Project no. **015403**

FONIO

Upgrading quality and competitiveness of fonio for improved livelihoods in West Africa

Specific targeted research project (STREP)

INCO

Final activity report

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This report cumulates and summarises the activities and results over the full duration of FONIO project (2006-2008). It was elaborated with collaboration of all project staff and particularly with following scientists:

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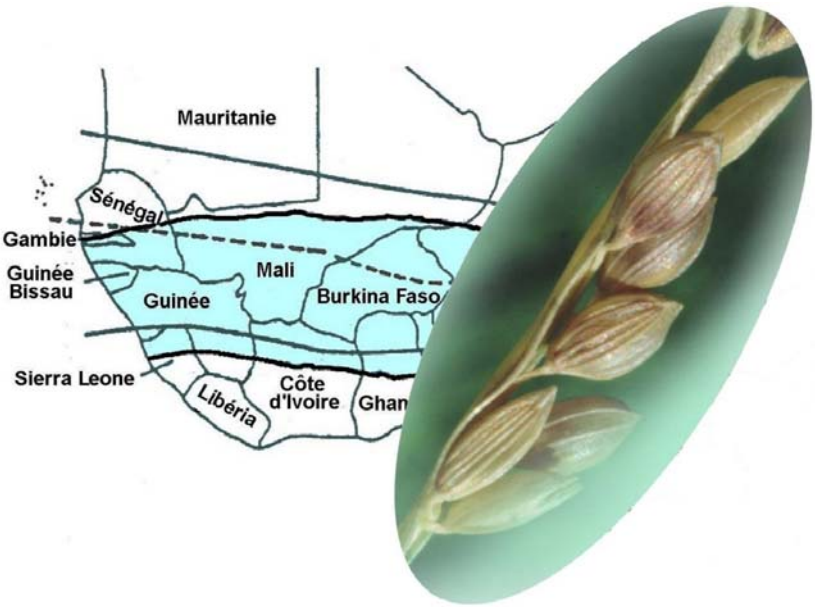

Nota:

- The activities presented in this report have been funded with support from the European Commission within the framework of the FONIO project.

- Information reflects the views only of the author and the Commission cannot be held responsible for any use which may be made of the information contained therein

1 - Context

Traditional cereals constitute the staple diet of many African populations and regions, especially in the most isolated rural areas, and play an essential role in providing food for the poorest populations. They are well suited to local conditions, being reasonably resistant to drought, and help to maintain the environment by providing a covering of vegetation on ground which is ecologically fragile, and considered of little value.

Among traditional cereals, fonio (*Digitaria exilis*), is considered as the most ancient indigenous West African cereal. Nowadays, fonio still grows in farmers' fields in a vast area extending from Senegal to Chad mainly on eroded lateritic soils. In West Africa, farmers cultivate mainly white fonio *(Digitaria exilis),* which is also called fundi, findi, acha or "hungry rice". The term 'hungry rice' well describes the role of this little plant in local population life. Fonio supplies to several million people food early in the growing season, when main crops are still too immature to be harvested and when other food resources are scarce. Fonio consumption varies between years and seems to be dependent on the availability of other cereals. When other cereals are not available, for example due to a failing harvest, fonio consumption is high, and thus fonio consumption could be considered as one of the coping strategies for increasing household food security.
The relative stagnation of production is partly explained by a lack of research and development devoted to this product. In order to ovoid the decline of this commodity, it is important to solve the many problems after the harvest, in particular by perfecting post-harvested techniques and by improving the quality and the follow-up of sales and distribution.

Today, fonio is produced by small enterprises and sold not only on local urban markets, but also to Africans emigrated in Europe and in United States. Indeed several small private enterprises, notably in Mali and Burkina, have been set up to cater for the export markets. There is strong consumer demand for fonio due to its nutritional qualities, and because it helps to satisfy the demand for a more varied cereal diet.

That is the reason why a research/development project named *FONIO - Upgrading quality and competitiveness of fonio for improved livelihoods in West Africa*- was elaborated to achieve the following objectives. The FONIO project started formally at January 1, 2006 per three years duration.

2 - Objectives

FONIO's objective is to upgrade quality and competitiveness of fonio in West Africa by improving production (adapted varieties, appropriated production and farming systems, …), technology (innovation in post-harvest mechanisation and processing,…) and marketing systems for local and export markets. In Africa, the increasing interest for fonio, as well from consumers than from small enterprises, demonstrates the possibility for the development of good quality products based on fonio. For European consumers, the desirable criteria are nutritional quality, originality, healthier properties and environmental friendliness. The production of exportable value added fonio products is conceivable and must be promoted.

To achieve the overall objective, FONIO project promote an interdisciplinary and innovative approach involving scientists from various backgrounds: food technology, nutrition, process engineering, mechanization, social sciences, and agronomy. It support research/development actions with a participatory approach involving producers, processors, women's groups and small enterprises that will benefit directly and quickly from the research results.

The main research activities (workpackages) of the project are the following:

- WP1 - Diversification of fonio products for niche export markets and local markets
- WP2 - Nutritional aspects of fonio and fonio products
- WP3 – Demand for new products and its effects on income generation and distribution
- WP4 - Small scale enterprises and innovation in product and process
- WP5 - Opportunities for diversification and multipurpose uses of fonio in crop-livestock systems
- WP6 - Improving knowledge on fonio based cropping systems and ways for improving productivity

3 - Participants

Research scientists are from three European countries and four West African developing countries (Mali, Guinea, Burkina Faso and Senegal). They belong to Research centres, Universities, National or International Research Systems.

Three from European countries:

Participant 1: Cirad (International Cooperation Centre in Agronomic Research for Development) France,
Participant 2: Wageningen University (Division of Human Nutrition) The Netherlands,
Participant 3: CRA-W (Walloon Center of Agricultural Research) Belgium.

Four participants from West African countries:

Participant 4: IER (Institut d'Économie Rurale) Mali.
Participant 5: IRAG (Institut de Recherche Agronomique de Guinée) Guinée.
Participant 6: CIRDES (Centre International de R&D sur l'Élevage en zone Subhumide) Burkina Faso.
Participant 7: ENDA-GRAF (Groupes Recherches Actions Formations) Sénégal.

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4 - Work completed

The first three months of operations were primarily given over to funding aspects (opening of accounts by partners, transfer of funds, etc), defining administrative and financial procedures and preparing and holding the project kick-off meeting.

4.1. Co-ordination and management

The project kick-off meeting was held in Bamako, Mali, from 20 to 24 March 2006. The meeting, which was organized jointly by CIRAD and IER, was attended by some forty people from the various partner organizations in Europe (France, the Netherlands and Belgium) and West Africa (Mali, Guinea, Burkina Faso, Senegal and Benin), and representatives of the private sector in Mali: AOPP, FENATRA and SMEs (processors, women's groups….). The meeting was led by the project's coordinator and set out to present the different partners in the project, finalize the annual programme of activities for 2006, and determine the strategies to be adopted to achieve the objectives set by the project. It was also very useful for creating links between the various researchers present and facilitating future collaboration. This kick-off meeting in March 2006 thus marked the real start of the project, although the official date was 1 January 2006.

During year 2006, were held different workshops. The first workshop for WP 5 & WP6 was held during March 2006 after the kick off meeting. Then, the first WP1 to WP4 workshop, organized jointly by Cirad and ENDA Graf, took place in Dakar (Senegal) June 26-30, 2006. This meeting was attended by about a dozen people from Cirad (Montpellier and Bamako), IER (Bamako), IRAG (Kindia), Université Abomey Calavi (Cotonou) and ENDA Graf (Dakar). This workshop was very helpful to establish the relationships between the WP1 to 4 scientists coming from various backgrounds: food technology, nutrition, process engineering, mechanization, social sciences and to define the precise activities of each Wp for the following six months. During autumn 2006, a "post rainy season" workshop of WP5 (farming systems) and WP6 (cropping systems) was held in Guinea in Fouta Djalon (IRAG Centre of Bareng) and in Upper Guinea (IRAG Centre of Bordo) from October 31 to November 4, 2006, then in Mali (IER Centres of Sotuba and Cinzana) during 4-9 November, 2006. It was attended by twenty or so people (agronomists, specialists in cropping and farming systems…). At the end of year 2006, the first annual coordination meeting was held in Cirad Montpellier, France, from 4 to 8 December 2006. Organized by the Cirad project coordination, this meeting was attended by about twenty people (Steering Committee and scientists) coming from Mali (IER), Guinea (IRAG), Senegal (ENDA Graf), Burkina Faso (Cirdes), Netherlands (Wageningen University), Belgium (CRAW) and France (Cirad). The meeting was dedicated to present and analyse the first research results obtained during the first year and to prepare and plan the scientific activities for the second year of the project.

