Journal of Applied Biosciences 170: 17690– 17703
ISSN 1997-5902

Improvement of the nutritional quality of a local germinated sorghum-based complementary food: effect of sorghum (*Sorghum* bicolor) and shea caterpillar (*Cirina* butyrospermie) combination

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Submitted on 29th November 2021. Published online at www.m.elewa.org/journals/ on 28th February 2022
https://doi.org/10.35759/JABs.170.3

ABSTRACT

Objectives: This study aimed to improve the nutritional composition and functional property of complementary foods developed from a formulation of sorghum seeds and insect larvae, *Cirina* butyrospermie, one of the most widely eaten larvae in the Northern part of Côte d'Ivoire as alternative protein source.

Methodology and results: After germination, sorghum seeds and shea caterpillar were milled into flour and formulated in the ratio 90-10 (sorghum/shea). Physicochemical analyses were conducted on the 10%-shea caterpillar enriched sorghum flours, germinated (GSSCF) and ungerminated (USSCF) and their traditional counterpart using standard methods. Proximate composition of the studied sorghum flours showed for traditional and enriched form significant differences ($p < 0.05$) with the enriched flours recorded the highest acidity, ash, fat, proteins, fibres, total sugar and energy values. These sorghum flours also exhibited lower value in phytates and in tannins and oxalates, and significantly influenced functional characteristics except for emulsifying and foaming capacity.

Conclusion and application of results: Overall, the present study has shown that shea caterpillar can be used to develop complementary foods that are nutritionally and functionally adequate to meet the dietary intake of infants at an acceptable level compared to their traditional counterpart. The incorporation of shea caterpillar flour in proportions of 10% in the germinated (GSSCF) and ungerminated (USSCF) sorghum flours has improved significantly ($p \leq 0.05$) nutritional and functional properties of sorghum flours and significantly reduced the negative impact of antinutrients on mineral assimilation. Thus, these results have the merit of indicating a level of incorporation *of C. butyrospermi* larvae in germinated and ungerminated sorghum flours favourable to their use in human diet to prevent undernourishment due to protein and could be recommended for formulations in food industries as good alternative for the nutritional management.

Keywords: physicochemical composition, sorghum, infant flour, complementary food, shea caterpillar

