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REVIEW

Developments on the cereal grains *Digitaria exilis* (acha) and *Digitaria iburua* (iburu)

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Abstract Research and development on these indigenous African cereal grains, acha (*Digitaria exilis* Stapf) and iburu (*D. iburua* Stapf), is experiencing renewed interest not just in Africa but the rest of the world. It is believed that acha and iburu may have nutraceutical properties, as it is used in some areas for managing diabetes. Value addition and exploitation of fonio (acha and iburu) in the development of health or speciality foods like acha-bread, biscuit, cookies, sour dough, traditional drinks, nonfermented steamed and granulated dumpling products are gaining interest. These grains may also contribute in addressing some very relevant challenges in today's food formulation—both from functionality and health perspectives. The constraint of low yield is receiving attention in cereal breeding programmes which may give rise to a new generation of 'healthy' cereal grains in future. Further research on acha and iburu whole grains will hopefully lead to increase understanding of the health effects of grain components and to increase the intake of health-protective grain components. Moreover, with strong consumer demand for these grains due to their potential nutritional and health benefits, and because they help to satisfy the demand for a more varied cereal diet, efforts should be made to tackle the obstacles militating against production, improved quality, competitiveness and value-addition.

Keywords Acha · Cereal · *Digitaria spp* · Fonio · Health benefits · Iburu · Wholegrain

Introduction

The world continues to depend and receive sustenance from grain crops (Conklin and Stilwell 2007) including the continent of Africa (Taylor 2004). An increasing world population necessitates high production of grains to cater for the food needs of the masses, resulting in the replacement of Agriculture with agri-commerce in most parts of the world. This fact is resulting in the shift from traditional to commercial crops, from non conventional to commercial cereal crops.

However, traditional cereals—sorghum (Rooney and Awika 2005), millet (Joshi et al. 2008; Balasubramanian and Viswanathan 2010), acha (white fonio), iburu (black fonio), tef, maize, and rice, still constitute the staple diet for human consumption, and play an essential role in providing not just food but healthy food for the poorest populations and regions. Healthy food in the sense that most of these traditional cereal grains are often consumed whole and the sorghum and millets are gluten-free, hence suitable for coeliacs (Taylor et al. 2006).

Among traditional cereals, acha (*Digitaria exilis* Stapf) and iburu (*D. Iburua* Stapf) which are also called fonio (Dendy 1995)*, fundi, findi*, hungry rice, and Asian millet (NRC 1996) have received increasing attention in research and development since the last review (de Lumen et al. 1993; Irving and Jideani 1997; Jideani 1990, 1999; Kwon-Ndung and Misari 1999; Nzelibe et al. 2000; Morales-Payan et al. 2002; Adoukonou-Sagbadja et al. 2004; Philip and Itodo 2006; Ayo and Nkama 2006; Jideani et al. 2000, 2007, 2008; Taylor 2008; Agu et al. 2008a, 2009). Such

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attention is seen in the European Fonio project—a cereal believed to be a healthy and cheap addition to European diets, while at the same time generating incomes for local producers in Africa (Dury et al. 2007). The project is managed by the French Agricultural Research Centre for International Development (CIRAD), and aims to increase production and bring the crop to the European market (CIRAD 2006).

The consumption of fonio (acha and iburu) like in *tuo (tuwo), djouka, couscous, gwete, achajollof, kunuacha*, etc. (Jideani 1990, 1999) should no longer be regarded as a coping strategy for increasing household food security considering the high comparative cost of this traditional cereal in area of production (Kone 1993; Jideani 1999; Dury et al. 2007) and the fact that they are sold to Africans emigrated in Europe and United States. The cereal, cultivated throughout West Africa, is now in high demand in English-speaking countries (Nigeria, Ghana, and Gambia) and in the Francophone countries (Mauritania, Niger, Chad, Benin, Burkina Faso Senegal, Mali, Cote d'ivoire, Togo and Guinea), where it is produced (Jideani 1990; Kone 1993; Obilana 2003; Ayo and Nkama 2006). These grains are now produced by small enterprise and sold not only on local urban markets, but also to Africans who emigrated to Europe and United States. Export markets are now in place arising from the strong consumer demand partly due to its nutritional qualities (Lasekan 1994; Jideani 1999) and because it helps to satisfy demand for a more varied cereal diet.