During year 2007, the first 2 months were devoted to reports writing (first activity and first management reports) with collaboration of WPs and team leaders. Then different meetings were organized during the year: "WP6 meeting" in Bamako (April, 3-4/2007), "WP3&4 workshop" in Bamako (May 29- June 2/2007),

"WP5&6 workshop" in Mali and Burkina Faso (October 16- 26/2007), "WP1 to 4 workshop" in Bamako (Oct. 29- Nov. 3/2007). Two specific missions were also realised: in Mali and Burkina Faso (March 6-13/2007) to study fonio precooking and in Guinea (April 16-27/2007) to analyse the Guinean fonio commodity chain in collaboration with WP3 and WP4. The general coordinator of the project based in Bamako (Mali) since the beginning of the project joined Cirad Montpellier (France) on September 1, 2007. The second annual coordination meeting took place at CRAW Center (Walloon Center of Agricultural Research) in Libramont (Belgium) on 25-29 November 2007. This meeting was attended by the project Steering Committee with representatives of each partner. The 4 days meeting was dedicated to present and analyse the research results obtained during the second year, to prepare the activities for the last year of the project and to plan the submission of reports and deliverables.

During year 2008, the main results of the FONIO project were presented to a large audience during the Fonio Conference organized in Bamako (Mali) during the SIAGRI (International Agricultural Show in Bamako)**.** This Fonio Conference took place on Monday, April 28, 2008 and was attended by a hundred of people (processors, professionals, scientists, NGOs, decisions makers...) from West Africa and Europe. Eight topics were presented and a specific posters session was organised (more than 20 posters). A specific CD-Rom of that conference was edited by Cirad. In parallel, a stand representing the FONIO project had been especially built to present various varieties of fonio, fonio products and fonio dishes and machines (GMBF fonio huller). During the week of SIAGRI, the stand had several hundreds of visitors and the official visit of the Prime Minister and the Minister for the Agriculture of Mali. Lastly, in November 14, 15, 16 – 2008, the FONIO project was part of the Cirad stand: "The Field of Tropical Cereals". The aims of Cirad's participation in the European City of Science, organized at the Grand Palais in Paris, are to show how involved Europe is in guaranteeing global food security and to demonstrate the role of scientific research in promoting local food products (http://www.villeeuropeennedessciences.fr/projet_FR_189.htm). During these 3 days, the stand presented tropical crops and particularly fonio (for that purpose, fonio plants were specially grown under greenhouse in Cirad Montpellier) and had several thousands of visitors. Hundreds of leaflets about fonio were distributed to the large public very interested by this unknown cereal. For larger public information, the FONIO project Website continued to be developed (http://inco-fonio.cirad.fr). The last annual coordination meeting took place in Dakar (Senegal) in 25-28 November 2008. This meeting, organized jointly by Cirad and ENDA Graf, was attended by the project Steering Committee with representatives of each partner: i.e. the project coordinator, the workpackage leaders and the team leaders coming from France (Cirad), Belgium (CRAW), Holland (University of Wageningen), Mali (IER), Guinea (IRAG), Burkina Faso (Cirdes), Senegal (ENDA Graf). A representative of "Université National du Bénin" (UNB) coming from Benin was invited to participate to this last annual meeting in order to enlarge the influence zone of the FONIO project in west Africa.

Table 1. FONIO project meetings timetable

Meetings	Country	Participants	Month	Duration (days)
Kick-off meeting	*Mali*	*Steering Committee + local staff involved*	*3*	*4*
WP5 and WP6 workshop	*Mali*	*Researchers involved*	*3*	*2*
WP1,WP2,WP3 & WP4 workshop	*Senegal*	*Researchers involved*	*6*	*5*
WP5 and WP6 workshop	*Guinea & Mali*	*Researchers + staff involved*	*3*	*15*
Annual coordination meeting	*France*	*Steering Committee + local staff involved*	*12*	*4*
WP6 "pre rainy season" meeting	*Mali*	*Researchers involved*	*16*	*2*
WP3 –WP4 workshop	*Mali*	*Researchers involved*	*18*	*5*
WP5 and WP6 workshop	*Mali-Burkina*	*Researchers involved*	*22*	*9*
WP1,WP2, WP3, WP4workshop	*Mali*	*Researchers involved*	*22*	*5*
WP1 and WP2 workshop	*Netherlands*	*Researchers involved*	*25*	*2*
Annual coordination meeting	*Belgium*	*Steering Committee + local staff involved*	*23*	*4*
WP1workshop	*Mali*	*Researchers involved*	*26*	*5*
WP1 to 6 workshop	*Mali*	*Researchers involved*	*28*	*5*
FONIO Conference "Final seminar"	*Mali*	*Steering Committee + researchers involved + NGOs*	*28*	*1*
Final annual meeting	*Senegal*	*Steering Committee*	*35*	*4*

4.2. Research activities

Research Activities were conduced in the framework of the 6 thematic work packages

4.2.1. Diversification of fonio products for niche export markets and local markets (WP1)

Workpackage 1 is directed by Cirad (France) in close cooperation with IER (Mali). The main WP1 objective is to develop high quality fonio products with appropriate processes for local markets in West Africa and for exports. Four main tasks were conducted during the three years of the project.

Precising quality criteria of milled and cooked fonio, improving laboratory protocols on assessment of cooking quality and relating sensory tests of the project with instrumental tests (task 1.1)

The objective of the first task was to better understand organoleptic properties of fonio in order to assess the quality of new products.

Quality criteria of milled and cooked fonio were identified in Bamako, Mali with different stakeholders all along the fonio chain. Qualitative surveys were conducted through individual or focus group interviews by using semi-structured questionnaires, then were completed by sensorial tests (range tests and triangular tests). Quantitative surveys have been done with structured questionnaires.
When selling or buying fonio, relevant descriptors of the grain quality concerned several characteristics such as grain hardness, size, colour, age, origin, but essentially the convenience for it to be subsequently processed: milling degree, absence of sand or impurities (dust, stones, other grains…) and sanitary aspect.
Among 143 persons interviewed, about 70 % preferred grain with good swelling properties that swells twice of three times during cooking (it should be older and harder); 65 % looked for cleaner grain with lower percentage of sand and other impurities, 58 and 55 % wanted respectively a light coloured grain almost completely milled. Grain size appeared less important for fonio purchasers.
The same criteria have been emphasized by processors or consumers who try, when processing fonio grain, to have this laborious task facilitated and shortened. They chose a cleaner, almost completely milled grain, dried with lower amount of brokens.
At the question "what's for you a good fonio when eating it", interviewed persons preferred first a well cooked fonio, with a soft consistency, swollen, not sticky and with no sand. Grains must be individual, smooth, not rough. Visually, colour must be light, with a minimum of paddy, weeds and other impurities.
Rank and triangular tests confirmed that consumer perception of cooked fonio. The most preferred cooked fonio were fonio from Bougouni and fonio from Guinea. Even very close, they were perceived as different and were appreciated because whiter, with a sweet taste and a softer consistency.

Laboratory protocols on assessment of fonio quality were developed from protocols usually used on rice and adapted especially to that tiny and covered grain with unique physical characteristics. Some of them, developed during a previous project, were improved, mainly the protocols for measuring cooking properties, following the identification of quality attributes of milled and cooked fonio through qualitative surveys.

Sensory tests were conducted in IER Mali on 20 fonio ecotypes collected in villages from Mali, Guinea, Burkina Faso by WP5. A panel of 25 members was first trained through successive sessions where 5 reliable descriptors were selected in consensus as well as the scale of intensity, the order of perception and the protocol to assess them: four visual descriptors (colour, size, cohesion, presence of impurities) and one tasting descriptor (consistency).
Among the 25 panel members, 17 were kept finally for the analysis of all the sensory data. 4 were first put aside because they have tasted less than half of the 60 products (20 varieties in triplicate), another one because his results were out of the scale and 3 others because too far from the mean of the panel and not enough discriminant.
Through a hierarchic ascending classification, four classes among the tasted products were identified. These classes were not linked directly to the countries where the varieties were collected. Classes 2 and 4 regrouped varieties appreciated for their light colour, smaller grain size and lower quantity of impurities. Classes 4 and 3 showed individual cooked grains, non sticky. Class 2 had the softer cooked grains opposite to class 3 with harder and darker cooked grains.
It was observed that the most appreciated fonio varieties came from Guinea and Mali. These varieties belong to the class 2: *Fonibagbè* (separated from the others, mainly because of its very softer cooked grain),

Kélianingbè from Guinea, *Finiba, Tioi, Tamatioi* from Mali, and to the class 4 : *Tamabè, Pétama, Péazo 2* from Mali and *Kökounin* from Guinea.
All the organoleptic properties perceived by the panel for each ecotype were related to its physicochemical, technological and cooking properties measured in the laboratory.
It was showed that Cohesion, the sensory attribute corresponding to the aspect of individual grains, non sticky, with a light and non compact texture, was correlated to Protein content of the milled grain (0.54) and could be predicted by cooked grain Firmness (kgf) measured with Instron machine in the laboratory. Consistency was also correlated to cooked grain Firmness (kgf) (-0.45). Colour could well predicted by Clearness L measured on milled or cooked grain opposed to Chromaticity a and b. This sensory attributes was well correlated to Minerals (- 0.81) as also Impurities (- 0.55).

Producing precooked and parboiled fonio products with constant and improved technological, organoleptic and nutritional qualities (task 1.2)

1/ Traditional precooking processes were identified at level of small and micro enterprises in Mali and Burkina Faso. Equipments used (stove, pot, metal pan) are very "rustic" but locally manufactured, at lower price. Women need several steam cookers to precook large quantities of fonio (more than one hundred kg) with several batches per operation. Some women prefer to use as much as possible the gas-burner in order to save energy. Fonio precooking diagram was elaborated and showed that precooking of 1kg of fonio needs 2.800 kJ of energy with a wood stove and only 660 kJ on a gas-burner (4 times less !).