INTRODUCTION

In accordance with FAO, (2014) access to sufficient food in quality and quantity is a fundamental right that must allow overcoming the problems of malnutrition that are prevailing throughout the world. Indeed malnutrition, which is an abnormal physiological state due to inadequate and unbalanced intake through excess or deficiency of nutrients, affects nearly 800 million people worldwide in 2017 (FAO, 2018). Malnutrition is therefore considered a public health problem worldwide and particularly in Africa where the prevalence of undernourishment is the highest as nearly 21% of the population is malnourished (FAO, 2018). In addition, it is estimated that this scourge responsible for 45% of deaths of children under five years of age globally and 33% of infant mortality at the level of Côte d'Ivoire is reportedly due to the low nutritional intake of staple foods consumed and poorly diversified diets (FAO, 2014). Indeed, the supplemental foods given to children during the weaning period are mostly local cereal or tuber/root based foods (Bamba *et al*., 2018). These first supplement foods are rich in carbohydrates but poor in proteins and some minerals and this make them unable to cover all the nutritional needs of the child. In order to address these deficits and solve the recurrent problem of malnutrition in a sustainable way, the strategies to be put in place must be based on the three principles of food security: availability of food, access to food, and use of food (Bamba *et al*., 2018). Therefore, complementary foods should be made from locally available, low-income, nutritionally adequate products to meet nutrient needs of the child (Rougbo *et al*., 2019). Among these local products, sorghum (*Sorghum bicolor*) is a food security crop especially in West Africa. It is the main staple food for about 300 million people living in the semi-arid tropics (Bamba *et al*., 2018). Although locally available, sorghum-based preparations (porridges and flours) have insufficient protein and energy densities to cover children's needs (Bamba *et al*., 2018). However, the various traditional processing methods used locally such as germination, fermentation contribute to the improvement of the nutritional and organoleptic quality of these foods (Xu *et al*., 2017). Indeed, germination allows, through the activation of a number of enzymes (amylases, proteases), the decomposition of reserve macromolecules namely starch and proteins into sugars, soluble proteins and amino acids (Xu *et al*., 2017) which are essential nutrients. Studies have thus shown an increase in the nutrient composition of sorghum with the effect of germination (Nwanguma *et al*., 1996) and all these authors agree on the interest of germinated sorghum meal to increase the energy density of weaner porridges. Regarding the improvement of protein density, the usual recommendation is to opt for the strategy of fortification of staple foods (Rougbo *et al*., 2019) to improve their nutritional quality. This involves the development of fortified supplementary foods essential for growth and development of the organism (FAO, 2018). Indeed, supplemental foods are the combination of different nutritional and functional foods rich mainly in proteins, fats, vitamins and minerals obtained from cereals like sorghum in our case and other source products (Xu *et al*., 2017). Very often, these other source products are plant foods that are potentially rich in proteins, lipids and essential nutrients such as legumes (soybeans, voandzou), oilseeds. However, these plant diets are deficient in essential amino acids that are indispensables for the organism since it is unable to synthesize them. This deficiency in terms of protein quality therefore requires the integration of animal proteins in the diet (Ehounou *et al*., 2018). The high cost of traditional animal proteins (egg, milk, meat, fish.) combined with food insecurity and the growing need for protein-rich foods is leading to the study of innovative approaches such as edible insects to increase their production and consumption in the poorest regions of the world. The affordable animal proteins of edible insects are important source of protein that can be used in the formulation of supplemental feeds (Ehounou *et al*., 2018). The use of edible insects in complementary food production is not extensively studied. Only few studies have been conducted on the use of insects as components of Complementary Food, such as palm weevil larvae, crickets (Agbemafle *et al*., 2020] with other local foods. Shea caterpillars (*Cirina* butyrospermie) are a very promising food resource, as they are available in northern Côte d'Ivoire and consumed by local populations. In addition, they represent an excellent source of protein that account for more than 50% of the weight with 62.74 g per 100 g of dry matter of which about half (47.64%) is made up of essential amino acids (Ehounou *et al*., 2018). Therefore, it is possible through this approach to develop safe and nutrient-rich supplementary foods from locally available and acceptable food raw materials that could be suitable for resource-poor settings (Rougbo *et al*., 2019). Different flours formulations of germinated and ungerminated sorghum composite flours with shea caterpillar flour were developed. An *in vivo* test carried out on young wistar rats showed that the germinated sorghum formulation with 10% of shea caterpillar flour was the one that induced the best growth characteristics in terms of zootechnical parameters, biological value (data not shown). In the context of sustainable food and malnutrition where entomophagy has a significant role to play in ensuring food security and improving the livelihoods of many of the world's people, we are interested in studying the nutritional quality of cereal-based complementary flour enriched with animal proteins in view to prepare complementary food for infants and young children (6 - 23 months). This study therefore aimed to evaluate the nutritional and functional composition of complementary foods made from mixtures of staple cereals and shea caterpillar.

MATERIAL AND METHODS

Study material: The plant material consists of sorghum (Sorghum bicolor) seeds harvested from a field near Ferkessedougou, a town located in northern Côte d'Ivoire. The shea butter caterpillars were purchased from a local salesperson at the Korhogo market who collected them in the localities around Korhogo.

Preparation of germinated sorghum grain flour (GSF): Five kilograms of sorghum grains were washed and soaked in 25 L of distilled water for 24 hours. After soaking, the sorghum seeds were spread on a damp cotton cloth to initiate germination in a chamber with humidity and temperature of 85 ± 5% and 28 ± 3 °C respectively for 4 days. Germination was stopped by oven drying (Biobase WGL-125B) for 72 hours, and then the manually degerminated sorghum grains were ground in a heavy-duty high-speed blender. The flour obtained (GSF) was sieved with a 250-µm mesh sieve (AFNOR) and stored in jars for analysis (Figure 1).**Preparation of shea caterpillar flour (SCF):** The shea caterpillars (*Cirina butyrospermie*) were sorted and then washed with water containing 1% bleach. They were dried in an oven (Biobase WGL-125B) at 45°C for 72 hours. They were ground in a Heavy Duty speed blender, then the resulting flour (SCF) was sieved with a 250 µm mesh sieve (AFNOR) and stored in hermetically sealed plastic jars for later use (Figure 1).

