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Development and Utilisation of Improved White-Seeded, Tan-Plant Grain Sorghum Cultivars in Mali

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Authors' contributions

This work was carried out in collaboration between all authors. Author AT designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors AOT and AGD collected field data and managed the analyses of the study. Authors AB and FC managed the grain and new food products analyses. Authors MD, NY and BD managed the pests, diseases and weeds control. Author AWT addressed the agronomy and cultural practices. All authors read and approved the final manuscript.

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ABSTRACT

The pedigree breeding method was successfully adopted to develop high yielding, white-seeded, grain sorghum cultivars with other attributes including "tan" plants, sensitivity to photoperiod and excellent adaptation to the Sudanian and Sahelian agro-ecological conditions in Mali. The new cultivars possess an excellent grain quality which added value for processing. The breeding process included crossing of local guinea race cultivars and improved or introduced Caudatum race varieties, selected from F2, F3, F4, F5 and F6 generations, conducting yield and grain quality trials of advanced lines on station and on-farm with farmer participatory selection. Processing quality of

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the grain was evaluated through measuring the decortication yield of each cultivar using the TADD (Tangential Abrasive Dehuller Device); measuring shelf life of processed flour in bags made of polyethylene for 3 months; manufacturing of new products by partially substituting wheat flour with flour of new sorghum varieties in pastry and biscuits. The study revealed a series of improved lines with "tan" plants, white grain, Guinea race type characterised by a loose panicle, long glumes and a hard grain. The best example of new cultivars N'Tenimissa, was described as the first white, "tan" plant, straw-coloured glume, photoperiod sensitive and high yielding sorghum cultivar with a white endosperm, and a thin pericarp developed in Mali. The cultivar has almost the same decortication yield with already adopted varieties by farmers. Its flour yield is similar to that of local guinea cultivars, and its flour is nearly as white as wheat flour. The analysis of various organoleptic parameters indicated that partially substituting wheat with 20% sorghum flour made the preferred biscuit by consumers prompting the commercial manufacturing of a biscuit called Deliken by the General Alimentation du Mali (GAM). A commercial sorghum supply chain was initiated by linking smallholders producing the new cultivar to a grain trader for selling the grain to the industry. This shows a path for the future in the diversification of uses of a local staple crop, sorghum. It is based on a strong Public-Private Partnership to link smallholders to the commercial supply chain, providing an incentive for farmers to grow new and highly productive cultivars for the development of value-added products.

Keywords: Sorghum; Guinea; tan; white; flour diversification.

1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a traditional food crop in Mali, grown essentially in rainfed conditions. Sorghum farming is practised in areas receiving 400 mm to 1300 mm rainfall with notable variability in time and space. In most of the African countries, sorghum grain is primarily used to prepare human foods and beverages including traditional stiff or thin porridges (tô), granulated foods (couscous), and beer (dolo) [1] and [2]. The most widely grown types of sorghum belongs to the guinea race, characterised by its photoperiod sensitivity, and long, loose and pendulous panicles. Its glumes are open at maturity, thus exposing the grain. Plants are medium to tall in height with small to medium sized grains, biconvex and nearly ovate at maturity [3]. The average grain yield of sorghum in Mali is less than 1mt per hectare which is far below the yield attained in other parts of the World like USA [4]. The development of high yielding sorghum varieties is a necessity for food security and to exploit the available opportunities to increase sorghum production through agricultural intensification in Mali. The development of adapted high yielding sorghum varieties offers the potential to achieve significant productivity gains. Additionally, the diversification of sorghum uses and the valorisation of local cereals, make sorghum poverty reducing crop by adding value through processing [5].

Earlier released improved sorghum varieties with "tan" plants and non-photoperiod sensitive, have poor quality because the grains are highly susceptible to mold and damage by panicle bugs. Since 1990, a special emphasis was given on the use of pedigree selection to develop grain sorghum cultivars that are high yielding, white-seeded, sensitive to photoperiod, possessing "tan" plants and well adapted to the agro-ecological conditions of the country. These types of sorghums are less susceptible to grain discolouration unlike local guinea sorghum enclosing anthocyanin pigments that migrate to the grains with high humidity during the maturation period. It was also envisioned that better grain quality would be added value for grain processing and be more attractive to commercial and small artisanal units of processing. Thus, obtaining "tan" plant coloured and photoperiod sensitive cultivars became compelling for the National Sorghum Breeding Program. The objective of this study is to develop stable, high yielding and high grain quality sorghum cultivars though breeding, selection and appropriate evaluations in Mali.