2/ In order to develop new fonio products and predict the ability of a variety to be milled, or cooked, or parboiled, some physical properties of fonio grain very difficult, quite impossible till now to measure with protocols usually used on other small cereal grain -considering the exceptional tiny size of that grain-, could be studied. A software was developed with Labview, to measure, after scanning 0.3 g of fonio milled grains and analysing the image through the shades of grey, several characteristics such as total number of grains, thousand kernel weight (g), whole grain number, percentage of brokens (%), percentage of floury grains (%), average grain length (mm), average grain width (mm), average grain shape (L/l), colour L, a, b and percentage of foreign grains (paddy, whole grain or other grains) (%). The software was calibrated on milled fonio grain but should be adapted to paddy or dehulled grain and certainly to other cereal grain after an appropriate calibration.

For the first time, it was showed that fonio is a cereal composed of completely vitreous grains containing, depending on the ecotype, a lower percentage of completely floury grains, from 0 to 12 %. Through an analysis of variance, 27 local ecotypes from Mali and Burkina appeared significantly different for all their physical characteristics. For the variable Percentage of floury grains (%), the ecotypes were separated in 3 groups using Newman Keuls test : 0 to 1 % of completely floury grains present in the sample, 1 to 5 % and 10 to 12 % for two ecotypes only (*Pétama* and *Foniba* from Mali). This new technique was applied on all the fonio ecotypes analyzed in task 1.1 for their relation with sensory profiles and in task 1.4 for the study on multi-location trials.

3/ In order to develop parboiled fonio products, a parboiling process traditionally used for rice was adapted to fonio. The optimization of parboiling process started at laboratory level. A diagram was developed using small quantities of grain and analytical methods were adopted. A Doehlert experimental design with three factors at 7, 5, and 3 levels respectively, and 15 runs, including three replicates at the central point, was performed for studying the effect of influent parameters on fonio quality product. The three independent factors chosen were soaking time (from 1 to 7 h), steaming time (10 to 26 min) and steaming pressure (0 to 0.4 bars), soaking temperature being fixed at 30°C. The proposed model to which the experimental data were fitted is a second-order polynomial model.
Response surface methodology showed that milling yield of parboiled products were higher than those of non parboiled ones (76,5-79,1% compared to 71,7%). Parboiling affected milled grain colour which became darker. Clearness of parboiled grain was lower than that of non parboiled grain (from 52.2 to 62.6 compared to 71.1). It was significantly and negatively influenced by soaking time and in a lesser extent by steaming time. After cooking, parboiled grain became lighter and less red or yellow than milled parboiled grain. It swelled more than non parboiled fonio during cooking, what is not observed with rice. 64 to 99 % of grain starch was gelatinized during parboiling. Higher percentages of gelatinized starch could be obtained with longer soaking time and lower steaming pressure and vice versa. Amylose-lipid complexes could form during parboiling by using higher pressures with shorter steaming periods but also with no steaming pressure

–as usually found in local conditions in West Africa- with longer steaming periods. Their presence and their importance (area of the enthalpy change), identified during melting at around 110°C, is a quality trait for parboiled grain.
A desirability function was used to define optimal parboiling conditions. Desirability profile including multiple responses (higher milling yield, lower percentage of brokens, softer consistency, higher swelling power and higher enthalpy change of amylose-lipid complexes melting) answered at 94 % and could be obtained in the following experimental conditions: soaking time of 3 h 47, steaming pressure of 0 bar and steaming time of 26 min..
The study of the effect of supplement influent parameters on paddy grain water content and milled grain colour were carried out in parallel in IER, Mali under controlled local conditions on larger quantities of grain (5 kg). Citric acid added into soaking water at different concentrations (pH from 6-7 to 3) did not reduce colour of parboiled grain. A soaking time of 4-5 h seemed to be sufficient to reach a water content of 32-35 % w.b. necessary for parboiling, even at lower temperatures (25-30°C). Soaking the grain all night long, that should be more convenient for a processor, affected grain colour. Among the varieties tested, some were more appreciated for parboiling: for instance *Tama* kept a clearer grain after parboiling compared to *Tamatioi.*
Parboiling larger quantities (30 to 60 kg) of fonio grain was also achieved in IER by using a «Cirad/PASAL» steam cooker already developed on rice and which was tested on fonio. Heterogeneity in the steamed product could be noticed: the grains in contact with steam cooker walls were more cooked and darker than the grains in the upper part. This equipment should be adapted before manufacturing. The improvement and modifications of this equipment require additional researches. Then the process will be transferred in small local enterprises.

Developing equipments adapted for drying fonio grain and products (task 1.3)

The objective of task 1.3 was to mechanize post harvest technologies such as drying in order to facilitate women labour.
After the achievement of engineering drawings (blueprints), two types of driers have been manufactured in Mali and set up in small enterprises producing precooked fonio: a counter current cross-flow gas drier (CSec-T) set up in Danaya enterprise and a greenhouse ventilated solar drier (CSec-S) in Ucodal enterprise. Experiments have been conducted in local enterprise conditions during two different seasons (humid or dry seasons) and tested with IER. Their performances were compared to that of two other existing driers (gas and solar driers : Fac 2000 and Hohenheim). Processors were asked to validate these equipments.
The greenhouse ventilated solar drier is composed by a galvanized tube structure covered with a plastic film and drying is obtained by direct sun radiance on the product. Two ventilators in the back provide a constant extraction of the air and two others on the ceiling improve the exchange between air and product. The drier is equipped with 8 metallic tables covered by a wire screen on which mats were put on before spreading precooked fonio for drying. The experiments carried out with this equipment were satisfactory during dry season and even during humid season in term of drying time (one day from 3 to 4 p.m. till 1 to 3 p.m. next day), final moisture content (5-9 % w.b.) and drying capacity (320 to 400 kg per day, depending of the quantity of fonio spread on each table screen: 40 to 50 kg). The advantages of this drier underlined by the processor were: lower handlings, protection against bad weather, birds, dust, rapid drying at lower temperature 50-60°C, lower cost in energy.
The counter current cross-flow gas drier (CSec-T) is composed of three sections, each one containing four stacked trays, an air heater (gas burner) and an air ventilator mounted on the axis of an electric engine of 1500 rpm to have an air speed of 0.17- 0.30 m/s. Drier was achieved in wood. Each section is closed by a door. 8 kg of precooked fonio are spread on a cloth, put on each tray. Hot air is introduced under the trays covering all the three sections and distributed homogenously all through the product mass, so that the exchange air-product was facilitated. The principle for drying is to produce a counter current flow between hot air flow going from bottom to top and the product which is transferred on trays from up (position 4) to down (position 1). The experiments carried out with this equipment were satisfactory in humid or in dry season, in term of capacity (2 or 3 batches of 96 kg per day : 190 to 290 kg), drying speed (4 to 5 h per batch of 96 kg), dried product quality, good energy efficiency with a lower gas consumption compared to other gas drier.
These equipments are polyvalent and can be used for drying other products such as couscous, dégué … They were validated by processors and can be distributed to others small enterprises.

Characterizing different fonio varieties at physical, technological level and identifying the varieties the most adapted to mechanical processing (task 1.4)

The objective of task 1.4 was to identify fonio varieties the most adapted to mechanical processing and look at the effect of cropping system on their physical, biochemical and technological characteristics.

1/ 54 fonio ecotypes were collected by WP6 and WP5 in Mali, Guinea, Burkina Faso : 15 varieties from Cinzana IER experimental station in Mali and 39 local ecotypes bought directly at farmers' (3 varieties per village, in 4 villages per country) : 13 from Mali, 11 from Guinea and 15 from Burkina Faso. These varieties were characterized at physical and biochemical level. Their dehulling, milling and cooking properties were determined. A Principal Component Analysis run on five quality traits showed a variability of these traits among the ecotypes per country: milling yield, percentage of brokens, lipid content of milled grain, consistency and swelling power of cooked grain.
Among the 15 varieties from Cinzana IER experimental station in Mali, *Pon de Madougou* and *Sanogola* appeared more friable with a lower milling yield compared to *Pébê, Tamabè, Kassangara* or *Tioi. Pon de Boré* showed good cooking properties with a low consistency value and a high swelling power value. It was opposite to *Tama* which presented firmer cooked grain.
Among the 11 local ecotypes from Guinea, a group of varieties fitted with high values of swelling power trait such as *Fonibagbè, Siraguè Danè. Kökounin* showed a high milling yield and *Yaouko* a high percentage of brokens in the standardized conditions of fonio milling.
Among the 15 local ecotypes from Burkina Faso, one variety stands apart from the others: *Fungban*, more easily broken with lower milling yield opposite to *Wanwoulé, Pébio, Péfoso, Pémousso, Wonotono*. A group of three varieties T*enaïlé, Funigbé, Warr,* should be firmer after cooking compared to another group such as *Foniba, Woussangué,* that swelled better and appeared softer.
Among the 13 local ecotypes from Mali, *Tamatioi* and *Tioi* showed higher swelling properties and *Tama* appeared firmer after cooking.
All of these technological data were compiled with agronomical data by WP6 to fill an individual specification sheet per cultivar.

