu, cultivated throughout West Africa, is in high demand in English-speaking countries and in the Francophone countries, where they are produced (Jideani and Jideani, 2011). Fonio (acha and iburu), is included in a list of grains considered as wholegrains when consumed in whole form (Jones, 2009; Jideani and Jideani, 2011). Acha and iburu are traditionally consumed whole as tuo (tuwo), *djouka,* couscous, *gwete*, achajollof, and kunuacha (Jideani, 1990, 1993). There is now sufficient evidence showing that higher whole grain diets compared with refined grain diets are beneficial for several health outcomes (Jones, 2009). Previous reviews (Jideani, 1999; Jideani and Jideani, 2011) and other workers (Balde et al., 2008) reported that acha and iburu help diabetic patients. *In-vitro* starch digestibility and glycemic property of acha, iburu and maize porridge has been reported (Jideani and Podgorski, 2009). There is increasing approach to use more of grains for health maintenance, especially as clinical trials using antihyperglycemic medications to improve glycemic control have not demonstrated the anticipated

Figure 2. Fonio (acha and iburu) with other cereal grains (Anonymous, 2006).

cardiovascular benefits (Pasupuleti and Anderson, 2008).

Whole grains are rich in fermentable carbohydrates that reach the gut and whole grain breakfast cereal has been shown to be more effective than wheat bran breakfast cereal as a prebiotic, increasing fecal bifidobacteria and lactobacilli in human subjects (Slavin, 2010). The health benefits of wholegrain cereal products are now widely recognised (Marquart et al., 2007; Jones 2008; Slavin, 2010) and considered to result from the presence of a range of bioactive components, including dietary fibre and phytochemicals (Shewry, 2009a), hence acha and iburu can help millions in sub-Saharan Africa. Plant sterols, also called phytosterols, found in plants, are clinically shown to lower LDL cholesterol by about 8 to 15% as part of a heart-healthy diet. Also wholegrain that are source of dietary fibre are useful in the prevention and treatment of constipation, cardiovascular diseases and hypertension (Kamran et al., 2008).

Sartelet et al. (1996) examined the potential contributory roles played by fonio to the goitrogenic processes by measuring the total content of flavonoids which amounts to 500 mg/kg of the edible whole cereal grains. They observed the presence of apigenin (A = 150 mg/kg) and of luteolin (L1 = 350 mg/kg), with 10% of A and 80% of L1 are present in free form, whereas the remaining 90% of A and 20% of L1 are bound as O-glycosylflavones; and that both A and L1 aglycones manifest strong anti-thyroid peroxidise (TPO) activities, resulting in a significant reduction of the hormomogenic capacity of this enzyme.

Coda et al. (2010) reported that acha and iburu flours have potential for sourdough fermentation and that sourdoughs from fonio flour were clearly differentiated. Using two-dimensional electrophoresis analysis they found synthesis of acetoin and y-amino butyric acid (GABA) only in iburu sourdoughs, thus demonstrating the potential of these grains for exploitation.

TAMBA (*ELUESINE CORACANA*) CEREAL GRAIN

Tamba (*Eleusine coracana*) also known as raji (India) and finger millet, like acha and iburu, is a grass crop grown in Africa, India Nepal, and many countries of Asia. The plant and grain is resistant to drought, pests, and pathogens. Chandrashekar (2010) reported that finger millet is rich in polyphenols and calcium. It is high in essential amino acid – methionine (Table 1). One major use for the grain is the making of fermented beverages after malting with α-amylase and β-amylase produced during germination. Food made from malted ragi is traditionally used for weaning (Srimathi, 2010) and has been the source of low viscosity weaning foods that can deliver more energy per feed than those based on gelatinized starch. There is some evidence that foods from finger millet have a low glycaemic index and are good for diabetic patients (Srimathi, 2010; Chandrashekar, 2010). Traditionally, tamba cereal grain has been processed into various value-added products in India (Mbithi-Mwikya et al., 2002) including *raji roti*–staple

Table 1. Some nutritional composition of unexploited food grain (per 100 g)

Food grain[1, 2]	Protein	Mineral	Methionine
Hungry rice (acha/iburu/fonio)	7.4	1.4	3.7
Finger millet (tamba, ragi)	7.3	2.7	3.1
Kodo millet	8.3	2.6	1.5
Proso millet	12.5	1.9	2.6
Foxtail millet	12.3	3.3	2.8
Little millet	7.7	1.5	-
Barnyard millet	6.2	4.4	1.9

[1]Millet food grains from Joshi et al. (2008); [2]Hungry rice food grain from Jideani (1993).