2. MATERIALS AND METHODS

2.1 Experimental Area and Materials used

Breeding activities were conducted in several research stations and on-farm in Sudan and Sahel zones representing sorghum growing area of Mali (600-1000 rainfall). Several genetic materials involving local landraces (for adaptation and grain quality) and improved

materials introduced from Ethiopia and USA (for grain yield) were used in the development of new cultivars. Farmer participatory approach was used in the identification of farmer preferred varieties.

2.2 Development of Cultivars

The genetical crosses were made between local cultivars (CSM 388, Tiemarfing, Bimbiri-Soumale) and improved or introduced varieties (Zerazera, Malisor 84-7, Sureno.) to develop new cultivars that are high-yielding, white-seeded "tan" plant, sensitive to photoperiod with guinea race type architecture. Individual plant selections were made in the F2, F3 and F4 generations at Sotuba (12°39' N- 07°56' W), Cinzana (13°17'N-05°58' W), Longorola (12°21' N- 05°41' W), Bema (15°02' N- 09°23' W) and Samanko (13°50' N-03°88' W). The best progenies identified in F4 generations were sown in off-season at Cinzana to produce F6 seeds from F5 plants to conduct a preliminary multi-location yield trial with 2 replications and 2 rows of 5 m long. A trial with a completely randomised block design with 4 replicon was used to compare the best progenies to their parents. Each entry was planted manually in an experimental plot of five rows of 5 m long. The interval was 0.75 m between rows and 0.50 m between hills. Plants were thinned to two per hill. The equivalent of 100kg of di-ammonia phosphate fertiliser per hectare were used during plantation and 50 kg of urea during the growth stage. After three years of assessment and characterisation of progenies, the best lines were selected in 1995 after farmer participatory selection in farm tests.

Crop data collected from each experimental unit included: plant height, maturity, 1000 seed weight, plant height, number of seeds/ panicle, grain yield. Data from each experiment were analysed using the General Linear Model procedure (PROC GLM) of SAS (SAS, 1997).

2.3 Grain Quality Evaluation

Decortication yields were evaluated for each cultivar. A 20 g sample was submitted over the periods of 3 and 5 minutes to the TADD (Tangential Abrasive Dehuller Device). The decortication yield was calculated as the weight of decorticated grain expressed as a percentage of weight of the non-decorticated grain. A screening method was developed by using mini-tests for determination of the parameters affecting the quality of local dishes tô and couscous [6]. Grains were decorticated by rubbing against abrasive surfaces mounted on a rotor. Decortication was done by wear of the envelopes through the grain slipping into the wheels. Grain vitrosity was determined by visual estimation of proportions of vitreous and floury of longitudinally sectioned grain endosperm. The grains were ground by using hammer mills. The data were collected for grain quality assessments are as follows: decortication yield, grain vitrosity, tô consistency, and tô colour.

2.4 Biochemical Analysis of Selected Sorghum Cultivars

Biochemical analysis was conducted at Texas A & M University in 2002. Ethero-soluble lipids were determined by Soxhlet method for extraction of fat contained in the flour to the ether or hexane. Free fat content was obtained after drying and weighing of extracted lipids. Total protein (N*6.25) content was determined by the method described by Kjeldahl [7] in 1883, after mineralisation of the sample by concentrated sulphuric acid in the presence of a catalyst through a glassware device in Tecator Kjeltec. In addition, grain samples were immersed in an alkaline solution for 2 hours. Thus, processed grains were dried and ground. The flours were preserved in polyethylene bags for 3 months, in order to see the evolution of microorganisms. Data collected involved: flour colour, flour smell, flour texture, dry matter content, NK or protein and fat content.