2/ Among all of these ecotypes, 12 were chosen for their agronomic and technological interest and were grown by WP6 in 4 different locations : 2 locations in Mali (Cinzana and N'Tarla) and 2 in Guinea (Bordo and Bareng) with the purpose of studying the effect of cropping system on quality traits of each cultivar.
10 common fonio ecotypes from N'Tarla and Bareng, the most opposite locations for their agroclimatic conditions, were analyzed at physical, biochemical, technological and rheological level. A Variance Analysis and a Principal Component Analysis were run on all the quality traits.
For each of the 23 variables analyzed, there was a highly significant location effect on most of the characteristics, specially the physical and technological characteristics except for Swelling power, Consistency, Proteins, Thousand kernel weight, Length, Width and Shape. At the opposite, there was no variety effect except for the variables Thousand kernel weight, Length, Width and Shape.
Ecotypes which have grown in Bareng had a higher milling yield with less percentage of brokens and were better degerminated compared to ecotypes which have grown in N'Tarla. They had clear grains, with a completely vitreous endosperm. The presence of floury grains was quite inexistent.
It was the first time we could observe fonio endosperm texture and understand why women in Mali who process traditionally fonio grain, prefer fonio from Guinea because they can wash it a long time to remove sand without disintegration of part of it.
All of these technological data will be added to agronomical data to determine the effect of cropping system on fonio grain quality.

4.2.2. Nutritional aspects of fonio and fonio products (WP2)

Workpackage 2 is coordinated by Wageningen University (Netherlands) and is implemented in collaboration with the Institut Economie Rural (Mali) and support of the University of Abomey Calavi (Benin). The general objective of WP2 is to determine the nutritive value of fonio and fonio products and its contribution to nutrient intake and nutritional status. This objective was achieved through the following specific objectives:

- To analyse the nutritional value of different fonio varieties, milled fonio and diverse fonio products (pre-cooked, parboiled).
- To determine the role of fonio in the dietary pattern.
- To determine the contribution of fonio to nutrient intake and nutritional status.
- To determine the bioavailability of iron from fonio-based diets.
- To determine the bioavailability of iron from low versus high phytate content fonio diets.

Studies under the Work package 2 are carried out among women in reproductive age living in Bamako, Mali. Anthropometry data showed the existence of undernutrition (17% with a Body Mass Index below18.5) as wel as overweight/obesity (28% with a Body Mass Index above 25) among women in reproductive age, and a high prevalence of anemia (32%) and iron deficiency (20%). Food consumption studies among the women of reproductive age in Bamako revealed that 73% of women did consumed fonio dishes, mainly djouka fonio (55%), foyo (41%) and fini zamé (4%). However, the frequency (on average 1-3 times per month) and portion size (152.4 ± 35.4 g/day with a range 113 – 208 g/day) of fonio, and hence the contribution to iron and zinc intake, was low. On average, women consumed from 7 different food groups and showed a probably of 54% (assuming a high iron bioavailability of 10%) or 7% (assuming a low iron bioavailability of 5%) of having an adequate iron intake.

To estimate actual dietary intake of energy, iron and zinc and the contribution of fonio to these, a qualitative good food composition database is needed. In Work package 2, the quality of the existing Mali food composition table was evaluated through a desk review. Based on the multi-nutrient expert system approach, a method for evaluating quality of food composition data bases was designed comprising decision trees consisting questions related to the 7 stages identified in the multi-nutrient expert system approach. Answers to the questions were based on the available documentation. Based on the desk review, all foods consumed during the food consumption study (n=90) and 13 nutrient values of interest (representing 1170 values) were evaluated and, if necessary, updated. This resulted in an updated Mali food composition data base, which was used in Work package 2. The developed procedure to evaluate the quality of a food composition database has been internationally recognized.

Whether fonio could contribute to improving iron intake, is dependent on the varietal differences in iron, effect of processing, the acceptability of fonio and the possibility of increasing iron bioavailability.
Twelve farmers fonio varieties were randomly collected in Segou and Sikasso regions. All varieties were cleaned in the laboratory using a standardized cleaning procedure, developed through Work package 1. Both the fonio paddy and the cleaned mid wet fonio were evaluated for proximate composition and inorganic constituents as Fe and Zn, and phytate concentrations. The Fe concentration ranged from 14.5 – 227.3 mg/100g dry matter in paddy while 0.8 – 1.9 mg/100g in mid wet, with average values of 48.1 mg/100g in paddy and 1.3 mg/100g in mid wet. The high iron values in paddy were probably due to contamination with soil. There was no difference in nutrient content between the different varieties. After milling and washing, the concentration of all the nutrients especially iron and zinc decreased considerably.

Effect of processing was studied comparing the mid wet, cooked and precooked products of two fonio varieties and their parboiled versions, complemented with 14 samples of parboiled fonio from CIRAD. Parboiling was carried out following the procedures developed by Work package 1. The concentration of Fe was practically the same in all fonio products analysed (around 2 mg/100 dm), the phytate concentration decreased from mid wet fonio to cooked fonio. Results do indicate that parboiling might increase the levels of iron and zinc (but not phyate), although this needs further confirmation.

Acceptability of fonio and identification of factors determining fonio consumption by women of reproductive age in Bamako were studied using a combined model of the Theory of Planned Behaviour and

the Health Belief Model. Intention was significantly correlated with fonio consumption (r_s = 0.78, P = 0.000). Attitudes towards behaviour (standardized β = 0.32, P = 0.016) was the best predictor for intention to consume fonio, after adjustment for age, education and interviewers' effect. Health behaviour identity was significantly correlated with attitudes towards behaviour (r_s = 0.67, P = 0.000) and perceived barriers (r_s = 0.33, P= 0.000). Health value (standardized β = 0.23, P = 0.010) contributed significantly to the prediction of health behaviour identity. Perceived barriers was a significant interaction term in the relation between intention and behaviour (standardized β = -0.72, P = 0.037). In the High-barrier-group (score on perceived barriers>70, n=54) the association between intention to consume fonio and fonio consumption was lower (r_s=0.69, P=0.000) compared to the Low-barrier group (score on perceived barriers≤70, n=54, r_s=0.85, P=0.000). To promote fonio consumption, intention of consumption could be increased by focusing on positive attitudes towards fonio consumption. General health consequences of fonio consumption should be emphasized to stimulate a positive attitude. Finally, a reduction of the barriers to consume fonio will encourage that intention leads to actual fonio consumption.

The non-haem iron bioavailability of the diets of urban reproductive women in Mali were estimated through the use of 6 different algorithms (including the algorithm of Hallberg and Hulthén) and the molar phytate to iron ratio. The iron bioavailability as predicted by the different algorithms varied from 1.6% to 6.2%, based on the presence or absence of foods inhibiting or enhancing non haem iron absorption. Using the tertiles of Conway et al. (2007) for measuring iron absorption to predict a low, moderate or high iron bioavailability (low 0.12-3.99%, moderate 4.0-10.88% and high 10.88-96.0%)), three algorithms indicated moderate bioavailability, while two indicated low bioavailability. The average molar ratio of phytate to iron of the diet of the women was 31.6 ± 33.9, being above 1 indicating poor bioavailability of iron. Although algorithms can not indicate the absolute non haem iron bioavailability, from this study it can be concluded that the iron bioavailability of the diet of urban reproductive women in Mali is poor. However, the exact iron bioavailability should be confirmed through human in vivo studies.

To study the feasibility of complete phytate degradation using natural phytase from whole wheat a study was carried out to determine phytate concentration, phytase activity and possible reduction of phytate level of fonio porridge blended with whole wheat flour in the ratios 90:10 and 75:25. The phytate degradation in the fonio porridge blended with 10% whole wheat decreased to 66% (0.36 g/100 g freeze dried sample (FD)) of the initial phytate level in the first aliquot, respectively to 62% (0.32 g/100 g FD) in the second aliquot. This is an insufficient decrease to increase bioavailability of micronutrients. In a second mixture with 25% whole wheat the phytate content was low (0.2 g/100 g FD) probably due to technical problems. It is advised to repeat the experiment with fonio porridge blended with 20% wheat flour under controlled conditions.
As results do indicate that adding natural phytase through blending fonio porridge with whole wheat flour has the potential of reducing phytate level of this porridge, and hence, increase iron bioavailability, a study protocol was developed to study the improvement of iron bioavailability through the addition of native phytase activity to fonio porridges using stable isotope studies.

In summary, Workpackage 2 showed the existence of the double burden among Malian urban women with high prevalences of both malnutrition and overweight/obesity, combined with a high level of iron deficiency. The diet had a low iron adequacy, mainly due to the low intake of bioavailable iron. Fonio did not contribute to iron intake as frequency and portion sizes were low. The acceptability of fonio was high, and reducing barriers would support fonio consumption among these women. Studies showed that iron content did not vary between varieties and processing strongly reduced the iron levels in fonio products. Results indicate that parboiling may improve iron levels, but needs further confirmation. Furthermore, experiments showed that blending fonio porridges with whole wheat flour may have the potential of reducing phytate levels of this fonio product and, hence, improve iron bioavailability of fonio. A protocol was developed to further study this improvement of iron bioavailability through stable isotope studies.