With the tempo of research and development activities around the crop, it is conceived that in the near future exportable value-added acha and iburu products will begin to emerge in the European and United States markets. For European consumers, the desirable criteria are nutritional quality, originality, healthier properties and environment friendliness (CIRAD 2006).

Acha and iburu—consumption as wholegrain cereal

The growing popularity of whole grains has opened up opportunities for more novel, flavourful and lesser-known types of grains. Acha and iburu cereal grains are mostly consumed whole, perhaps because of their small size (Jideani and Akingbala 1993)—each seed is only slightly larger than a grain of sand. Progress has been made with respect to whole grains on many fronts cumulating so far to three international whole grain summits. Wholegrain is defined as intact and/or processed (e.g., de-hulled, cleaned, ground, cracked, flaked or the like) grains, where the fractions endosperm, bran and germ are present in the same proportion as found in the least processed traditional forms of the edible grain kernel of the same species (Jones 2009). Another definition says that "whole grains shall consist of the intact, ground, cracked or flaked caryopsis, whose principal anatomical components—the starchy endosperm, germ and bran—are present in the same relative proportions as they exist in the intact caryopsis". A list of cereal grains, including acha and iburu, that are considered as wholegrains when consumed in whole form is shown in Table 1 (Jones 2009). There is now sufficient evidence showing that higher whole grain diets compared with refined grain diets are beneficial for several health outcomes (Marquart et al. 2007). Incidentally, acha and iburu are naturally and always consumed as whole grain. In recent years, increasing demand possibly reflects consumer interest in less-processed foods and the subsequent health benefits of these grains. It is possible that acha and iburu are potentially important source of nutraceuticals such as antioxidant phenolics and cholesterol-lowering waxes. It was previously reported (Jideani 1999) that acha and iburu help diabetic patients in parts of West Africa. The healthful, cholesterol-lowering, and cancer-risk-reduction potential of cereals and cereal fractions has been predicted by evaluating their in vitro bile acid binding under physiological conditions (Kasarda 2001; Kahlon 2009). There is increasing approach to use more of grains for health maintenance. Consumption of the grain as whole grain makes it an excellent source of dietary fibre and associated nutraceutical benefits of whole grain suitable for the health conscious and for obesity and diseases, such as diabetes. The research and discussions have focused on whole grain cereals. One of such is the Healthgrain EU Integrated project aimed to provide the scientific basis for increasing the intake of protective grain components relevant for reduction of risk of metabolic syndrome-related diseases. The research program, during 2005–2010; includes breeding, technology, nutrition, and consumer research, and interactive network with different stakeholders (Poutanen 2009). Food products that are source of dietary fibre are useful in the prevention and treatment of constipation, cardiovascular diseases and hypertension (Kamran et al. 2008) hence acha and iburu stand the chance of helping millions in the continent of Africa and also alleviate the prevailing food insecurity.

The health benefits of wholegrain cereal products are now widely recognised (Marquart et al. 2007) and considered to result from the presence of a range of bioactive components, including dietary fibre and phytochemicals (Shewry 2009). The Codex Alimentarius Commission's Committee in Nutrition and Foods for special dietary uses at its meeting in Nov. 2008 adopted a new definition of dietary fibre as "Carbohydrate polymers with 10 or more monomeric units, which are not hydrolysed by the endogenous enzymes in small intestine of humans" (Codex Alimentarius 2010).

The use of whole grain product in the development of specialty food has been on the increase with Kroger

Table 1 The AACC Intl. Task Force on Defining Whole Grains in Foods' list of cereals and pseudocereals that when consumed in whole form, including the bran, germ, and endosperm are considered whole grain