2.5 Development of New Processed Food Products

As part of the diversification of sorghum uses and the valorisation of local cereals by adding value through grain processing, a study was conducted to partially substitute wheat flour with flour of the new sorghum varieties and develop pastry and biscuit. The study was carried out at the National Food Technology of IER, Mali during 1998 to 2004. Analyses focused on the preliminary test on cookies and pastries made from the composite flour sorghum/wheat. Various substitutions were made by increasing amounts of sorghum flour to 10%, 20%, 30%, and 40%. New products with 100% improved sorghum flour were also developed. All these products were analysed for organoleptic and culinary characteristics (taste, texture, smell, colour, consistency). An assessment was made of all products base on their organoleptic quality, visual appearance and technology. Thus, all

products were evaluated by consumers in taste tests. These tests were considered to check the quality of the products. A total of 57 volunteers tasted the dishes offered, compared them and gave their opinion and notes based on a scale of appreciation from 9 to 1 and 5 to 1 according to the product.

2.6 Early Development of Commercial Supply Chain of Tan Sorghum

There is a lack of diversification of the uses of sorghum and also a lack of consistent supply of good quality identity- preserved grain, required for increased commercialisation and processing of sorghum into value-added products. A strong Public- Private Partnership was initiated to link smallholders to the commercial supply chain that have many advantages. It also provides an incentive for farmers to focus on higher productivity, increasing the use of inputs such as improved seeds and fertilisers, thereby making the agricultural sector more competitive.

3. RESULTS AND DISCUSSION

The direct crosses of local cultivars of Guinea race (Red and purple plants) with improved cultivars of Caudatum race (tan plant) resulted in a series of improved guinea race type of lines with "tan" plant, and white grain. Sorghum plant colour refers to the visible pigmentation where plant tissue is wounded. In sorghum, three primary plant colours are: red, tan, and purple. The new improved lines have a loose panicle and a high number of grains per panicle (Photos 1 and 2).

Photo 1. N'Tenimissa, tan guinea tall plant

Photo 2. N'Ténimissa with loose panicle and a high number of grains per panicle

They were also characterised by long glumes and hard grain. Thus, N'Tenimissa, the first white seeded, "tan"plant, straw-coloured glume, photoperiod sensitive sorghum cultivar was developed and released in Mali. This new improved "tan" variety has the best features of guinea race of sorghum and it is high yielding (Table 1). It has a white endosperm and a thin pericarp. "Tan" plant is critically characterised for producing sorghum grain with acceptable food quality. White seeded "tan" plant type sorghums, also referred as food-grade sorghums [8], have been developed through breeding for inherently improved sensory attributes of foods produced from them, such as light colour, and blend taste and flavour, compared to sorghums with a pigmented pericarp and white tannin [9,10,11,12]. White seeded tan-plant sorghums have a white pericarp, tan-plant colour and straw or tan coloured glumes, and their endosperm texture ranges from hard to medium [11] and [13].

Decortication yields (3.0 min) varied between 72 and 86% and were lower after 5.0 minutes of decortication. N' Tenimissa has almost the same decortication yield as the varieties already adopted by farmers (Tables 2, 3 and 4). This is mainly due to the constitution of its endosperm, which is the semi-floury type. Decortication is the removal of outer part of the sorghum grains, consisting mostly of non-fermentable materials such as fibres [14]. Most of African sorghum-based foods are processed from decorticated grain. Yields of 75-80% in manual sorghum decortication and of 90% in mechanical sorghum decortication were reported respectively [15].

Table 1. Grain yield and other traits of sorghum lines and progenies measured at Sotuba in 1994 and 1995

Cultivars	Grain yield (Kg/ha)	No. of seeds/ panicle	1000 seed wt.	Maturity (Days)	Plant height (m)
N'Ténimissa	2440	2961	19.89	88	3.23
Bimbiri-Soumalé*Malisor 84-7	1350	3504	11.95	92	1.62
CSM 388*Malisor 84-7	1620	1971	16.84	86	2.66
Malisor 84-7*Tiémarfing	950	1945	14.75	92	2.47
CSM 388*Sureno	1080	3050	8.65	94	2.29
Bimbiri-Soumalé	960	2112	20.85	104	4.43
Zerazera	1860	2894	12.53	67	1.06
CSM 388±	2090	2923	21.03	92	3.87
Malisor 84-7±	1250	3272	14.32	82	1.32
Tiémarfing±	1990	3050	20.79	84	3.88
Sureno	1460	3174	10.84	84	1.96
Mean	1550	2805	15.68	88	2.62
CV (%)	32.22	27.75	6.73	6.54	17.23
Significance	**	**	**	**	**
LSD	390	508.5	1.02	5.61	0.42