4.2.3. Demand for new products and its effects on income generation and distribution (WP3)

Workpackage 3 is coordinated by Cirad (France) and is implemented in collaboration with ENDA Graf (Senegal), Institut Economie Rural (Mali) and IRAG (Institut de Recherche Agronomique de Guinée). The general objective of WP3 is to assess the drivers and the characteristics of the demand for innovative products from African and export markets and to understand the effect on income generation and distribution of the development of these products in comparison with the old ones. This objective was achieved through the following specific objectives:

- On African markets, to understand how innovative fonio products are accepted by the consumers. Identify the key factors (variables) and measure their specific effect on the demand and on the decision of purchase.
- On European markets, to identify and rank the consumers' expectations regarding fonio products. Evaluate the willingness to pay for fonio products.
- To assess the generation and the distribution of incomes by different existing innovative products, and to estimate the possible impact of the development of new products on income distribution among the different stakeholders of the market chain.

During the project, the demand for new products - i.e. washed, precooked and packaged- was assessed both in Bamako, Mali and in Montpellier, France. The impact of these demands on the different stakeholders of the market chains was also assessed. The demand in Africa and in France is growing. New products are considered as good quality products in Bamako where people know fonio. In France, consumers who see, buy and eat fonio for the first time appreciate it mainly because of the organic and fair-trade characteristics. Two directions of progress are possible to increase the size of the market: the reduction of prices in Bamako, and the creation of new and easier recipes in France. Jobs and new income opportunities were - and are being - created all along the different market chains national-regional and international.

Traditional versus new products in the Bamako markets: a difference in terms of price, quality and customers

In Bamako, where most surveys were conducted, "traditional" products are dehulled (or decorticated), sometimes whitened, and sometimes washed and sold in bulk in open markets. "New" products are precooked, packaged, sealed in plastic bags and sold in supermarkets or groceries.

174 purchases of traditional products and 65 new products were observed on the markets and in supermarkets in 2006. Prices varied from 250 Fcfa to 475 for decorticated, 205 to 650 for whitened, and from 700 to 1000 fcfa for pre-cooked fonios. The contribution of each characteristic to the formation of the price was estimated. It showed that the level of processing explain 92% of the price variation. The characteristics "colour", "size of the grain" and "origin" "recipe" have a small but significant influence on the price of traditional products. For new products, the place of sale is the main source of variation of price, and the characteristics of the product itself (colours, aspect, and packaging) explain no difference in price.

Buyers' profiles and final uses are quite different according to the types of purchased fonio. This confirms the hypothesis that the retail market is segmented between "traditional products" and new ones. The main characteristics of the two segments are as follows:

- The buyers of the « traditional segment » are mainly female (90%). They mainly buy fonio in the markets. They usually buy decorticated or milled fonio. The buyers usually do by themselves or with the help of an assistant (maid or family member) the last stages of the process: pounding if necessary, cleaning, washing, and cooking. 25% of the purchases are used in an income generating activity: sale of *djouka* in schools or in the street, or sale of meal including fonio in small restaurants. 25% of the purchases are given, and half are consumed at home.

- The buyers of the « new segment » have a higher level of education, many of them are male (between 30 and 60%), and many are civil servants (from 30 to 50%). The regularly go shopping in the supermarkets and they often possess a vehicle. They usually buy washed or precooked fonio. Most of the fonio is consumed at home and a small part is given.

Reactions to new products from new consumers in Europe: a demand for Organic and Fair trade characteristics

A survey was conducted in Montpellier from Mai to November 2007 with people who did not know and buy fonio but who may become costumers. A first stage concerned 38 persons, who use to buy and eat Quinoa-a exotic small grain-. They were asked about their feeling concerning the products (precooked whole grain, different brands of whitened and precooked ones), and then chose one or two samples and to cook them. A second stage concerned 355 persons, chosen randomly in faire trade or organic stores, who were asked about their interest and reaction concerning buying fonio.

The cereal itself is not considered as very attractive

The results show that the perception of the taste of the cereal is heterogeneous. 8 persons said they liked the taste, 4 said they hated it, and the other 13 said the taste was neutral (positively for 7 and negatively for 6). The results of the cooking were also mitigated. Altogether half of the cooking tests done by the consumers were considered as a success, half was a failure. This is not a very good result since someone who never tried a product will not be encouraged to try it a second time if she/he failed to cook it at the first time. As an operational consequence, an as the product is completely new for the targeted costumers, as many different cereals are in competition, it seems essential to formulate and disseminate well adapted recipes to consumers from different cultural backgrounds.

A colourful packaging, including many different information, an organic label and Fair trade assumption, is the key for a first purchase.

People were asked "what may encouraged or discouraged you to buy this product?" about three existing different brands (packages) of fonio sold in different organic or fair trade stores. The question was open, and the essential answer was the "global aesthetic of the package", quoted both as positive and as negative by almost all the sample. Then the Organic label (AB) was quoted positively by 56% of the sample and the fair trade aspect by 50% of the sample. These, open questions and answers were confirmed by closed questions concerning notation of different characteristics. Altogether the consumers gave a higher note (preference) to "organic label", "faire trade label", "cereal cultivated by small producers", "whole grain" and "cropped in Africa", in a decreasing order. The addition of the different attributes increased the interest of the consumers (the note), with the exception of "cropped in Africa", "cereal cultivated by small producers".

Effect of socioeconomic characteristics of the consumers on the preferences for fonio's characteristics

There was almost no difference in the ranking of the different characteristics of fonio according to the socioeconomic characteristics of the interviewees. There were however slight differences in the level of the notation. For instance women or people who follow a regime (vegetarian or gluten free) tend to give higher notation than men or person with no regime for the product as a whole. The presence of children in the household influenced positively the notation of the organic label.

Impact of the new products on production and employment

Mechanization and new products: innovation and revival of the market

According to different stakeholders of the fonio market, fonio used to be disregarded both in rural and urban areas. Following different initiatives of private entrepreneur (mainly in Mali) it has gained a new popularity since the mid 90'. The presence of mechanised dehullers played an important role in the development of the market chain since. It seems that both in Mali and in Guinea it played a key role in the "revival" of the cereal. They are present inside a few urban small enterprises in Bamako, but also in "service" units where people (private or very very small entrepreneur) come with their "decorticated" fonio to whiten it, for a small charge. Dehullers have been also working in rural areas in Guinea and in Mali more recently. In Guinea, it seems to have had an impact on fonio production in areas well connected to markets. In Mali, the presence of dehullers in production zone is expected to both improve the quality of the product to be sold to urban markets, and to improve the margin of the farmers.

New products = new markets and opportunities: no competition with traditional products and markets

The new products in Mali are now well known and distributed in almost all supermarkets and groceries in Bamako. According to our surveys, most consumers of new products continue to buy traditional products of fonio. New products are used for different purposes, and they do not replace the traditional products, or in a small proportion. As a consequence, every job created in the market and production chain is a net creation. Concerning the export market, the new products –packaged with the AB or ethical label- are really new.

Employment due to these new markets, has risen since 1991, the year of the creation of the first small scale enterprise (SME) of fonio processing. According to our estimation, fonio processing for these new markets concerns 150 to 300 persons in these SME. About 70% of them are women. Activity is mainly visible in these SME, located in urban centres in Mali, but in the end it concerns also farmers, either directly (some have contract with sme) or indirectly (through the market).

The volumes of new products are still small (less than 500 tons in 2007) but, as the international demand is growing, it is likely to expand. According to WP5 farmers selling directly to fair trade organisations have decided to expand their fonio production. However, it is too early to assess the real impact on production and income generation of these new opportunities.

4.2.4. Small scale enterprises and innovation in product and process (WP4)

Workpackage 4 is coordinated by ENDA Graf (Senegal) and is implemented in collaboration with Cirad (France), Institut Economie Rural (Mali) and IRAG (Institut de Recherche Agronomique de Guinée). The overall aim of WP4 is to assess and explain the impact of developing new products and processes on the organization, strategies and economic results of micro- and small-scale enterprises (MSEs). This objective was achieved through the following specific objectives:

- Identification and typology of the SMEs involved in the process of fonio.
- Assessment of the different formal and informal relations between SME and their suppliers and their clients and of the internal organisation.
- Assessment of capacity and constraints of each type of SMEs to develop new products and process

Typology and characterization of fonio processing enterprises in West Africa

In Guinea, Mali and Senegal, fonio processing micro-enterprises were created with the main objectives of generating wealth, of enhancing the grain based on innovations from the combination of traditional know-how and modern knowledge. Thus, an expertise has evolved over the years in the field of fonio processing and marketing. Opportunity niches have been discovered and several networks have been created. Support agencies are working in collaboration with producers' networks both to increase domestic production and marketing. African and non-African private promoters embarking on international markets included fonio in their products traded in European and American markets. While they specialize as distribution agents, others are on the entire sector with an emphasis on the European market (production-processing-marketing at the international level). But there is an increasing linkage between the two categories of players, thus leading to further specialization in the trade.

