

## **Fonio as a staple food in West Africa: An approach to upgrade nutritional value**

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### **Abstract**

Fonio (*Digitaria exilis*) is the most ancient West African traditional cereal, used as a staple food particularly during the food shortage periods. The potential of the grain for contributing to food security, while alleviating nutritional deficiencies among vulnerable groups of West African communities has been reconsidered. The value chain approach for nutritional goals has been explored for upgrading the nutritional value of fonio products. In the present research we assessed the acceptability of fonio and tested the effect of degrading phytic acid on iron absorption from fonio meals. Subjects involved were women of reproductive age randomly selected in Bamako, the capital city of Mali (108 women aged 15-49 year-old from 3-stage cluster sampling procedure), and Cotonou, the largest city of Benin (16 women aged 18-30 year-old from simple random sampling for iron absorption study). Data collection included an acceptability survey based on a behavioral model; and an iron absorption study using stable isotopes in a cross-over design. In the used behavioral model, fonio consumption was strongly predicted by intention to consume ( $r = 0.78$ ,  $P < 0.001$ ). Intention to consume fonio in urban areas was influenced by positive beliefs and attributes such as the good cooking, organoleptic and nutritional qualities, softness, easy digestibility, healthfulness, contribution to weight maintenance, appetite stimulation, contribution to meal variation, and traditional value of fonio ( $\hat{a} = 0.32$ ,  $P < 0.05$ ). Subjective norms, namely husbands' opinion, were also more likely to motivate intention to consume fonio ( $r = 0.26$ ,  $P < 0.001$ ). The model also allowed identifying potential barriers to fonio consumption, being seasonal shortage, time-consuming processing and cooking, the high costs of fonio products in urban markets, and the lack of skills in cooking fonio ( $\hat{a} = -0.72$ ,  $P < 0.05$ ). The obstacles appeared to have a significant interaction between intention to consume and fonio consumption. This indicated that the more the women have intention to consume fonio, the more likely they will face some obstacles for consuming fonio. Adding wheat to fonio porridge reduced phytate-to-iron molar ratio from 23.7:1 to 2.7:1. Iron fortification of the fonio-wheat porridge decreased the molar ratio to 0.3:1. Mean (95% CI) iron absorption ratio from single fonio porridge and fonio-wheat porridge was 2.6 (0.8-7.8) and 8.3 (3.8-17.9) respectively. Fractional iron

absorption from fonio-wheat porridge was 3.2-fold higher compared to single fonio porridge meal (paired *t* test,  $P < 0.0001$ ). As conclusion, the study found that consumer-oriented activities for enhancing fonio consumption should emphasize positive attitudes and opinions of men, family and neighbors, while strengthening skills of women in cooking good quality fonio meals. The use of locally available and widely used cereals as wheat for dephytinisation is a promising practice that needs to be further explored in developing countries with other traditional cereal-based porridges. The technical feasibility of this technology with regard to users' compliance need to be further explored in developing countries household conditions.

**Key words:** Behavioural model, *Digitaria exilis*, iron bioavailability, phytic acid degradation, stable isotope

## Résumé

Le fonio (*Digitaria exilis*) est la plus ancienne céréale traditionnelle Ouest-africaine, utilisé comme un aliment de base en particulier pendant les périodes de pénurie alimentaire. Le potentiel du grain pour la sécurité alimentaire, tout en atténuant les carences nutritionnelles chez les groupes vulnérables des communautés d'Afrique de l'Ouest a été reconsidérée. L'approche de la chaîne de valeur pour des objectifs nutritionnels a été explorée afin d'améliorer la valeur nutritionnelle des produits de fonio. Dans la présente étude, nous avons évalué l'acceptabilité du fonio et testé l'effet de dégradation de l'acide phytique sur l'absorption du fer à partir de repas à base du fonio. Les sujets impliqués étaient des femmes en âge de procréer choisis au hasard à Bamako, la capitale du Mali (108 femmes âgées de 15 à 49 ans provenant d'une procédure d'échantillonnage en grappes à 3 étages) et de Cotonou, la plus grande ville du Bénin (16 femmes âgées de 18 à 30 ans à partir d'un échantillonnage aléatoire simple pour l'étude de l'absorption du fer). La collecte de données consistait en une enquête d'acceptabilité basée sur un modèle de comportement; et une étude de l'absorption du fer en utilisant des isotopes stables dans un modèle cross-over. Dans le modèle de comportement utilisé, la consommation de fonio a été fortement prédit par l'intention de consommer ( $r = 0,78$ ,  $p < 0,001$ ). L'intention de consommer le fonio dans les zones urbaines a été influencée par des croyances positives et des attributs tels que la bonne cuisson, les qualités organoleptiques et nutritionnelles, la douceur, la digestibilité, l'avantage sanitaire, la contribution au maintien du poids, la stimulation de l'appétit, la contribution à la variation des repas, et la valeur traditionnelle de fonio ( $\hat{\alpha} = 0,32$ ,  $P < 0,05$ ). Les normes subjectives, à savoir l'opinion des 'maris' étaient également plus susceptibles de motiver l'intention de consommer le fonio ( $r = 0,26$ ,  $P < 0,001$ ). Le modèle a également permis d'identifier les obstacles potentiels à la consommation du fonio que sont : la pénurie saisonnière, son traitement et sa cuisson prennent du temps, les coûts élevés des produits à base de fonio dans les marchés urbains, et le manque de compétences dans la cuisson du fonio ( $\hat{\alpha} = -0,72$ ,  $P < 0,05$ ). Les obstacles semblent avoir une interaction significative entre l'intention de consommer et la consommation de fonio. Ceci indique que plus les femmes ont l'intention de consommer le fonio, plus elles seront susceptibles de faire face à des obstacles pour consommer le fonio. Ajout du blé à la bouillie du fonio réduit le rapport molaire du phytate au fer de 23,7: 1 à 2,7: 1. L'enrichissement en fer de la bouillie de l'association blé-fonio a diminué le rapport molaire de 0,3: 1. Le taux d'absorption moyen (IC à 95%) du fer de la bouillie à base de fonio seule et de la bouillie à