Cereal	Scientific name
True cereals	
Wheat, including spelt, emmer Faro, einkorn, kamut, durums	*Triticum* spp.
Rice, African rice	*Oryza* spp
Barley	*Hordeum* spp.
Corn (maize, popcorn)	*Zea mays*
Rye	*Secale cereale*
Oats	*Avena* spp
Millets	*Brachiaria* spp.; *pennisetum* spp.; *Panicum* spp.; *Eleusine* spp.; *Echinochloa* spp.
Sorghum	*Sorghum* spp.
Teff (tef)	*Eragrostis* spp.
Triticale	*Triticale*
Canary seed	*Phalaris arundinacea*
Job's tears	*Coix lachrymal-jobi*
Fonio (acha, iburu, black fonio, hungry rice, Asian millet)	*Digitaria* spp.
Pseudocereals	
Amaranth	*Amaranthus caudatus*
Buckwheat, Tartar buckwheat	*Fagopyrum* spp.
Quinoa	*Chenopodium quinoa* Willd.-is generally considered to be a single species within the Chenopodiaceae
Wild rice	*Zizania aquatica*

Jones (2009) with slight modification on fonio

recently offering 6 varieties of cholesterol-lowering bread with 100% whole wheat bread (IFT 2008). Plant sterols, also called phytosterols, found in plants, are clinically shown to lower LDL cholesterol as part of a heart-healthy diet. Clinical studies suggest that plant sterols can reduce cholesterol by 8–15%. Plant sterols have been determined to be Generally Recognized as Safe in a variety of food and beverage applications (Kowalski 2010).

Uniqueness of acha and iburu cereal grain proteins

Research and development on acha and iburu cereal grains is experiencing renewed interest in Africa and the rest of the world, particularly for its flavour and nutritional qualities (Jideani et al. 2000; Shewry 2002; Koreissi et al. 2007). Acha and iburu proteins have composition similar to that of white rice (Temple and Bassa 1991; Jideani and Akingbala 1993), but having relatively higher sulphur amino acid (methionine and cystine) content (de Lumen et al. 1993; Lasekan 1994; Jideani et al. 1994a). Sulphur amino acids are crucial for proper heart function and nerve transmission, and cereals are an essential source of amino acids for people with low meat intake (CIRAD 2006). This and other attributes of acha and iburu show the uniqueness of the grains and their potential in contributing significantly to whole grain diets. Undoubtedly, utilisation would also lead to improvement in economic status of the producers in Africa.

Acha proteins have been shown to be less susceptible to denaturation than durum protein (Jideani et al. 1994b, c). In-vitro protein digestibility (IVPD) values for cooked and uncooked acha using pepsin were similar to those of cooked and uncooked durum wheat; without much change in the IVPD for both cereal grains at cooking temperatures of 100–140 °C and times 10–40 min in either water or salt solution. Most, if not, all countries in Africa still import substantial amount of wheat and wheat end products. Such importation has implication on the already weak economy of these countries hence the need for concerted effort to develop acha and iburu grains. Preliminary results show that these grains, based on the functionality of the proteins, can be used to create a number of value added food products (Table 2). Acha grain would therefore be suitable as a good source of calories and digestible proteins for many people living in and beyond the semi-arid tropics who depend largely on maize, sorghum and millet grain supplies. The relatively high level of hydrophobic residues in prolamin protein fraction of acha is a potential that could be exploited as bioplastic films and coatings for foods.

Table 2 Food use potential of acha (*Digitaria exilis*) and iburu (*D. iburua*) with corresponding references

Food use	References
Biscuits: Acha/iburu –flour, -wheat, -soybean biscuit	Ayo and Nkama (2003)
Wheatless acha/iburu bread	Jideani et al. (2007, 2008); Ayo et al. (2008)
Composite acha/iburu bread	Ayo and Nkama (2004); Igyor (2005); Jideani and Ibrahim (2005)
Alcoholic beverage—malting	Nzelibe and Nwasike (1995); Nzelibe et al. (2000)
Non alcoholic beverage	Gaffa and Jideani (2001); Gaffa et al. (2001, 2002a, b, c, 2004)
Dumpling product—*dambu*	Agu et al. (2007, 2008a, b)
Porridge	Obizoba and Anyika (1994)

Starch properties of acha and iburu cereal grains

The molecular features of acha and iburu starches are similar to tef (*Eragrostis tef* Trotter). Bultosa et al. (2008) observed slow rate of retrogradation, slightly lower percent crystallinity, lower gelatinisation temperatures and lower gelatinisation enthalpy for tef starches (as compared to maize starch) and related these to the shorter outer (A + B1) chain lengths of their amylopectin molecules, and suggested could be the foundation of the good keeping quality of tef injera, the main staple on the Ethiopian diet. The lower setback viscosities of acha and iburu starches upon cooling to 50 °C would make them suitable for use in preparing gels with tendencies to synerese (Jideani and Akingbala 1993).