The typology of the fonio businesses has a strong profile with varied production levels and operating modes depending on the type of enterprise or the country of establishment. There are 3 types of fonio enterprises in West Africa: "processing enterprises", "Service delivery enterprises" and "Distribution enterprises". Over a hundred fonio MSE were identified in 3 countries, namely Guinea, Mali and Senegal. More than half are found in Mali. They are not all functional and those that are active are still at a varied production level. Their age varies between 3 and 17 years (between 1992 and 2006). Although Guinea is the largest producer (more than 130000 tons), fonio processing is still at a primary level. Mali, the world's 3rd producer with about 30 000 tons/year, is the leader of the processing industry thanks to dynamism and market niches developed and enhanced by small fonio processing entreprises. Although Senegal is among the last countries in terms of production (less than 1500 tons per year), it still is dynamic in processing and marketing thanks, on the one hand to the value adding and labeling of the fonio from Kedougou, but also on the other hand, due to the dynamism of enterprises processing and/or distributing a significant part of the fonio mainly imported from Guinea. Theses imports are regularly supplying the Senegalese market.

Fonio companies commercialise a variety of fonio products (precooked fonio, dried whitened washed fonio, whitened toasted fonio, "Djouka", etc.), but sometimes, they trade also other products (grains, …). However, for most cases, fonio remains dominant. In Mali, the share of fonio in the production of fonio MSEs is between 70 and 100%. For all processing agents and service providers in Senegal, fonio takes between 70% and 100% of their activities. For distribution enterprises, fonio is a secondary activity and represents between 10% and 20% of the volumes traded in cereals. In Guinea, fonio is less than 2% for luxury restaurants (great restaurants, hotels), 15 to 25% of the medium-sized restaurant (modern restaurants with a choice of several dishes), 40 to 60% of the popular restaurant (under sheds, near public buildings).

Internal management and organization of the SME.

The internal functioning and organization of fonio MSEs repeated the same pattern as other grain trading enterprises. The enterprise generally is managed by the main promoter, whether individual (belonging to one person) or community-based (belonging to a group, association, or a family). Most often a woman is the leader/manger of the enterprise. She decides on recruitments, distribution of roles and tasks within the enterprise, negotiation of contracts, signing contracts and monitoring the relational life of the company. Very often it is the most educated or the most "networked". This form of administration is both a strength and a weakness for the enterprise.

Women constitute over 90% of the workforce, approximately 80% of which are temporary. The number of working days by fonio enterprises is very variable. It depends on the size of the enterprise, the level of activity in its ability to supply raw materials and production capacity, but also the extent of its market. Irregular and low production capacity enterprises work approximately 100 days per year, while the most successful ones work between 250 to 300 days per year. The rainy season is a less favourable period for many of them, due to lack of adequate drying devices. Activities around the fonio sector have helped create direct and indirect jobs in Guinea, Senegal and Mali. Women's jobs are far more important. Women hold more than 90% of direct jobs created in the countries. Temporary jobs are strongly (73%) predominant. Permanent women only represent 27% of the total. Men hold 10% of the jobs created. These jobs are also unevenly distributed according to the type of enterprise. Most jobs are created by processing companies.

The quantities of processed fonio produced in Mali, Senegal and Guinea over the past 3 years are increasing. Mali is the leader in the field of fonio processing. Although Guinea is the largest producer and direct exporter of raw or primarily processed products, the production fonio products (including pre-dried) is still embryonic. Senegal imports “semi-finished” fonio (whitened washed or unwashed) from Guinea or precooked fonio from Mali. A great part of the precooked fonio imported is later re-exported to Europe. Guinea, Senegal and Mali have produced and marketed 670 tons of fonio in 2006, 720 T in 2007 and around 800 tons in 2008. Production of precooked fonio was over 460 T in 2008 mainly produced by Mali. The share of Senegal and Guinea remains very low (less than 25 T)

In Mali, numerous small SMEs processed fonio through service providers (about 500 tons per year). These service providers receive also fonio from traders (semi wholesalers and retailers), households… In Guinea, they are the main go-between of housewives. Whether in Diountou, Brouwal Kassa, Lélouma, Pita, Labe, Dongola Touma, Kindia and elsewhere, service providers play a fundamental role in the way back to the consumption of fonio. Citizens’ associations invest in their native villages for the mechanization of fonio husking. To some extent it helps women free up time to dedicate to other activities such as girls’ education and gardening. Impacts in terms of social and economic dynamics are real. A female leadership is consolidating around the sector. Women are present in the collection (sometimes production) to the distribution of finished products. Thus, fonio seems to be a niche of opportunities in terms of job creation and self-employment, but also wealth generation. This has mainly enabled some women to enhance their know-how and to undertake investments.

Fonio has developed a market, which is maintained and expands gradually. This market is local, sub-regional and international thanks to the demand of the Diaspora and business opportunities related to promotion of dry cereal in West Africa (dry processed products in plastic bags). Fonio is placed in a dynamic of progress, fairly sustained. Fonio does not only have tradable value, but appears as a source for creating multifaceted relationships across borders. It provides space for trade and social exchanges. Destination countries are very diverse. In Europe, mainly precooked, and secondarily Djouka are sold in France, and particularly in Spain). In the U.S., the precooked is sold in New York, Boston, Atlanta, Philadelphia, etc.). In Africa, Malian

precooked and djouka are sold in Senegal, Côte d'Ivoire, Congo, Gabon, etc.). In Asia precooked is sent to in Saudi Arabia

The SME and their relations with suppliers and customers

The analysis of the network of enterprises makes it possible to understand that they have a multitude of links to many stakeholders upstream and downstream the processing and distribution channel. From the viewpoint of SMEs links with their environment, the links with raw material suppliers are the most complex and most maintained. This is the first level which requires a perfect mastery of risk. These risks can be defined in terms of availability, quality, regularity, price variability depending on seasons, adjusting to or ability to withstand various external or internal crises. It is for this reason that here, a sense of relationship has a pattern, which is not only economic but also social. Supply is the basis for operations. In this relationship, the notion of trust is crucial, it is even decisive. It is central to the sustainability of linkages and configures them. In the three countries, fonio SMEs have developed several strategies to ensure their supplies: stock up just after harvest, production, financing production, imports from neighbouring countries.

In the fonio products distribution system at the local level, SME are not always satisfied with the conditions of transfer of the product to distributors, including supermarkets and minimarkets, shops, filling stations shops, etc. The mode of payment, the setting and negotiation of prices are not usually in favour of SMEs. Key to divergence is the sharing of the capital gain from fonio. The margins generated by fonio are unevenly distributed among the distributors and SMEs. Those earned by distributors exceed those of enterprises.

In the export segment, the customer-distributor-exporter combines not only the margin but also the assimilation to the product through the dispossession of the processing agents form their identity and that of the product. In this market, the exporter is a screen between its customers and the manufacturing enterprise, the latter not having the capacity to access the markets directly. Processing SMEs are thus in a situation of ambivalence: the need to maintain and stimulate the growth of relationships with distributors and to expand their visibility through the product and the label. It appeared that the same problem arises between the three countries in terms of product reputation. In Senegal, fonio from Mali or from Kedougou region is very famous, but in fact, the most part of this fonio processed and marketed in the region or exported comes from Guinea. Thus, Guinea, where processing techniques and export markets are less developed loses in terms of label (identity), recognition, but also loses in terms of economic gains,.

Some technological constraints are still preventing the sustainable development of fonio processing and marketing: the removal of sand, fonio washing, the development of networks of skilled manufacturers for the construction and dissemination of existing equipments, the technical, financial capacity-building of enterprises. On the other hand, despite the diversity of stakeholders who are in connection with fonio SMEs, the latter are facing the main issue of inadequate construction of the sector. This construction is developing. Regulation is weak (for instance for traceability) and compliance with agreed rules is very questionable. So, enterprises try to adjust according to the challenges they face.

Conclusion

In Guinea, in Mali or in Senegal fonio remains very popular and is becoming increasingly well known. But, there are many constraints despite the potential. However, the activity maintained and grows. Some companies manage to become successful in niche markets and become indispensable in the development of the sector. They become places for the assertion of female leadership, but also for the creation of a great deal of employment for women, while enhancing their know-how at the same time. If the internal organization and control of some constraints are still detrimental to most of them, the innovations on products and mechanization of processing (husking….) have made it possible to achieve important annual turnover, which is modestly contributing to the consolidation of local economies.

4.2.5. Opportunities for diversification and multipurpose uses of fonio in crop-livestock farming systems (WP5)

Work package 5 is coordinated by CIRDES (Centre International de R&D sur l'Élevage en zone Subhumide) in Burkina Faso and is implemented in collaboration with Cirad (France), Institut Economie Rural (Mali), IRAG (Institut de Recherche Agronomique de Guinée) and CRA-W (Walloon Center of Agricultural Research) in Belgium.

Objective and rationale of the study

Fonio (*digitaria exilis*) is a minor African cereal, neglected by research and development. There is a lack of updated and summarised data on West Africa's major production basins which makes it difficult to assess and compare fonio cultivation as well as the evolution of its role in production systems. The studies conducted under this project were aimed at filling this gap by studying the fonio-producing countries included in the Fonio project (Guinea, Mali and Burkina-Faso).

WP5's objective was to study how fonio could be a diversification crop in West Africa's savannah areas by making a significant contribution to the food needs of a growing population, contributing to the producers' financial incomes, and contributing to the sustainability of production systems through the diverse use of the straw while preserving the environment by using few agricultural inputs.