base de la combinaison fonio-blé était respectivement de 2,6 (0,8 à 7,8) et 8,3 (3,8 à 17,9). La fraction d'absorption du fer de la bouillie de l'association porridge fonio-blé était de 3,2 fois plus élevée par rapport au repas de bouillie à base de fonio seul (test t apparié,  $P < 0,0001$ ). Comme conclusion, l'étude a révélé que les activités axées sur les consommateurs pour améliorer la consommation de fonio devraient mettre l'accent sur les attitudes positives et les opinions des hommes, la famille et les voisins, tout en renforçant les compétences des femmes dans la cuisson des repas de bonne qualité à base de fonio. L'utilisation de céréales disponibles localement et largement utilisés comme le blé pour la dephytinisation est une pratique prometteuse qui doit encore être exploré dans les pays en développement avec d'autres bouillies à base de céréales traditionnelles. La faisabilité technique de cette technologie en conformité avec les besoins des consommateurs doivent encore être explorées dans les conditions des ménages des pays en développement.

Mots clés: modèle comportemental, *Digitaria exilis*, biodisponibilité du fer, dégradation de l'acide phytique, isotopes stables

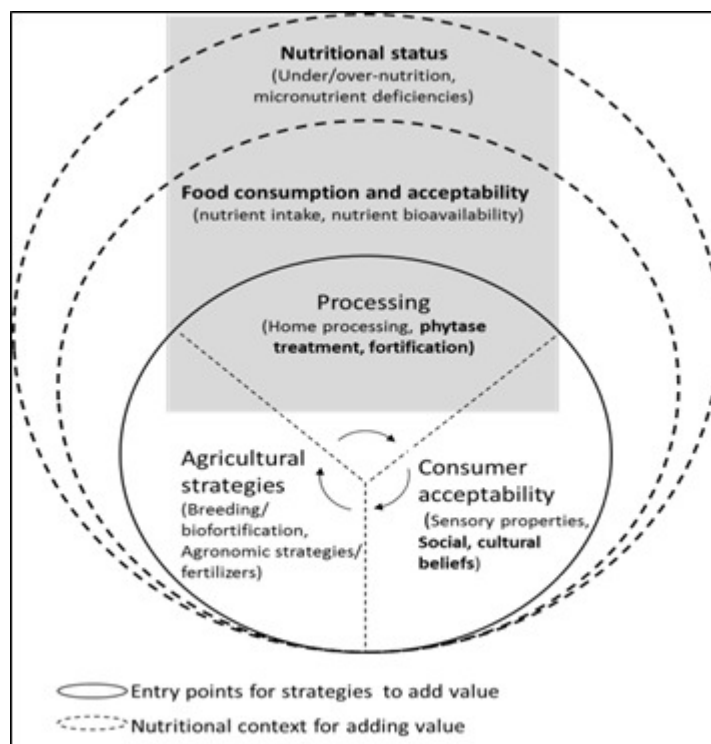
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## Background