*Source Toure et al., 1998, CV: Coefficient of variation, ** Significance at 0.01, ± Release cultivars*

Table 2. Processing attributes of selected sorghum cultivars grown in Mali in 1996[a]

Processing attributes	N'Ténimissa	Local Control	N'Daril a	Dususum a	89-SK-F4-192-2PL
1000 Seed Weight (g)	21.4	20.5	21.3	21.3	27.0
Decortication Yield (3.0 min) %	86.	85.0	75.0	82.0	72.0
Decortication Yield (5.0 min) %	68.8	79.0	54.0	72.0	54.2
Vitrosity[b]	2.8	3.1	3.0	3.1	3.4
Tô Consistency[c]	1.0	1.0	1.0	1.2	2.0
Tô Color	1	1	1	1	1
Plant Color	Tan	Red	Tan	Tan	Tan

Source Toure et al. 1998

[a] Data based on the average of four samples of grain of each cultivar grown at Yrimadio, Mali in 1996

[b] Scale 1-5; 5 = Soft, 1 = vitreous

[c] Scale 1-5; 5 = Soft, 1 = consistent

[d] Scale 1-5; 5 = Very poor, 1 = Very Good, the colour was acceptable from all the varieties after decortication

Table 3. Manual and mechanical decortication yields of three sorghum cultivars

Cultivars	Manual Decortication (%)	Mechanical Decortication (%)	Vitrosity
CSM	76.5	78.21	1.5
Foulatiéba	77.82	77.82	2
N'Ténimissa	75.9	78.2	2.5

The new "tan" plant-white grain sorghums produce flour of excellent quality that can be used for making of bread, cookies etc. The improved tan sorghum cultivars also demonstrated good properties for the preparation of traditional dishes like tô (Table 2 and Photo 4). Flours obtained following the different processes of decortication showed that N'Tenimissa gives as much flour as varieties Foulatieba and CSM 388 which are already adopted by farmers (Table 4). The colour of N'Tenimissa flour is white in colour nearly that of wheat (Photo 3).

Table 4. Tô attributes of flour obtained in manual and mechanical milling of the grain of three different selected sorghum cultivars

Cultivars	Flour from mechanical milling (%)	Flour from manual milling (%)	Tô Consistency manual milling	Tô Consistency mechanical milling	Tô Colour manual milling	Tô Colour mechanical milling
CSM 388	75	65	2	2.5	2	2
Foulatiéba	72.5	61.5	2	2	2	2
N'Ténimissa	90	70	1	1.5	1	1

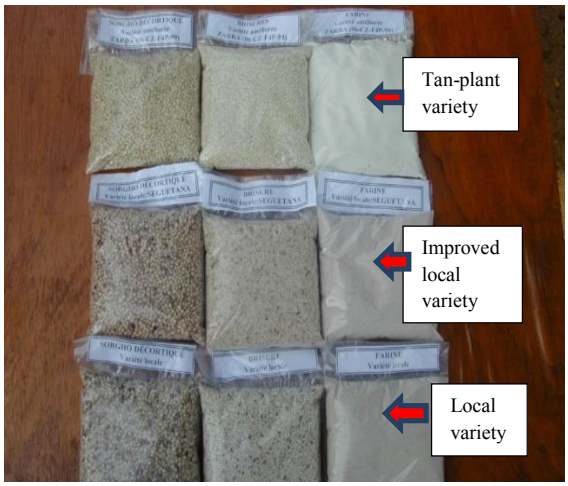

Photo 3. Decorticated grain, grits and flour of traditional tô sorghum varieties (left to right)

Photo 4. Good properties of N'Tenimissa in preparation

Table 5. Effect of the shelf life on the flour of N'Tenimissa

Dates	Treated Alkali Flour			Control Flour no treated		
	Colour	Smell	Texture	Colour	Smell	Texture
06/06/98	4.8	4.2	4.6	4.8	4.5	4.9
21/06/98	4.7	4.1	4.4	4.4	4.5	4.8
06/07/98	4.6	4.1	4.3	4.35	4.45	4.8
21/07/98	4.8	4.1	4.3	4.3	4.5	4.65
05/07/98	4.7	4.1	4.3	4.2	4.5	4.6
22/07/98	4.3	3.91	4.2	4.25	4.45	4.45
07/08/98	4.4	3.82	3..6	4.15	4.34	4.5
22/08/98	4.5	3.61	3.2	4.13	4.21	4.4
05/09/98	4	3.4	3.1	4.12	4	4