Methodology

In each country, the studies were focused on the two major fonio production basins which are found in three agro-ecological zones:

- the semi-arid zone: Tomininian (Mali) and Kossi (Burkina Faso) ;
- the hilly sub-humid zone: Bougouni (Mali), Kénédougou-Houet (Burkina Faso), Bordo (Upper Guinea) ;
- high altitude sub-humid zone: Bareng (Middle Guinea).

First there was an analysis of the diversity of the production systems that incorporate fonio (survey of 300 fonio-growing producers, 100/country). It was followed by an analysis of the cropping systems and the different production variation factors (agronomic monitoring of fonio plots with 84 producers, Guinea (34), Mali (30), and Burkina (20). These first two steps identified possible areas of intervention to improve production techniques. These options were then tested either on farms or on stations (effect of organic manure on fonio, composting of fonio straw, treatment of fonio straw with urea for ruminant feed). In order to prioritize the options, two complementary studies were conducted (with 40 fonio producers from Burkina Faso, Mali and with fonio production support service providers): (1) analysis of fonio producers' strategies and (2) description of the social and technical environment.

Main results

Depending on the agro-ecological zones where it is produced (semi-arid zone, hilly sub-humid zone, and high altitude sub-humid zone), fonio is found in very different production systems. Its significance in crop rotation varies according to the cropping systems, 12% in semi-arid zones, 23% in hilly sub-humid zones, 19% in high altitude sub-humid zones (table below).

Table 2. Chacteristics of the production units in the various agro-climatic zones

Agro-ecological zones	Semi-arid	Hilly sub-humid	High altitude sub-humid
Number of mouths to feed /PU	15.0	14.2	12.2
Number of workers /PU (workers)	10.2	6.9	7.5
Total surface area cultivated /PU (ha)	11.7	8.1	5.8
Tropical Livestock Units /PU (TLU)	10.8	7.7	4.5
Nb of fonio plots per PU	1.1	1.4	1.7
Fonio surface area per PU (ha)	1.4	1.9	1.1

Fonio is primarily used as a food to complement other cereals in order to meet carbohydrate requirements. In the semi-arid zone, it complements millet and sorghum; in the hilly sub-humid zone maize, sorghum, rice and tubers; in high altitude sub-humid zones, rice and potatoes. In the semi-arid zone, because of its early harvest, it is the staple food between September and November. Fonio contributes modestly to the

households' financial incomes because the quantities sold are low. In the areas where some organizations (NGOs, Farmers' associations) guarantee a larger market, larger quantities are sold. Also, some women producers produce and collect fonio for the urban markets (Bamako, Bobo-Dioulasso…).

Overall, fonio's technical itinerary is the same in all the agro-ecological zones and has not evolved much in 100 years apart from the introduction of ploughing by animal traction. Producers generally have three varieties (early, semi-early, late), all broadcast (30 to 40 kg/ha) after ploughing by animal traction or, on weak soils, by hand with a hoe. Fonio does not receive any inputs; it is manually weeded once or twice. It is harvested with sickles, dried in the field and threshed by sticks or tramped upon. Fonio yields vary mainly with rainfall (500 to 600 kg/ha in the semi-arid zone versus 600 to 700 kg/ha in the sub-humid zone), the presence of weeds in the fields, and soil fertility. However, under appropriate growing conditions, some producers obtain yields exceeding 1 t/ha.

Table 3. Characteristics of fonio's technical itinerary in the various agro-climatic zones

Agro-ecological zones	Semi-arid	Hilly sub-humid	High altitude sub-humid
Age of the field (years)	21.3	6.4	5.4
Fonio cultivated in plains (%)	89 %	44 %	45 %
Ploughing by animal traction (plough)	95 %	73 %	63 %
Date of fonio sowing (mean)	30/5	10/5	1/7
Seed dose (kg/ha)	33.4	34.3	25.0
Manual weeding (number)	0.8	1.2	1.0
Date of fonio reaping (mean)	19/9	17/9	10/11
Interval between sowing and reaping (j)	104.1	124.2	132.0
Paddy fonio yield (kg/ha)	646.0	553.9	467.5

Fonio has many advantages. In comparison with the other cereals, it is a completely organic crop, with a very low cost (15,000 CFA F/ha versus 70,000 CFA F/ha for maize), with low labor needs until just after the harvest. It is therefore a crop which is adapted to the possibilities of the most modest producers (poor, women…). It has, however, a few constraints. It has a low yield in comparison with the other cereals (paddy fonio yield: 500-700kg/ha ; millet-sorghum : 800-1,000kg/ha ; maize : 1,100-2,500kg/ha); it has a high selling price on the market (WP3 estimates the price of whitened and cleaned fonio at 470 CFA F/kg versus 220-270 CFA F /kg for the other cereals on the Bamako market); it requires significant harvest and post-harvest work (husking); it doesn't benefit from any social and technical support services.

Several recommendations for technical and organizational improvements have been made to strengthen fonio as a diversification crop. The recommendations which seek to increase productivity while preserving the « organic » nature and which were tested under WP5 include:

1) *Organic fertilization of fonio* and early weeding: the use of organic manure on farmers' fonio plots at the rate of 5t DM/ha increased the fonio paddy grain yield by about 100 kg/ha ;
2) *Use of the straw for composting*: the tested technique consists of putting fonio straw into pits at the end of the dry season (April) in order to obtain mature compost the following year at the same period. The most efficient method is the following. While it is put into the pit, fonio straw is mixed with animal manure at the rate of 20% to which water can be added to accelerate the beginning of the decomposition process. During the first three months, the pit is turned twice (one month and 2 months after filling). With one ton of raw mixture about 200 kg of compost can be obtained after 6 months. This technique mostly concerns the sub-humid zone where the straw is usually abandoned near the threshing area.
3) *Use of fonio straw as fodder***.** Owing to its low lignin and cellulose content, in comparison with the other cereals, the digestibility of fonio straw is higher than the measured digestibility of more coarse cereal straws (respectively 53-59% versus 40-49%). The voluntary ingestion of fonio straw is comparable to other cereal straws. The treatment of fonio straw with 5% of urea has not resulted in the improvement of wilful ingestion and digestibility. The use of fonio straw as fodder can be an appropriate technique in the semi-arid zone which experiences a fodder shortage in the dry season.

There is a direct link between availability of mechanized husking and the quantities of fonio marketed. Whenever producers' organizations or NGOs invest in the mechanization of husking (a necessary condition to lower the price of husked fonio) and guarantee a market by ensuring the primary collection and

distribution of fonio on the local urban markets and/or for the international (organic and fair) market, there is a rapid and significant increase in the quantities of marketed fonio. Under such conditions, fonio can play the role of a commercial income-generating crop for producers.

Conclusion

In the semi-arid zone, although fonio is less significant in crop rotation than in the sub-humid zone, the commercial potential and the possible expanded use of the straw indicate that fonio could be a diversification crop. The comparison of fonio with the other cereals cultivated in each of the zones also shows its organic and low cost nature. However, the low yields and the difficult post-harvest work explain why the other cereals which require more inputs are surpassing fonio. Research findings in the production of organic manure based on cereal straw or in the area of post-harvest equipment could help to remove these constraints. But the greatest challenge is to structure the producers' organizations in order to facilitate the acquisition of this equipment or provide the training in new techniques. Despite the differences noted in the various agro-ecological zones this study shows the persistence of fonio in West Africa's production systems. This persistence can be explained by its role of ensuring the flexibility of systems faced with unpredictable climatic and economic changes. Overall, this study shows the interest of upgrading traditional cereals in the development of innovative cropping systems.

4.2.6. Improving knowledge on fonio based cropping systems and ways for improving productivity (WP6)

Work package 6 is coordinated by CRA-W (Walloon Center of Agricultural Research) in Belgium and is implemented in collaboration with Cirad (France), IRAG (Institut de Recherche Agronomique de Guinée), IER (Institut Economie Rural) in Mali and CIRDES (Centre International de R&D sur l'Élevage en zone Subhumide) in Burkina Faso. The general aim of WP6 is to improve the existing knowledge on fonio based cropping systems and ways for improving their productivity with attractive socio economical and environmental benefits and in phases with the market chain expectations. This objective was achieved through the following specific objectives:

- Better knowledge on fonio varieties (morphologic diversity, genetic functioning, photoperiodism, cycle duration…) and capacity building for seed production and conservation meeting the needs of the different WP of the project and its follow up.
- Climate- soil- nutrients -biomass potential and efficiency analysis: Potential production of biomass for collected varieties depending on climate and nutrients resources. In situ flux study, water and nutrients balance for representative ecosystems.
- Present Fonio based Cropping System diagnosis: rapid survey of existing cropping systems and practices and analysis of actual biophysical performances under farmers conditions (link with WP5). Comparison of actual productivity with potential.
- Close the gap through innovation: To identify with farmers the desirable experiments aiming at increasing the resiliency of the cropping system (water nutrient efficiency, higher productivity, externality control)

Through a strong collaboration between teams of Guinea, Mali, Burkina Faso, France, Belgium and Netherland, this project has lead to the description and characterisation of the most popular fonio varieties found in these African Countries. So a catalogue characterises more than 35 fonio cultivars from their botanical, from their ability to be processed and from their nutritional value point of views. Such activity has to be maintained across years in order to improve the panel of the described varieties and the robustness of these descriptions under contrasted soil and climate conditions, to sustain farmer choice.