Fonio (*Digitaria exilis*) is the most ancient West African traditional cereal having a large ecological adaptability. In some communities, fonio is a staple grain particularly during the food shortage periods. As such, its potential for contributing to food security, while alleviating nutritional deficiencies among vulnerable groups of West African communities has been reconsidered. The value chain approach for nutritional goals is a set of strategies that can be explored for upgrading the nutritional value of fonio products. Strategies to add nutritional value to foods through the value chain approach include i) agricultural strategies to improve the nutrient content of foods, ii) food processing to improve the level and uptake of nutrient from foods, and iii) improving the acceptability of the food with consumer-oriented strategies (Fig. 1) (Adoukonou-Sagbadja *et al.*, 2006). Particularly for West African women living in urban areas facing the double risk of iron deficiency and overweight/obesity, adding nutritional value to fonio products can be relevant in improving their nutritional/health status while enhancing household food security. Processing and investigating fonio acceptability may be key entry points of a value chain approach for adding nutritional value to fonio products. The main objective of the present research was to upgrade the nutritional value of fonio through home processing and fortification. To achieve this objective, some specific research questions were addressed. First we assessed the role of the grain in urban diet patterns, as well as the beliefs, attributes and perceived barriers related to its consumption. The influence of these factors on the intention to consume fonio was investigated to document the acceptability of fonio in urban areas. An iron absorption study investigated the effect of degrading phytate in fonio with intrinsic wheat phytase on iron absorption from iron-fortified fonio products in a sample of Beninese young women.

## Literature summary

Fonio is one of the most ancient traditional cereals cultivated across the West African dry savanna regions along the Sudanese zone (Hawkes and Ruel, 2011). Particularly white



**Figure 1.** Conceptual framework for adding value to a product: the value chain approach for nutritional goals. Adapted from Hawkes and Ruel (Adoukonou-Sagbadja *et al.*, 2006)

fonio (*Digitaria exilis*) is primarily grown in Guinea, Mali, Burkina Faso, Ivory Coast, Nigeria and Benin, in marginal, mountainous and hilly zones with sandy, poor and degraded soils, without fertilizers and pesticides. In West African semi-arid areas, fonio is the major part of the diet during harvest periods, and in sub-humid zones it is stored during the post-harvest period, for use as food supply during the food shortage periods (Konkobo-Yameogo *et al.*, 2004). Major constraints reported in fonio cultivation and harvesting are related to the small size of the grain. This leads to tedious and time-consuming post-harvest and cooking processes. As with most traditional cereals, fonio is produced in traditional systems with little or no external inputs (Hawkes and Ruel, 2011). Most activities are manually performed, making post-harvest activities more laborious and time-consuming. During the past decade, national agricultural research centers of the main producing West-African countries have collected and conserved important germplasm of fonio genetic resources (Sun *et al.*, 2006). Moreover, in the perspective of defining appropriate strategies for conservation of fonio on farm, information has been produced on ethnobotanical and indigenous knowledge related to fonio production, diversity, use and conservation, genome content and size of the crop as well as its genetic diversity. To improve fonio processing and cooking techniques, modern and new equipment have been developed at small companies and women's groups in West Africa. Also, modern small-scale processing industries for ready-to-cook products have been developed in urban areas and modern fonio-based recipes have been experienced. However, less effort has been made to document and improve the potential of fonio to contribute to nutritional and health-related issues in West Africa.

## Study description

Subjects engaged in the study involved were women of reproductive age randomly selected in Bamako, the capital city of Mali (108 women aged 15-49 year-old from 3-stage cluster sampling procedure), and Cotonou, the largest city of Benin (16 women aged 18-30 year-old from simple random sampling for iron absorption study). Data collection included an acceptability survey based on a barrier analysis using a behavioral model; and an iron absorption study using stable isotopes in a cross-over design.

## Research application

In the used behavioral model (Fig. 2), fonio consumption was strongly predicted by intention to consume ( $r = 0.78$ ,  $P < 0.001$ ). Intention to consume fonio in urban areas was influenced by positive beliefs and attributes such as the good cooking, organoleptic and nutritional qualities, softness, easy digestibility, healthfulness, contribution to weight maintenance, appetite stimulation, contribution to meal variation, and traditional value of fonio ( $\beta = 0.32$ ,  $P < 0.05$ ). Subjective norms, namely husbands' opinion, were also more likely to motivate intention to consume fonio ( $r = 0.26$ ,  $P < 0.001$ ). The model also allowed identifying potential barriers to fonio consumption, key among them being seasonal shortage, time-consuming processing and cooking, the high costs of fonio products in urban markets, and the lack of skills in cooking fonio ( $\beta = -0.72$ ,  $P < 0.05$ ). The obstacles appeared to have a significant interaction between intention to consume and fonio consumption. This indicated that the more the women have intention to consume fonio, the more likely they will face some obstacles for consuming fonio. Numbers of positive social and cultural attributes and social barriers have been related to the consumption of fonio in West Africa (Konkobo-Yameogo *et al.*, 2004; Sun *et al.*, 2006; Vall *et al.*, 2011). However, scientific evidence of the relationship between fonio consumption and the treatment of these diseases has not been demonstrated so far. The identified determinants in this study are relevant for use in a behavioral change programme.