Formulation of composite flour of germinated sorghum flour (GSSCF): After the nutritional tests performed in vivo on wistar rats, the formulation 90-10 was used to prepare the composite flour from the previously prepared flours GSF (90%) and SCF (10%). Composite flour samples were blended properly, packed in sealed bags and stored until further analysis (Figure 1).

Analytical Methods

Proximate Composition: The moisture, crude protein (N×6.25), were determined in triplicate according to the Standard Association of Official Analytical Chemists (AOAC, 2005) procedures. The crude fat content was determined by continuous extraction in a Soxhlet apparatus for 8 h using hexane as solvent (AOAC, 2012). The pH value and titratable acidity was carried out following AOAC, 2005 method. The total ash content was determined by incinerating in a furnace at 550 °C (AOAC, 2012). The crude fibre content was determined by AOAC, (2012) methods.

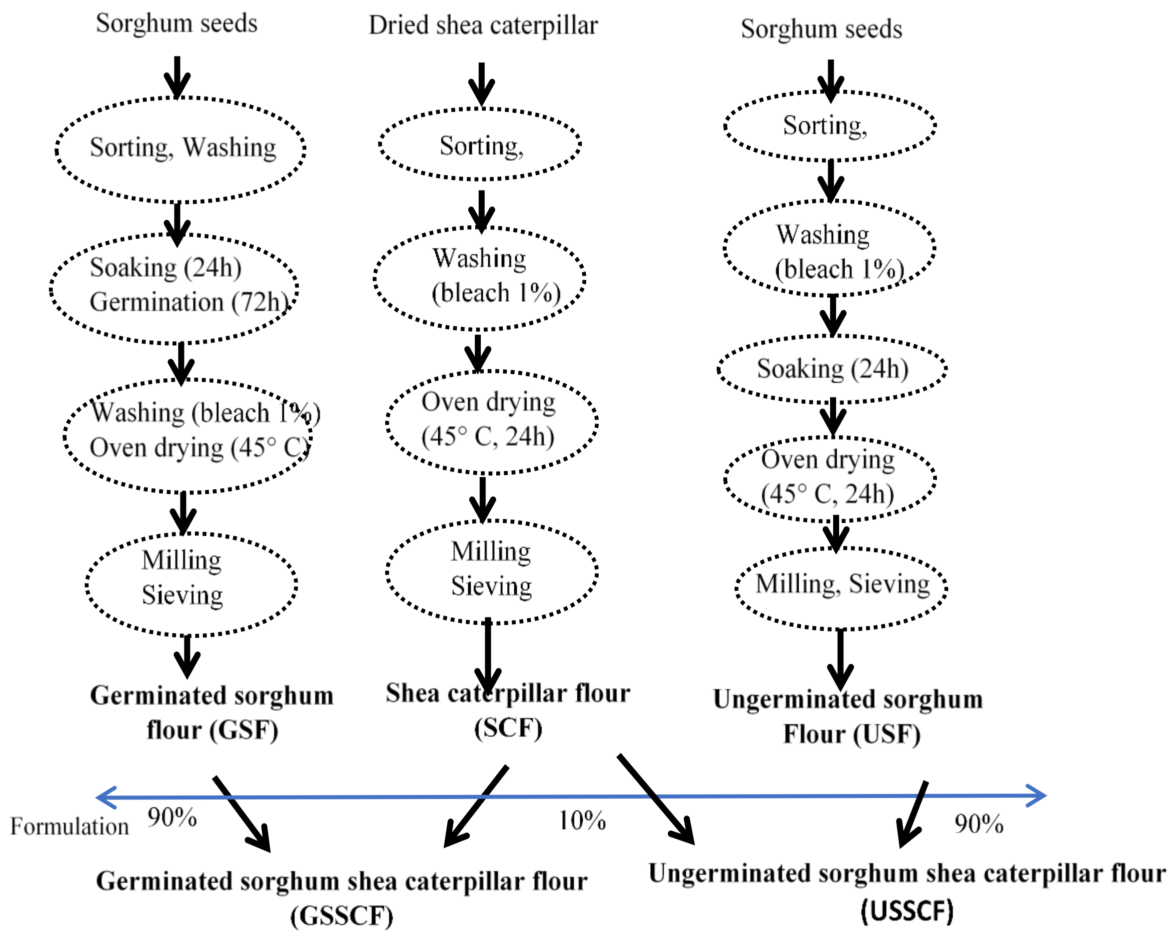

Figure 1: Process flowchart on the preparation of flours

The amount of total soluble sugars was estimated by Phenol sulphuric acid reagent method (Dubois *et al*., 1951). The amount of reducing sugars was determined by using 3, 5-dinitrosalicylic acid colorimetric procedure developed by Bernfeld (1955). The carbohydrates content were determined by difference. Energetic value was calculated using Atwater factors of 4-× % protein, 4 × % carbohydrate and 9 × % fat and then taking the sum. The starch content was determined by considering the starch/glucose ratio as 0.9 by formula (1) according to Atwater and Benedict (1902) procedure.

Amidon=0.9 x (% carbohydrates - % total sugar) (1)

Three main anti-nutritional factors such as tannins, phytic acid and oxalates were evaluated in the studied samples. The tannins content of each sample was determined by vanillin HCl method (Bainbridge *et al*., 1996). As concern the phytic acid content, it was evaluated based on the method described by AOAC, (2005) and Oxalates content was determined by Day and Underwood, (1986) method.

Functional properties:

Bulk density (BD) Measurement: Bulk density was determined using the method described by Narayana and Narasinga (1982). Fifty (50) g sample (ME) were weighed and placed in a 100 mL volumetric cylinder and the sample on the cylinder was holding on a vortex vibrator for 1 min to obtain a constant volume of the sample. The bulk density value was calculated as the ratio of mass of the flour and the volume occupied in the cylinder (V_t) according the relation (3)

$$BD\ (g/mL) = ME / V_t \quad (3)$$

Wettability measurement: The method described by Onwuka (2005) was adopted. One (1g) of roasted corn flour was placed in a 25 mL measuring cylinder with a diameter of 1 cm. The cylinder was inverted at 10 cm above the water contained in 600 mL beaker. The finger was used to close the cylinder disallowing the flour sample from falling. By removing the finger and giving the cylinder a gentle tap, the flour sample was discharged into the water surface. Remove finger and pour contents into beaker. The time taken by the sample to get completely wet was recorded as the time of wettability.

Water absorption capacity (WAC) and water solubility index (WSI): Water absorption capacity is the ability of flour to absorb and retain water. Water absorption capacity (WAC) and water solubility index were determined using the method described by Phillips *et al*. (1988). One (1) g of flour (M_0) was weighed and dissolved in 10 mL of distilled water contained in a centrifuge tube. The mixture was stirred for 30 min by a stirrer and held in a water bath at 37 °C for 30 min. Then, the mixture was centrifuge at 4200 rpm for 12 min (Ditton LAB centrifuge, UK). The resulting sediment (M_1) was weighed and then dried at 105 °C to constant weight (M_2). The WAC was then calculated as follows the relation (4) and (5):

$$WAC\ (\%) = (M_2\text{-}M_1) / M_2 \times 100 \quad (4)$$

While the WSI was calculated using the following equation:

$$WSI\ (\%) = (M_0\text{-}M_1) / M_0 \times 100 \quad (5)$$

Oil absorption capacity (OAC): For the oil absorption capacity, the method described by Eke and Akobundu, (1993) was used. One (1) g of flour (M_0) is weighed and dissolved in 10 mL of oil. The mixture was then stirred for 30 min at room temperature using a magnetic stirrer and centrifuged at 4000 rpm for 10 min. The pellet was recovered and the mass was recorded (M_1). The OAC was then calculated as follows the relation (6)