Scale: 5 to 1, 5 = Very good, 4 = Good, 3 = Acceptable, 2 = Poor, 1 = Very poor

After three months of conservation, the flour quality of N'Tenimissa (control and treated) remained very good in terms of taste, smell, texture and colour (Table 5). Rooney and Waniska [11] endorsed that the highest quality sorghum flours and food products are produced using grain from tan-plant, food grade sorghum varieties. Several key traits has been considered in developing food grade sorghum varieties including white pericarp colour, thin mesocarp, normal endosperm type, low tannin content, and tan-plant necrotic lesion colour. The percentage of lipids is significantly reduced during the decortication. Biochemical analysis of selected sorghum cultivars did not showed significant differences for the parameters studied. The protein and fat content were varied between 9.8 to13.33% and 3.45 to 5.04%, respectively. N'Tenimissa presented 11.72% of proteins and 4.63% of fats (Table 6).

Table 6. Biochemical analysis of selected sorghum cultivars

Cultivars	Dry matter content %	Nk or Protein content %	Fat content %
Sorgho rouge	90.32	10.27	3.96
N'Tenimissa	90.65	11.72	4.63
Malisor 92-1	91.82	9.80	3.68
CSM 388	91.37	12.52	3.75
Foulatiéba	90.95	13.33	3.88
MID SOR 88-10-01	93.55	11.96	3.45
MID SOR 88-10-02	93.45	10.50	3.90
MID SOR 90-30-43	93.17	10.53	5.04
MID SOR 88-10-06	93.02	11.08	4.41
MIK SOR 86-30-41	91.12	10.15	4.91

Photo 5. Biscuit Deliken manufactured by Général Alimentation du Mali (GAM)

Consumer preference tests of biscuits made of composite flour indicated that the most preferred biscuits contained up to 20% sorghum flour. Biscuits with 30% and 40% sorghum flour were acceptable for texture, colour, and odour. For shelf life, there is no difference between the different biscuits. From the various organoleptic parameters studied, it was revealed that biscuits made with 20% sorghum flour were better in compared to biscuits of 30% and 40% of sorghum. Based on this fact, it is worthwhile to mention that the food processing company named 'Générale Alimentation du Mali' (GAM) decided to manufacture a biscuit called Deliken (Delicious Keninke) containing 20% of sorghum flour and 80% wheat flour (Photo 5). Our results are in accordance with those reported by Olatunji et al. [16] who indicated good quality bread can be baked with blends containing either 20% sorghum or 15% maize flour. Higher substitution levels were found possible with the use of improvers. Authors also reported that higher substitution levels (up to 55%) made acceptable biscuits, cakes, doughnuts and pastries with as good as the texture and eating quality of 100% wheat flour.

The analysis of the composite flour biscuits gave roughly the same compositions as the standards recommended by FAO (Table 7). In studies of long term shelf life, no change was noted in the organoleptic parameters measured of Deliken biscuits kept for a year (Tables 8 and 9). Also, snacks, cookies and pasta with 100% sorghum flour were developed. Thus, SORBIS, a new cookie made entirely with flour of the white–seeded, tan-plant cultivar, N'Tenimissa, became a value-added product for commercial utilisation of sorghum. Several variances of Sorbis were subsequently made and fortified with dates, Coconut, peanut, amends and butter.

To link smallholders to the commercial sorghum supply chain, four villages were involved in the production of N'Tenimissa grains viz., Tamala, Tadjana, Kafara and Tadjanabougou. All these villages were selected because they are located in sorghum production zone (Sudan agro-ecological zone) and their proximity to Bamako, center of grain processing units, and low transportation costs. A total of 50 farmers from farmer organisations took the risk of embark in this new venture by contracting with a grain trader. The grain trader bought certified seeds of N'Tenimissa from selected seed growers who received the foundation seed from the National Research Institute (IER). More than 220 t grain yield, with an average of 2000 kg/ha, were produced during the first year. Part of this production was sold to the grain trader and the rest in local markets with an increased price of 10-20 FCFA per kg in compared to local market price. The contracts were established for the market price at sale and premium for quality. The contracts specified that sale was to be made soon after harvesting when threshing was done. The grain trader sold the grain to the Général Alimentation du Mali through a contract to manufacture the biscuit Deliken containing 20% of sorghum.