Exploring processing as strategy for adding nutritional value to fonio showed that adding wheat to fonio porridge reduced phytate-to-iron molar ratio from 23.7:1 to 2.7:1. Iron fortification of the fonio-wheat porridge decreased the molar ratio to 0.3:1. Geometric mean

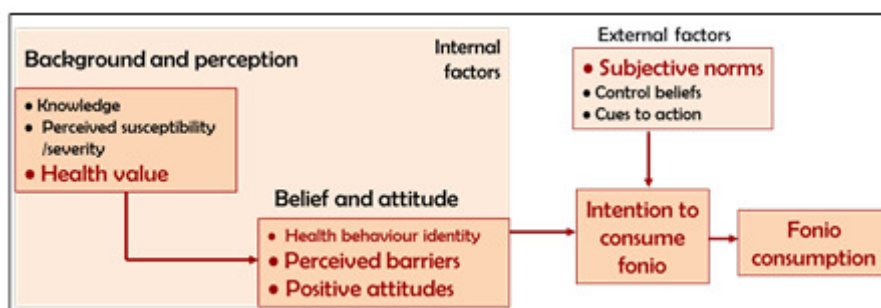
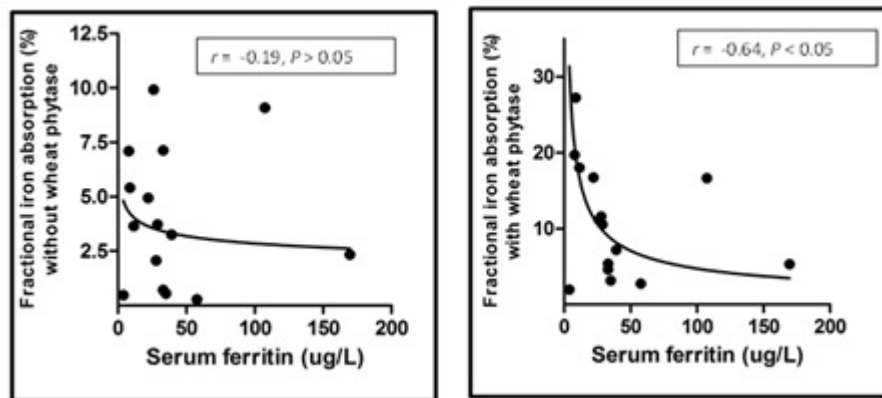


Figure 2. Behavioral model based on combined Health Belief Model and Theory of Planned Behavior based on Sun *et al.* (2006)



**Figure 3.** Iron absorption showed by serum ferritin concentration from non-dephytinised (without wheat flour) and dephytinised (with wheat flour) fonio porridge using stable isotopes ( $n = 15$ ). Black lines represent non-linear log-log fitting regression lines

(95% CI) iron absorption ratio from single fonio porridge and fonio-wheat porridge was 2.6% (0.8-7.8) and 8.3% (3.8-17.9) respectively (Fig. 3). Fractional iron absorption from fonio-wheat porridge was 3.2-fold higher compared to single fonio porridge meal (paired  $t$  test,  $P < 0.0001$ ). Inhibition of iron absorption by phytate in plant-based meals occurs at very low concentrations of 2-10 mg phytate/ meal (Hurrell and Egli, 2010). Thus, phytate:iron molar ratio should be preferably lower than 0.4:1 to achieve a significant iron absorption when no enhancers of iron absorption are added to the meal.

The study found that consumer-oriented activities for enhancing fonio consumption should emphasize positive attitudes and opinions of men, family and neighbours, while strengthening skills of women in cooking good quality fonio meals. An essential finding was that adding wheat flour to fonio porridge before consumption reduced the phytate content, decreasing phytate-to-iron ratio in iron-fortified fonio porridge from 23.7:1 down to 0.3:1. The use of locally available and widely used cereals such as wheat for dephytinisation is a promising practice that needs to be further explored in developing countries with other traditional cereal-based porridges. The technical feasibility of this technology with regard to users' compliance need to be further explored in developing countries household conditions, as wheat phytase can reach its optimal activity only within a limited range of temperature and after more than 1h of incubation.

### Acknowledgement

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