Nutraceuticals are now said to play a role in diabetes. It is believed that acha and iburu may have nutraceutical properties. Resistant starch is part of some ingredients that assist in preventing and managing prediabetes and type 2-diabetes. Some of the other ingredients include bioactive peptides, traditional herbs from China, India, and Mexico, Cinnamon, Chromium, soybeans and soy components and others (Pasupuleti and Anderson 2008).

One source of dietary fibre that is receiving increased interest for use as a food ingredient is resistant starch (RS), Starch that resists digestion and absorption in the small intestine (Mermelstein 2009). Four types of resistant starch exist: RS1—Physically inaccessible or indigestible starch, found in seeds, legumes, and unprocessed whole grains; RS2—Starch that occurs in its natural granular form, such as uncooked potato, green, banana flour, and high-amylose corn; RS3—Starch with digestion-resistant crystalline regions formed when starch-containing foods are cooked and cooled e.g. cooked-and-chilled potatoes or retrograded high-amylose corn; and RS4—Chemically modified starches not found in nature, including starch ethers, esters, and cross-bonded starches (Anderson et al. 2010).

It is believed that acha and iburu contain resistant starches. Resistant starches have shown promise in the management or prevention of certain diseases or health conditions. Now, researchers are studying how resistant starches can reduce the glycemic and insulin response (Pasupuleti and Anderson 2008; Yadav et al. 2010; Deepa et al. 2010).

The in-vitro starch digestibility and glycemic property of acha, iburu and maize porridge has been investigated (Jideani and Podgorski 2009). The study showed that the total starch (TS) for maize, acha and iburu flours were 45.3, 43.6 and 41.5% respectively. The resistant starch (RS) was 2.9, 2.1 and 1.2 respectively for maize, acha and iburu flours and the digestible starches (DS) 43.7, 41.4 and 40.0%. The authors conclude that acha and iburu may have potential in a low GI food as porridge from both grains had low estimated value of 40 (Jideani and Podgorski 2009). As the number of people diagnosed with diabetes continues to increase around the world, nutritional approaches to diabetes prevention is one step researchers should take to address this serious situation by formulating a diet to optimise health and counteract the risk factors of metabolic syndrome in an aging population (Aoe 2008). Clinical trials using antihyperglycemic medications to improve glycemic control have not demonstrated the anticipated cardiovascular benefits. Low-glycemic index diets may improve both glycemic control and cardiovascular risk factors for patients with type 2 diabetes, and Jenkins et al. (2008) demonstrated that in patients with type 2 diabetes, 6-month treatment with a low-glycemic index diet resulted in moderately lower glycated haemoglobin A levels compared with a high-cereal fibre diet.

Today, with diabetes on the rise even among teenagers coupled with the advocacy to avoid refined grain products, whole grain acha and iburu can present a healthier alternative in the form of diabetes-friendly products and other health management products.

Development of value-added acha and iburu products

Acha and iburu have considerable potential in foods and beverages (Jideani 1997, 1999; Jideani and Ibrahim 2005). Towards adding value to the promotion of acha and iburu as convenience and conventional foods and drinks some products have gone through laboratory production as discussed in this section.

Production of non-wheat bread from acha (*D. exilis*) was successful on laboratory scale (Jideani et al. 2007), awaiting development at pilot scale level. The focus being the development of 'bread' from acha and iburu for dietetic purposes considering the possible technological uses of the grains (Jideani 1997) coupled with the advantage of being gluten-free. Similar studies have been done on non-wheat bread from rice (Ylimaki et al. 1988; Kadan et al. 2001) and sorghum (Schober et al. 2005) in search of novel ways of making bread to reduce the Third World's dependence on imported wheat for white bread (Satin 1988; Lovis 2003). The possibility of producing acha bread with Irish potato starch (IPS) (Alexander 1995) as gluten replacer (Ranhotra et al. 1975) with varying (1–4%) quantity of carboxymethylcellulose (CMC), and the effect of sprouted soybean flour on the acha bread have been reported (Jideani et al. 2008). The addition of CMC (Dziezak 1991) gave an increase in loaf volume (LV) of 40.0% in acha bread (AB) with 1% CMC to 59.5% in AB with 4% CMC. The specific loaf volume (SLV) did not differ significantly from each other. AB with 4% CMC compared favourably with wheat bread in sensory characteristics. The addition of 5% sprouted soybean flour made the bread softer and significantly increased the crude protein and fibre content of the loaf (Jideani et al. 2008).