$$OAC\ (\%) = (M_1\text{-}M_0) / M_0 \times 100 \quad (6)$$

Foaming Capacity and Foam Stability: The foaming capacity (FC) and stability (FS) of flour were studied according to Coffman and Garcia's (1977) method. Three grams of flour were transferred into clean, dry and graduated (50 mL) cylinders. The flour sample was gently levelled and the volumes noted. Distilled water (30 mL) was added to the sample; the cylinder was swirled with a vortex (Genius 3 France) for 5 min. Initial foam volume was registered and then the cylinder was allowed to rest for 120 min while the change in foam volume was recorded every 15 min. Foaming capacity and foam stability were calculated using the relation (7) and (8), respectively

$$FC\ (\%) = ((V_t - V0) / V_0) \times 100 \quad (7)$$

$$FS\ (\%) = (FC / FC_0) \times 100 \quad (8)$$

Where V_0 is the original volume of the sample (mL), V_t is the total volume after different times (mL) and FC_0 is the initial foaming capacity (FC).

Emulsion capacity measurement: The emulsion (EC) capacity of the compound flours was determined according to the slightly modified Beuchat (1977) method. Two (2) grams of flour were dispersed in 50 mL of distilled water contained in an Erlenmeyer. The mixture was homogenized with a magnetic stirrer for twenty (20) min. The suspension was transferred to a centrifuge tube and 10 mL of oil (V_0) was added. This mixture has been stirred continuously for 5 min, and then heated in a water bath for 15 min at 85 °C. The tube is removed and cooled at room temperature (25 °C) for 5 min and centrifuged at 4500 rpm until the volume of oil (V_1) separated from the emulsion (V_2) becomes constant. The results are expressed as a percentage of emulsified oil / gram of composite sorghum flour used (relation 9).

$$EC (\%) = VE \times 100 / V \times W \quad (9)$$

where: W: weight of sample, VE: Volume of emulsion layer E and V: Total volume of mixture

Statistical Analysis*:* All experiments in this study are reported as means of three replicate analyses. The collected data were thus subjected to one-way Analysis of Variance (ANOVA) ($p < 0.05$) using SPSS 11.0 software. Means with significant differences were separated using Duncan's multiple range tests.

RESULTS AND DISCUSSION

Proximate composition: Food composition evaluation and information are needed to assess diet quality and to develop and implement food-based dietary recommendations (Elmadfa and Meyer, 2010). The proximate composition of the studied flours, traditional sorghum flours (germinated and ungerminated form) and their shea caterpillar enriched flours is summarized in table 1. The results revealed that the enriched sorghum flours showed significant differences ($p < 0.05$) with enriched germinated sorghum flour exhibited the higher value except for pH, carbohydrates and starch.

Table 1: Proximate composition of traditional germinated and ungerminated sorghum flours and their enriched flours with shea caterpillar

Physicochemical Parameters	**Traditional sorghum flour**		Enriched sorghum flour with 10% shea caterpillar flour	
	GSF	**USF**	**GSSCF**	**USSCF**
Moisture (%)	**06.23 ± 0.43^{a}**	06.17±0.01^{b}	06.04±0.00^{c}	<u>05.97±0.63^{d}</u>
Acidity (mEq/100g)	05.55 ± 0.26^{b}	<u>01.82±0.04^{d}</u>	**06.08±0.01^{a}**	02.71±0.00^{c}
pH	<u>06.01 ± 0.00^{d}</u>	**06.73±0.01^{a}**	06.12±0.02^{c}	06.54±0.24^{b}
Ash (%)	01.99 ± 0.01^{b}	<u>00.51±0.04^{d}</u>	**02.07±0.00^{a}**	00.73±0.00^{c}
Fat (%)	04.39 ± 0.07^{b}	<u>02.46±0.16^{c}</u>	**06.58±0.00^{a}**	04.83±0.01^{b}
Proteins (%)	07.24 ± 0.22^{c}	<u>04.91±0.23^{d}</u>	**22.74±0.06^{a}**	10.30±1.56^{b}
Fibres (%)	05.16 ± 0.57^{b}	<u>03.33±0.28^{d}</u>	**06.54±0.00^{a}**	04.87±1.02^{c}
Carbohydrates (%)	80.14 ± 0.33^{b}	**85.81±0.24^{a}**	<u>72.90±0.22^{d}</u>	77.99±2.23^{c}
Starch (%)	**70.41 ± 0.28^{a}**	76.02±0.27^{b}	63.53±0.31^{c}	<u>68.56±1.95^{d}</u>
Total Sugar (%)	01.94 ± 0.08^{b}	<u>01.35±0.10^{d}</u>	**02.23±0.00^{a}**	01.69±0.00^{c}
Reducing Sugar (%)	00.22 ± 0.05^{b}	00.14±0.00^{c}	**00.34±0.00^{a}**	00.26±0.00^{b}
Energy (kcal/100g)	<u>389.10 ± 1.97^{c}</u>	<u>386.23±1.60^{c}</u>	**400.48±0.43^{a}**	397.88±2.45^{b}