In parallel, varieties comparison trials were performed in 2006 and 2007 in, respectively, 3 and 4 experimental stations in Guinea and in Mali, under contrasted rain levels, ranged between 600 mm and 1500 mm, and temperatures (one Guinean site was lated 1000 m asl). In 2006, with mean yields of, respectively, 788 and 922 kg/ha, no significant difference was observed between varieties performances nor in Bordo (Guinea) neither in Cinzana (Mali). In Bareng (Guinea) there was a clear impact of variety precocity on its productivity: the earlier varieties, with an average yield of 952 kg/ha, showed better performances than late ones' (672 kg/ha). In 2007, the mean performances, of the varieties that close their cycle of development, were of 437 kg/ha in N'Tarla (Mali), 498 kg/ha in Cinzana (Mali), 905 kg/ha in Bordo (Guinea) and 1330 kg/ha in Bareng (Guinea). The results from 2007 confirmed the ones of 2006 with the early heading varieties

being at the top ranks in the 4 sites. The varieties with an intermediate cycle length performed well in the Guinean sites, with a longer rainy season, while they showed poor yields in Mali sites. The varieties with a late heading date have led to the poorer performances whatever the site.

These observations are unexpected. Indeed, as showed by WP5 inquiries, farmers usually highlight the better performances of late heading varieties in Guinean locations where the rainy season is longer, allowing them to close their development cycle. Now, from results obtained, it seems more risky to crop late than early varieties, so why to maintain such late varieties? The explanation could be plural. Late heading varieties are of interest to distribute manpower need in a more uniform way all along the rainy season, moreover, in the area where they were maintained, the maturity of these varieties coincides with the beginning of the dry season. So they can be harvested and stored under good conditions.

It would have been very interesting to remake such multi-locations comparison during three to four years in order to cover, as much as possible, the diversity of the rainy season profiles that could be observed under these latitudes.

The observations performed on fonio response to photoperiod support the adaptation of this species to its environment in synchronizing its physiological state to climatic conditions under natural conditions, without irrigation. Such a response allows flowering grouping under good climatic conditions, whatever the sowing date and, so, to reduce mould risk associated to early flowering or water stress associated to late flowering. So the definition of fonio varieties response to photoperiod allows characterizing their adaptability/plasticity face to environmental variations and their sensitivity to the sowing date (cycle length).

So, results obtained in Bordo (Guinea – 10.38° Lat N) and Sotuba (Mali – 12.65° Lat N), during two years (2006 and 2007), confirmed the photopheriodic character of fonio varieties, with a flowering induction under shortening day length. In this way, the plants sown later had a shorter vegetative cycle and, in parallel, a lower biomass production than the ones sown earlier. Nevertheless, each variety was characterized by its own intrinsic cycle length. On this basis, as underlined in the variety comparison trial, three groups can be identified: the early, intermediate and late-heading varieties. Based on these results, a model of fonio response to photoperiodism, for different cultivars, was elaborated. Thus it is possible to determine, in crossing this model with the length of the rainy season, the potential area of valorisation for the different fonio varieties.

In order to have a better evaluation of fonio potentialities in term of soil nutrient valorisation and so to have a better definition of the place of fonio in the cropping system (after manure spreading, at the end of the rotation, …), fonio response to N, P and K fertilisers was explored. These experiments were done under contrasted soil and levels of precipitations, in Bareng (Middle Guinea), Bordo (Upper Guinea) and Cinzana (Mali). Indeed, this response could depend of the production potential of the area, as fonio is found in area with high potential, such as in Upper Guinea, till area with a low production potential, such as in the Segou area, in Mali, characterized by short rainy seasons, high average temperature and sandy soil with a low fertility level.

The results of fertilisation trials undeline the risk to supply only one nutrient to the fonio if the others are under shortage. It is more efficient, from an agronomical and economical point of view, to supply the different macro-nutrients at a moderate level that to focus on one to be applied at a huge amount excepted if soil analysis or carence phenomenum support this. These results also underline the positive impact of moderate fertilisation level (less than 30 units of each of these macro nutrients) on fonio productivity. Due to the high cost of these fertilisers, innovations, to be assessed have to be based on organic fertiliser valorisation or to the implementation of the fonio at the good place in the crop rotation scheme, for example after the rotation head.

In order to analyze the impact of variety and fertilization schemes on fonio quality, different tools, based on near infra-red spectrometry, were also developed and validated during this project.

Finally, different demonstration trials were set up in 2008, in two villages of Guinea, Mali and Burkina Faso. In Guinea and Mali, activities focus on cultivar comparison and confirm, in this way, the results obtained in experimental station with better performances of early heading varieties. Nevertheless, as underlined before, this could lead to some mould risk during the harvesting time in Guinea. While in Burkina Faso, activities focus on fonio fertilization through manuring.

All these results underline the work remaining to be done in terms of:

(1) Fonio cultivar characterization, in order to be able to isolate true varieties that can be used further in selection plan, taking into account the advantage of early heading varieties in term of productivity. Such cultivar characterization has to take into account consumers needs and expectations in terms of final product quality.
(2) Crop rotation, succession, definition in order to improve fonio yield in an ecological way, without increasing costly inputs needs. Such increase of global soil fertility has also a negative impact on the development of a very damageable weed that is striga.

Conclusions

Many results were obtained under the FONIO project, in terms of knowledge of the fonio commodity chain. On a scientific level, the project enabled the development of analysis protocols specifically suited to studies of small grains, and precise results were obtained, notably in terms of knowledge of the fonio product (physical, biochemical and nutritional characteristics and quality) and criteria for promoting fonio on urban and export markets. Major information were also collected and analysed on farming and cropping systems (inventory of the main ecotypes, innovations to use fonio as a diversification crop….) and practical results were obtained to identify and satisfy the expectations of local operators as SMEs (e.g; adapted dryers).

The many results obtained under the project should not be seen as the culmination of the work done, but rather as a starting point for future operations, with a view to more effective promotion of fonio, a cereal that has long been neglected.

CD-Rom of “Fonio Conference”

Annex 1

List of some scientists and staff involved in the project

Coordination and management

Project coordinator: Jean-François Cruz – Cirad (France)
Administrative and financial matters: Ms Pascale Lantier – Cirad (France)

WP1 - Diversification of fonio products for niche export markets and local markets

Responsible scientist: Ms Geneviève Fliedel - Cirad (France)

Participant n°1- Cirad (France) : Ms G. Fliedel, Ms V. Fallet, J. Grabulos, M. Rivier, C. Marouzé, J.F. Cruz
Participant n°4- IER (Mali) : Ms Y. Koureissi, Ms Coulibaly S. Sidibé, Ms Boré F. Guindo, Ms Tangara Ms Cissé O. Traoré, M. Diarra, K. Tangara, F. Koné
Participant n°5 - IRAG (Guinea) : Ms M. Ndiaye

WP2 - Nutritional aspects of fonio and fonio products

Responsible scientist: Ms Inge D. Brouwer - Wageningen University (The Netherlands)

Participant n°2 - Wageningen University (The Netherlands) : Ms. I. Brouwer
Participant n°4 - IER (Mali) : Ms Y. Koureissi,
Participant n°1 - Cirad (France): Ms G. Fliedel
Others : UAC (Benin): R. Dossa, Ms. N. Fanou

WP3 The demand for new products and its effects on income generation and distribution

Responsible scientist: Ms. Sandrine Dury – Cirad (France)

Participant n°1 - Cirad (France) : Ms S. Dury, N. Bricas
Participant n°4 - IER (Mali) : L. Diakité, M. Traoré
Participant n°5 - IRAG (Guinea) : Ms M. Ndiaye, Y Chaloub
Participant n°7 - ENDA Graf (Senegal) : B. Touré, O. Gueye

WP4 - Small scale enterprises and innovation in product and process

Responsible scientist: Babacar Touré – ENDA Graf (Senegal)

Participant n°7 - ENDA Graf (Senegal) : O. Gueye, B. Touré, Ms F. Ndoye, P. Seck
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Participant n°4 - IER (Mali) : M. Traoré, Ms Boré F. Guindo, D. Dramé
Participant n°5 - IRAG (Guinea) : Ms M. Ndiaye, Y Chaloub

WP5. Opportunities for diversification and multipurpose uses of fonio in crop-livestock farming systems

Responsible scientist: Eric Vall – CIRDES (Burkina Faso)
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Participant n°3 - CRAW (Belgium) : D. Stilmant, B. Dupuis
Participant n°4 - IER (Mali) : D. Sogodogo, Y. Coulibaly, V.F. Dembélé
Participant n°5 - IRAG (Guinea) : F. Béavogui, T. A. Diallo, Ms. M. A K. Soumah, S. Diallo

WP6 - Improving knowledge on fonio based cropping systems and ways for improving productivity.

Responsible scientist: Didier Stilmant – CRAW (Belgium)
Participant n°3- CRAW (Belgium): D. Stilmant, B. Dupuis
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