Some investigators are currently using starter cultures of lactic acid bacteria and yeast for sour acha, cassava flours, and cassava starch in production of sour dough (compared with sour maize bread) based on conventional technique. Preliminary results show the great potential inherent in acha and iburu for sour dough. The investigation will include development of starter cultures for acha and iburu sour doughs (Edema 2009, Personal communication. University of Agriculture Abeokuta Nigeria).

The use of acha in the production of dambu—a non-fermented, steamed and granulated dumpling product from cereal grains has been demonstrated (Agu et al. 2007). The findings suggested that acha among other cereal grains (pearl millet, maize, and sorghum) could serve as a substitute and complementary to millet, sorghum and maize grains in the production of dambu. Of particular interest was that the amino acids profile of dambu made from acha (DAH) (in g/100 g protein) were comparatively higher than those made from other cereal grains. Sensory tests indicate that products made with acha and iburu have desirable taste, texture and appearance. (Table 3); substantiating the fact that acha grains can be exploited in the development of health or speciality foods. Dambu is a popular midday meal of the Fulanis, normally sprinkled into fermented skimmed milk or whole milk and sugar may be added to taste. The Fulanis are ethnic group of people spread over many countries predominantly in West Africa and also found in Central and North Africa (Wikipedia 2010) between the latitude 4°N to 30°N and longitude 15°W to 18°E.

Other food uses of acha and iburu

Cakes, cookies and other snack foods have been successfully made from acha and iburu. Wholemeal acha and iburu flours can be used in the preparation of a number of biscuits and snacks that could be useful for individuals with gluten intolerance (Ayo and Nkama 2003). The use of sorghum and pearl millet flours in cookies have been reported (Badi and Hoseney 1976; Chiremba et al. 2009). From functionality and health perspectives, acha and iburu can serve as ingredients in formulating bars, breakfast mueslis and ready-to-eat cereals, pasta, crackers, cookies and biscuits. Ancient grains have been emerging in recent months, like chia, quinoa, teff, amaranth and millet in new product development. Acha and iburu have similar functional properties with these grains that are believed to represent the highest quality of vitamins, minerals and fibre; hence there is great potential in their use as ingredients in product formulation.

The low-starch gelatinisation temperature (Jideani et al. 1996) and high-beta-amylase activity (Nzelibe and Nwasike 1995; Nzelibe et al. 2000) shows the brewing potential of acha and iburu in partial substitution of barley malt.

Table 3 Sensory qualities of dambu produced from maize (DME), millet (DMI), sorghum (DSO), and acha (DAH)

Dambu	Aroma	Texture	Appearance	Chewiness	Overall acceptability
DME	6.3±1.86	5.5±1.79	5.7±2.03	6.2±1.60	5.8±2.10
DMI	7.2±1.80	6.4±1.76	6.1±2.05	6.1±1.74	6.7±2.16
DSO	6.6±2.11	5.6±2.58	6.2±2.21	5.7±2.34	5.7±2.50
DAH	6.5±1.64	7.2±1.98	7.6±1.32	6.6±2.28	6.6±1.64

Values are mean ± standard deviation; Means with different superscript within the same column differ significantly ($p<0.05$) using Duncan multiple range test

Agu et al. (2007)

Constraints and opportunities for commercialisation

The need for tedious harvesting and postharvest processing of *Digitaria* spps still pose problems to utilisation of this potential indigenous crop in Africa (Adoukonou-Sagbadja et al. 2006). Results obtained by Adoukonou-Sagbadja et al. (2007) are relevant for acha and iburu breeding, conservation and management of their genetic resources in West Africa.