Table 7. Chemical composition of biscuits made with 20% of sorghum (analysis on 100g of biscuits)

Composition	Quantity
Glucides	76.2g
Proteins	8.17g
Fat	10.8g
Ashes	0.74g
Water	4.5g
Energy	421Kcal

This market linkage led to an increase in income for rural populations, thereby stimulating local economic growth. Thus, a commercial supply chain was initiated based on a public-private partnership involving the public sector represented by IER and the Ministry of Agriculture, and the private sector by farmers and GAM. This is an excellent innovative model ensuring that the use of higher inputs with sorghum is profitable. However, for the system to sustain, there are significant needs to introduce higher production technologies that motivate the farmer organisations. Kim and De-Ruiter [17] endorsed that partial substitution of wheat flour by non-wheat flour saved some foreign

Table 8. Sensory evaluation of biscuit containing 20% sorghum flour (one week after preparation)

Statistical	Sensorial parameters					
Parameters	**Texture**	**Smell**	**Taste**	**Colour**	**Arome**	**Acceptability**
Minimum	1	1	1	3	2	2,2
Maximum	9	9	9	9	9	9
Standard deviation	2,2	1,74	1,67	1,51	1,88	1,41
Mean	6,93	7,09	7,48	7,56	6,92	7,23
Total appreciation (%)	68,26	75,45	77,72	80,01	72,82	80,51

Scale of appreciation: 9 to 1

9= Like it extremely, 8= Like it very much, 7= Like it moderately, 6= Like it a little, 5= Neutral, 4= Dislike it a little, 3= Dislike it moderately, 2= Dislike it very much, 1= Dislike it extremely

Table 9. Sensory evaluation of biscuit containing 20% sorghum flour (12 months after preparation)

Statistical	Sensorial parameters					
Parameters	**Texture**	**Smell**	**Taste**	**Colour**	**Arome**	**Acceptability**
Minimum	1	1	1	1	1	2
Maximum	8	7	6	6	7	8
Standard Deviation	2.1	1,5	1,35	1,22	1,63	1,12
Mean	6,01	6,99	6,48	6,86	6,22	7,23
Total Appreciation %	70,33	79,23	80,02	83,12	76,82	80,51

Scale of appreciation: 9 to 1, 9= Like it extremely, 8= Like it very much, 7= Like it moderately, 6= Like it a little, 5= Neutral, 4= Dislike it a little, 3= Dislike it moderately, 2= Dislike it very much, 1= Dislike it extremely

exchange. Diversification of the use of sorghum though shelf-stable foods and industrial sorghum-based products would entrance and encourage the production. Sorghum prices are low and stable which affect production. Many of the new improved cultivars are not adopted because of a lack of farm policy which would encourage adoption.

4. CONCLUSIONS

The breeding of sorghum cultivars with “tan” plants and photoperiod sensitivity in guinea race improved productivity and grain quality leading to value-added processing. Thus, resulting new improved variety, N’Tenimissa showed a high level of grain yield and quality through several tests and studies. It has long glumes, hard grain, a white endosperm, a level of sensitivity to photoperiod allowing its maturation at the end of the rains. Crosses are underway to improve the harvest index of tan guinea sorghums by shortening the plant height. N’Tenimissa, a "tan" variety with white grain produces flour of excellent quality that can be widely used by industrial as well as small processing units. Studies carried on the sorghum processing and the use of composite sorghum-wheat flour for making pasta, and total sorghum flour in manufacturing biscuits, have shown a path for the future for diversification of uses of a local staple crop, sorghum. A strong public private partnership between Malian farmers, private processing companies and scientists from the public research institute made this possible and is a demonstration of the power of aligning interests towards achieving food security and income around sorghum in Mali. A consistent supply of good quality identity-preserved grain is required for increased commercialisation and processing of sorghum into value-added products.

We believe that various improvements in the quality of the sorghum-based products are still possible. Therefore, intensification of research in this direction is needed. Breeders should endeavour to develop cultivars of sorghum with improved food processing qualities in such areas as colour, grain shape, flour, binding properties, and good quality protein.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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