Table 2. Recent food and pharmaceutical uses of acha (*Digitaria exilis*), iburu (*D. iburua*) and tamba (*Eluesine coracana*) with corresponding references.

Food/ pharmaceutical uses	References
Acha and Iburu (Digitaria* spp.*) - Fonio	
Snack-type products	Ayo and Nkama (2003), Ayo et al. (2010).
Wheatless acha/iburu bread/sourdough	Jideani (1997), Jideani et al. (2007, 2008), Ayo et al. (2008), Coda et al. (2010)
Composite acha/I buru bread	Ayo and Nkama (2004), Igyor (2005), Jideani and Ibrahim (2005)
Alcoholic beverage – brewing and malting	Lasekan et al. (2010), Crux (2004), Lasekan (2004), Lasekan and Feijao (2002), Nzelibe et al. (2000), Nzelibe and Nwasike (1995)
Non alcoholic beverage	Gaffa and Jideani (2001), Gaffa et al. (2001, 2002a, b, 2004)
Dumpling product - *dambu*	Agu et al. (2007, 2008a, b)
Porridge	Ladekan et al. (2001), Obizoba and Anyika (1994)
Tablet formulation - starch	Muazu et al. (2010), Ogaji and Famoriyo (2010)
Miscellaneous products	Koreissi et al. (2007)
Tamba (Elusine coracana)	
Antihypercholesterolemic metabolites (statin and sterol)	Venkateswaran and Vijayalakshmi (2010)
Raji roti – flat bread, *raji urundai* – steamed finger millet dumplings, Laddoo – sweet ball	Mbithi-Mwikya et al. (2002), Srimathi (2010)
Beverage – malting, *Mangisi* – fermented food/beverage	Chandrashekar (2010), Malleshi and Deikacher (1986), Amadou et al. (2011), Singh and Raghuvanshi (2012).
Snack products - popping	Chakraborty et al. (2011), Singh and Raghuvanshi (2012).

flat bread, *raji urundai* – steamed finger millet dumplings, Laddoo – sweet ball (Table 2); and in much of Africa, millet is commonly eaten as porridge, and also used for brewing millet beer.

Venkateswaran and Vijayalakshmi (2010) have demonstrated that germinated finger millet, used as an alternative economically viable substrate, enhanced nutrient and mineral availability for maximum production of antihypercholesterolemic metabolites (statin and sterol) when fermented with the fungus *Monascus purpureus* in solid state fermentation. This study shows that the sprouting of finger millet and fermenting with fungus adds value for effective utilization and provides scope for development of functional food. Various studies (Mbithi-Mwikya et al., 2000; Makokha et al., 2002; Wadikar et al., 2006; Inyang and Zakari, 2008) have shown that germination and fermentation of millets and sorghum significantly reduce the amount of antinutrients (tannin and phytate) leading to effective starch and protein hydrolysis and increased mineral bioavailability (free sugars, soluble protein and minerals). The investigation of Wadikar et al. (2006) showed that puffing improved the nutritional quality of ragi. Inyang and Zakari (2008) observed an increase in the levels of protein, ash, crude fibre, phosphorus, calcium and iron in fura – a millet based dumpling.

WHOLE GRAIN CEREAL FIBRES AND PHENOLICS FOR HEALTH AND WELLNESS

As investigations continue to establish the protective cancer preventive and healthful compounds in cereal grains (Kasarda, 2001; Pietta, 2003; Jenkins et al., 2008; Kahlon 2009; Poutanen, 2009), these minor cereals are considered as health grains in the sense that they are often consumed whole and are gluten-free, hence suitable for coeliacs (Taylor et al., 2006; Pasupuleti and Anderson, 2008). Millets are rich source of dietary fiber, phytochemicals, micronutrients, nutraceuticals, and could be rightly termed as nutricereals (Desikachar, 1977). It has been shown that the whole wheat flours of different wheat varieties contain significant amounts of phenolic antioxidants and dietary fibers. Dietary fibers present in wheat as pentosans are beneficial against diabetes, colon cancer and cardiovascular diseases (Aoe, 2008; Revanappa and Salimath, 2010). Hamaker et al. (2009) examined the potential functionality of corn bran in extrudates implying that cereal bran fibres, good for colon health, show good potential for high incorporation into extruded foods. Sorghum phytochemicals have been shown to have potential impact on human (Awika and Rooney, 2004). There is now evidence that the consumption of whole grains and whole-grain products is implicated in the prevention of cancer and other chronic diseases (Poutanen, 2009), hence acha, iburu and tamba (AIT) usually consumed as whole grain may have more significant roles in human health than conventional cereal fibres and other bioactive compounds. This speculation needs concerted scientific investigation by all stakeholders with support from governments, donor organisations, academia, food industry and the private sector.