Each value is the mean of triplicate analyses. Different letter in the same line Indicate statistical difference (p<0.05**).**

Legend: In bold, highest values; underlined, the weakest. GSF: germinated sorghum flour; USF: ungerminated sorghum flour; GSSCF: germinated sorghum shea caterpillar flour and USSCF: ungerminated sorghum shea caterpillar flour

The lower moisture content observed with the enriched sorghum flours GSSCF (6.04%) and USSCF (05.97%) comparatively the traditional sorghum flour with 6.23 and 6.17 % for germinated and ungerminated sorghum, respectively (Table 1) should be advantageous. Indeed, according to Sanni *et al* (2006) the lower the moisture content of a product to be stored, the better the shelf stability of these products. This fortification using insect larvae reduced the available water and thus would extend the shelf life of the composite sorghum flour by reducing its susceptibility to microbial spoilage making this formulation recommended for convenient food for children (Elmadfa and Meyer, 2010). On the other hand, the traditional germinated sorghum flour (05.55 mEq/100g) and its counterpart enriched with shea caterpillar (06.08 mEq/100g) showed a relatively **pronounced acidity** than those of the other two studied sorghum flours (01.82 and 02.71 mEq/100g for both ungerminated traditional and enriched flours, respectively. This potential acidity is an advantage insofar as it could contribute to improve the shelf life of these flours (Caplice and Fitzgerald, 1999). Indeed, the acidity generally linked to the presence of organic acids might help to reduce the incidence of diarrhoea in infants. So the consumption of this formulated sorghum-based with 10% shea caterpillar could contribute to the health status of infants (Lorri and Svanberg, 1994).

As regards the crude fat content, results also showed that shea caterpillar flour fortification increased significantly the fat content of germinated sorghum enriched flours with 6.58 (GSSCF flour) unlike the other three studied flours 4.39 (GSF flour), 02.46 (USF flour) and 04.83% (USSCF flour). Fat is essential for the supply of energy in the body, facilitate absorption of fat-soluble vitamins and provide essential fatty acids that are required for normal development (Aranceta and Pérez-Rodrigo, 2012). They are also essential in complementary food as they increase the palatability of foods by absorbing and retaining their flavours (Elmadfa and Meyer, 2010). This could explain easily why the larva is very appreciated and renowned for its palatability. Edible insects contain good quality fatty acid especially long chain omega-3 fatty acids such as alpha-linoleic acid, linoleic acid (Aranceta and Pérez-Rodrigo, 2012). As all types of complementary flour was not able to provide them, this germinated sorghum enriched-10 % larvae flour will also play a nutritionally role in providing essential fatty acids in addition to providing the recommended fat level (less than 10 %) for weaning foods (PAG, 1972).

In the same way, ash content of the germinated sorghum flours, traditional (01.99 %) and shea caterpillar enriched (2.07 %) counterpart, was higher than that of the ungerminated sorghum flour (00.51 and 00.73 % for traditional and enriched flours, respectively). This suggests that the fortification with this edible insect increased ash content making this flour an excellent source of minerals as the ash content indicates a rough estimation of the mineral salts content of the product. Mineral salts are necessary for human body processes such as osmotic concentration and enzymes systems regulation (FAO, 2014). Thus, the germinated sorghum complementary food enriched with the 10%-shea caterpillar flour is an excellent source of mineral salts for infant and growing children.