There is a need to improve productivity of acha and iburu (from the present 500–600 kg of grain/ha through non-mechanised, labour intensive process) through development of adapted varieties, appropriate production and farming systems, etc.; technology by way of innovation in post-harvest mechanisation and processing; and distribution systems for local and export markets. It is believed that these grains are well positioned for improved production considering that present production cannot meet a quarter of demand (NRC 1996).

There should be attempts to measure the levels of phytochemicals in acha and iburu and characterise the physiological relevance of the whole grain bioactives at levels provided by a diet of whole grain foods. It is known that modern varieties of grains do have higher levels of phytochemicals (Shewry 2009). 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 2009). It would be helpful to know the amounts and compositions of bioactive components, including dietary fibre and phytochemicals, among these *Digitaria* spps and whether this can be exploited to produce new types of grains with enhanced health benefits. Awika and Rooney (2004) reported phytochemicals and potential impact on human health for sorghum. Acha and iburu grow in the same or similar climatic condition with sorghum, millet and maize in West Africa. Variation in amounts and compositions of dietary fibre and phytochemical components in cereal grains is genetically determined, although environmental effects were also observed (Shewry 2009). Effects on African cereal grains, particularly acha and iburu consumed as wholegrains, are therefore needed in this emerging area with apparently much benefit to human nutrition.

Acha and iburu are believed to be high in fibre (NRC 1996). There is general consensus among public health authorities and nutritionists that the inclusion of fibre in the human diet provides health benefits (Pietta 2003). That benefit message has reached consumers, and many food and beverage companies have responded by launching products fortified with fibre. Accurately measuring the fibre content of foods is critical to making a sound benefit claim, whether it is a nutrient content claim, structure-function claim, or health claim (Mermelstein 2009). Further work is needed on the health benefit of acha and iburu as not all whole grains have equal effects on health, the same physiological benefits, or equal levels of evidence. In terms of levels of evidence regarding various whole grains and health, it is said that the following continuum exists: oats> barley>rye>wheat >>rice>corn (Jones 2009). There is need to evaluate the healthful properties of acha and iburu using various assays like the bile-acid-binding approach. For greater health-promoting potential of plant foods, commercial breeding companies have been making use of this in vitro bile-acid-binding methodology in their selection. In vitro bile binding is a valuable tool for screening food fractions for their healthful potential before animal and human studies are warranted (Kahlon 2009).

There should be work on sensory attributes and consumer acceptance. This will help to also create a consumer demand versus technology push in the development of not just a good quality product from acha and iburu as in other grains (Talukder and Sharma 2010) but exportable value added products from these cereal grains.

Conclusion

Acha and iburu cereal grains have received some attentions and show an impressive future and huge potential for wider use. No doubt, these grains are becoming important to world's scientists hence the fonio (acha and iburu) research (2006–2009) under the EU's Research programme.

As rich source of fibre and other phytonutrients, they can be used as ingredient helping to improve nutritional profiles without compromising taste and quality in products. The advantage of incorporating acha and iburu as whole grains into formulations looks enormous, for example blending them with refined grains. Following these strategies, innovative formulations can be developed ranging from pastas designed specifically for diabetics to varied dishes combining exotic flavour with whole grain benefits. On the consumption of these two grains as whole grain and healthful benefit, future work might focus on attempts to further establish the health claim on acha and iburu grains. Although few studies mentioned above have started looking into the area of resistant starch, it appears that the issue needs further research including phytochemicals to ascertain the potential impact on human health. Health benefit is critical for a broad acceptance of acha and iburu by consumers, if it is to be produced on a high scale and not on the present small restricted areas.

However, some serious technical problems remain. Some of the challenges to geneticists and cereal scientists include whether it is possible to increase the seed size through selection, hybridisation, or other genetic manipulation; and the yield of acha and iburu. There is the need to use modern knowledge of cereal-crop improvement to make some advances and improvements. Concerning genetic manipulation of acha and iburu seeds for increased yield, application of transgenics (Gressel 2008) might be an option for plant breeders to consider as prerequisite for commercialisation in light of food security, globalisation and Africans emigrated to Europe and United States as consumer demand in Africa and Europe continues to increase.

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