Similarly it is speculated that natural antioxidants from whole flours from AIT grains may contain scavengers of free radicals in biological systems, and therefore, it would provide health benefits to consumers. Studies have shown that plant food material with polyphenolic constituents have more potent antioxidant and anti-inflammatory activities. Therefore, investigation into AIT cereal grains could reveal economic potential for development into health promotion products. In many epidemiologic studies, an inverse association between high cereal intake and low cancer incidence has been observed (Marquart et al., 2007; Poutanen, 2009; Shewry, 2009a).

VALUE-ADDED PRODUCTS MADE FROM ACHA, IBURU AND TAMBA (AIT)

Various value-added products are made from AIT cereal grains in countries of sub-Saharan Africa and in India – a major finger millet-producing country in the world. In special bakery products, health and organic foods including the expanding gluten-free market (Lovis, 2003); cereal grains such as rice (Ylimaki et al., 1988; Kadan et al., 2001), sorghum, millet (Badi and Hoseney, 1976; Satin 1988; Rooney and Awika, 2005; Schober et al., 2005) and teff (Bultosa et al., 2008) are of particular interest (Tilley, 2009). AIT cereal grains are found in the same geographical region (Jideani and Jideani, 2011) and they can be exploited in similar ways as conventional cereals.

Animal study showed that rats fed with acha-soybean and acha biscuits had feed efficiency ratios of 0.154 and 0.151; and protein efficiency ratios of 0.996 and 0.985 respectively (Ayo et al., 2010). This study observed that there was no significant effect ($p<0.05$) in terms of nutrient improvement on addition of soybean. On the concern about the presence of antinutrients in finger millet, various processing techniques now give promising result for inactivation in food materials such as irradiation (Makokha et al., 2002). The value addition to finger millet by germination and fermentation decrease the antinutrient levels and enhance digestibility (Sripriya et al 1997), and with *Monascus purpureus* provides scope for development of functional food (Venkateeswaran and Vijayalakshmi, 2010).

Some work that could lead to guided utilization of AI&T in the production of malted and roasted products by the food industry have been done. This is on the recognition that these processes produce more nutritious beverage products (Coda et al., 2010). The investigation on malting of acha and iburu include those of Nzelibe et al. (2000), Nzelibe and Nwasike (1995), Lasekan and Feijao (2002), Lasekan (2004); and Lasekan et al. (2010); and on tamba those of Malleshi and Deikacher (1986) and Chandrashekar (2010). There is prospect of the commercial use of these nonconventional cereal grains indirectly as adjunct or directly in alcoholic and non-alcoholic beverages (Gaffa et al., 2001; 2002a; 2004; Lasekan et al., 2010).

PROSPECT FOR INCREASED PRODUCTION OF NEGLECTED CEREAL GRAIN CROPS

Attempts have been made on fonio grains using biotechnology tools on genetic improvement (Kwon-Ndung and Misari, 1999; Kuta et al., 2003) on yield increase through rotation (Ndiaye et al., 2008) and on response to nitrogen, phosphorus, and potassium (N-P-K) fertilizers under varying climatic conditions (Gigou et al., 2009). The first genetic improvement of acha (*D. exilis*), with a protocol for regeneration using stem segment (culm) as an explants source, has been established by Ntui et al. (2010). The procedure as reported is expected to be useful in micropropagation and genetic transformation of various genotypes of this species to incorporate characteristics such as disease resistance, stress resistance, for increasing the yield potential of this crop.

Notwithstanding the vast potential of these traditional cereal grains, they are still being sidetracked in technological innovation by development and funding agencies. The input, investment in infrastructure, technology and agricultural research made to the "new rice for Africa drought-resistant rice variety" project that helped to boost production in Africa is equally needed for AIT cereal grains that are more nutritious. This is necessary as these grains grow under different agro-climatic conditions unfavourable to conventional cereal crops. To increase the value of fonio, European Union financed an international research project (INCO) under the 6th European Union Programme (FP6), in the priority area of "Bio-diverse, bio-safe and value added crops" dealing with food security. This initiative is commendable with more of such expected in the near future on "minor" grains. As stated by IFT (Floros et al., 2010), scientific and technological advancements in agriculture and food technology must be accelerated and applied in developed and developing nations alike, if we are to feed a growing global population.

With present advancement in technology, the challenge to geneticists and cereal scientists regarding AIT is to increase the seed size and yield through selection, hybridisation, application of transgenics (Gressel, 2008) or other genetic manipulation. Such plant genetic improvement and breeding programmes would target the inherent potentials in these grains, like bioactive components (Sartelet et al., 1996; Taylor et al., 2006; Chandrashekar, 2010) and the high methionine content (Jideani et al., 1994a) for beneficial genetic transformation.