Protein is one of the most important nutrients required in weaning foods. Similarly, the two sorghum flours enriched with 10% shea caterpillar flour had the highest protein content with 22.74 for the enriched germinated and 10.30% for the enriched ungerminated sorghum flours. An over three-fold and two-fold increase in protein content was observed for these enriched sorghum flours, when compared to their traditional flours counterpart (7.24 and 4.91% for GSF and USF flours, respectively). Similar increased has not been report yet in food formulation with proteins vegetables source including legumes, nut seeds since only protein increases of up to 90% have been reported in the literature (Rougbo *et al*., 2019). The high protein contents of this formulation might be due mostly to inclusion of insect larvae, which boosted the overall protein content (Banjo *et al*., 2006). The high protein content is an indication that the flour fortification with insects larvae can be of value in weaning foods, thus replacing more costly sources of animal protein that are usually absent in the diet of rural dwellers in developing countries. They contain in their dilapidated form over 80% of high quality protein with high content of essential amino acids (USDANAL, 2005) and can be useful in weaning food applications. The balanced intake of protein is essential for meeting the growing demand children especially during this critical stage of growth. Growing children require a constant supply of protein for growth, building up new tissues and body maintenance (Banjo *et al*., 2006). The crude fibre content of the studied flours were significantly different for each other at $p < 0.05$ with the enriched germinated sorghum flour displaying the highest value (06.54%) followed by its traditional germinated form (5.16%), the enriched non-germinated flour (4.87%) and finally the traditional non-germinated flour (3.33%). Fibre helps make us full and keeps things moving in the digestive tract. A diet that includes good sources of fibre may help prevent constipation. These foods also are good sources of nutrients and vitamins that may help reduce the risk of heart disease, specific cancer, and obesity. Fibre-containing foods share unique characteristics with nutritional and metabolic implications for the weaning infant. So these enriched sorghum flours with adequate fibre content would be suitable for weaning flours (Banjo *et al*., 2006) as their ash content met the recommended value (< 4%) for infants and young children complementary foods formulation (FAO, 2017).

Unlike to previous results, the carbohydrates content of the 10%-shea caterpillar enriched sorghum flours, ranging from 72.90 to 77.99%, for GSSCF and USSCF flours, respectively, was lower than that of their traditional counterpart (Table 1). However, these contents remained higher than those of cereal and legume-based supplementary foods such as 5% (soybean)-5% (peanut) roasted maize meal (62.31%) (Rougbo *et al*., 2019) and are within the range of values (60-75%) recommended by FAO (2017) in the Guide for the Formulation of Supplementary Foods for Infants and Young Children. Carbohydrates are important sources of energy for the brain, which depends on them for proper functioning, as do many other organs in the body (Rougbo *et al*., 2019). Thus, the carbohydrate contents of all the studied sorghum flours were below the limit (41.13-73.79 %) recommended by the Codex Alimentarius Standards (FAO, 1994) indicating their adequacy on providing energy. Moreover, it is to be noted that the traditional sorghum flours with the highest carbohydrate content are those with the highest starch content and inversely for the enriched sorghum flours (R^2=0.97). The correlation observed between the total carbohydrate and starch contents of the studied flours attests the fact that starch represents the major part of the total carbohydrates of the formulations and could justify that these sorghum flours could constitute a suitable source of energy for rural populations in northern Côte d'Ivoire (Aryee *et al*. 2006). As concerned the sugar content of the studied sorghum flours, it should be noticed that the 10%-shea caterpillar enriched sorghum flours exhibited the higher values with 0.34 for GSSCF and 0.26 % for USSCF flours. With regard to the previous applications, the importance of sugar content (mainly reducing sugar) should be stressed. Indeed, this sugar content could give a natural sweetness to the products and made these enriched sorghum suitable for food industry.

The energy contents of both types of sorghum flour, traditional and enriched, were also depicted on Table 1. The obtained energy value (400.48 kcal/100 g) only energised by the enriched germinated sorghum flour was within the recommended value (400-425 Kcal/100 g) for infants and young children complementary foods formulation. Energy from the diet is recommended to be adequate to meet the physiological requirement of the body. Thus, given that the consumption of 100 g of this complementary food could provide about 47.11% of the Recommended Dietary Allowance (FAO, 2017) for 6-12 month, this enriched germinated sorghum flour with edible insect could be categorized as source energy diet and represent a good alternative to prevent the risk of food chain insecurity in developing countries.