RESEARCH DIRECTIONS FOR TECHNOLOGICAL EXPLOITATION OF ACHA, IBURU AND TAMBA CEREAL GRAINS

1. Previous reports analysed storage proteins of acha using sodium dodecyl sulphate polyacrylamide electrophoresis technique and isoelectric focusing (IEF) and showed the various protein subunits (Jideani et al., 1994a, b, 2000). Additional research using separation techniques like HPLC, capillary electrophoresis used in the classification of cereals will reveal more details of the various protein fractions, particularly the prolamin and glutelin fractions in these minor cereal grains. Amino acid sequencing of the predominant protein subunits having molecular weight in the range of 20 to 25 kDa, as well as a 65 kDa subunits that could not be extracted by conventional methods (Jideani et al., 1994a, b) would reveal more information. A major protein component with molecular weight 25.2 kDa, which was absent in durum wheat forms a basic structural component of acha storage protein and needs subjection to further biochemical investigation.

2. The relatively high level of hydrophobic residues in prolamin protein fraction of acha (Jideani et al., 1994a) is a potential that could be exploited as bioplastic films and coatings for foods. This is with the understanding that grain proteins are particularly important in determining the end use quality, particularly for nutrition of humans and for food processing (Shewry, 2009a). From what is known about acha protein fractions and the disulfide-bonding resulting from the high content of sulphur containing amino acids (de Lumen et al., 1993; Jideani et al., 2000) there could be both negative and positive effects on their nutritional and functional properties as in kafirin and zein disulfide bonding in sorghum and maize (Taylor, 2009).

3. Further studies are needed on the high content of sulphur containing amino acids, like the synthesis of methionine-rich protein with a view to cloning the DNA. Since cereal grains are primary food stuff for humans and livestock, their amino acid balance is important for proper nutrition. Methionine, an essential amino acid and a primary source of sulphur, has been shown to be high in acha and iburu but negligible in other cereal endosperm. The populations of *D. exilis* could be further developed through breeding with enhanced methionine content. Ali et al. (2011) through zein genes selection expressed in the endosperm demonstrated enhanced methionine biosynthesis in high and low methionine maize populations. This shows the focus and emphasis on conventional cereals compared to "lesser known" cereals with the inherent potential of high methionine for exploitation.

4. There is need in exploitation of the inherent health benefits of AIT. The consumption of these grains as whole grain would result in retention of minerals and vitamins that would have been lost during processing. Similar to other emerging ancient grains, like chia, quinoa, teff, and amaranth (Pszczola, 2009), AIT cereal grains have potential in new product development as they are believed to represent the highest quality of vitamins, minerals, fibre and the sulphur containing amino acids. The food industry may look into ways of incorporating these cereal functional ingredients in baked product and other food systems.

5. Effects of processing techniques such as extrusion on starches from AIT cereal grains need investigation. Preliminary investigation pointed to the presence of

resistant starch in acha (Jideani and Podgorski, 2009). Further investigation into the nature of polysaccharides could reveal non-cellulosic polysaccharides and oligosaccharides like arabinoxylans, pectins, arabinogalactans and (1-3), (1-4)-beta-glucans speculated to be associated with low cancer incidence and high cereal intake.

6. Research directed at breeding for genetic improvement, conservation and management of genetic resources still has much to cover on these grains. Selection for high levels of bioactive components in cereal breeding programmes leading to a new generation of 'healthy' cereal grains is now possible (Kleter et al., 2001; Shewry, 2009b).

7. Considering the small size of these cereal grains, innovation in harvester technology would improve productivity of grain/ha through development of adapted varieties, appropriate production and farming systems technology by way of innovation in post-harvest mechanisation and processing (Jideani and Jideani, 2011).

CONCLUSION

Cereal grains, like acha, iburu and tamba (AIT), with excellent culinary and nutritional properties contain phytonutrients believed to be functional ingredients responsible for some health promoting properties. These grains have been put into various new uses like decortications, puffing, extrusion, expansion, sprouting, fermentation and roasting. However, process optimisation with regard to value added extruded products is an area for investigation. An increasing global population necessitates structural and policy improvement in the food challenge facing sub-Saharan Africa by scientists, food industry, governments, international donors and the private sector for high production of both major and minor edible grains to cater for health, wellness and other needs of human population. The scarcity of research funding as well as other constraints militating against these traditional and non-conventional cereal grains requires collaborative efforts from industry, governments, academia in the region as well as international funding agencies to tackle scientific investigation into these grains believed to have significant beneficial roles in human health. The expectation from this review is for more scientific investigation on acha, iburu and tamba cereal grains.

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