Antinutrients: Antinutrients in complementary foods for children may affect negatively on their health status, especially when they are cereal-based. However, the different traditional processing methods allow to reduce them significantly in formulated diets. Thus, their evaluation in formulated cereal-based foods appears useful to assess their nutritional potential. The anti-nutrient composition of the both types of sorghum flour under study, traditional and enriched in mg/100 g is reported in Table 2.

Table 2: Anti-nutrients composition of the traditional germinated and ungerminated sorghum flours and their enriched flour with shea caterpillar

Anti-nutrient content	**Traditional sorghum flour**		**Enriched sorghum flour with 10% shea caterpillar flour**	
	GSF	**USF**	**GSSCF**	**USSCF**
Phytates (mg/100 g)	50.87±0.57^{b}	**52,76 ± 2,25^{a}**	47.72±2.05^{d}	49.40±1.00^{c}
Tannins (mg/100 g)	36,94 ± 1,93^{d}	47.55±1.42^{c}	53.01±1.44^{b}	**62.57±1.58^{a}**
Oxalates (mg/100 g)	110,57 ± 0,57^{d}	166.26±4.40^{b}	135.34±3.40^{c}	**185.48±3.47^{a}**

Each value is the mean of triplicate analyses. Different letter in the same line Indicate statistical difference ($p < 0.05$).
Legend: In bold, highest values; underlined, the weakest. GSF: germinated sorghum flour; USF: ungerminated sorghum flour; GSSCF: germinated sorghum shea caterpillar flour and USSCF: ungerminated sorghum shea caterpillar flour

The analysis of these values showed a significantly different distribution ($p \leq 0.05$) depending on whether the sorghum was germinated or not. Indeed, in the case of phytates, enrichment with the 10% shea caterpillar flour results in formulation with the lowest content (47.72) for germinated sorghum in contrast to the formulation with ungerminated sorghum (49.40). Similarly, the same formulation of germinated sorghum yields complementary flours with lower tannins (53.01) and oxalates (135.34) contents than with ungerminated sorghum (62.57 and 185.48, respectively) even though these values are higher than those of traditional sorghum flours. Cereal-based complementary foods are rich in oxalates, tannins and phytates among other anti-nutrients, which limit the bioavailability of nutrients, especially divalent ions such as iron, calcium, zinc and protein macromolecules, which are essential for infant development (Amagloh *et al*., 2012). Indeed, phytates/oxalates-bivalent ion complexes (iron, zinc, calcium) could make these essential minerals for the growth and harmonious development of infants unavailable; similarly, the formation of tannins-protein complexes can make these proteins unavailable and thus contribute to the decrease in protein digestibility (Amagloh *et al*., 2012). Therefore, the enrichment of germinated sorghum with 10% shea caterpillar flour, which leads to formulation with low levels of these anti-nutrients, could help reduced the occurrence of protein-energy malnutrition, particularly in regions where shea caterpillars are part of the food habits of rural populations with low-income levels.

Functional Properties*:* The functional properties of the studied sorghum flours were summarized in Table 3. It is noteworthy that germination combined with the enrichment of 10% shea flour greatly influenced functional characteristics insofar as significant ($p \leq 0.05$) differences were observed in all parameters except for emulsifying and foaming capacity.

Table 3: Functional properties of traditional germinated and ungerminated sorghum flours and their enriched flour with shea caterpillar

Functional properties	Traditional sorghum flour		Enriched sorghum flour with 10% shea caterpillar flour	
	GSF	**USF**	**GSSCF**	**USSCF**
Foaming capacity (%)	**05.64±0.08[a]**	**05.75±0.03[a]**	**05.37±0.00[a]**	**05.47±0.01[a]**
Emulsion capacity (% par g)	**41.12±0.00[a]**	**41.87±0.21[a]**	**41.06±0.00[a]**	**41.74±1.26[a]**
Bulk density (g/ml)	**00.86±0.00[a]**	**00.88±0.01[a]**	**00.84±0.00[a]**	**00.86±0.00[a]**
Wettability (s)	**03.28±0.10[a]**	**03.51±0.00[a]**	02.44±0.02[b]	02,75±0.00[b]
Water absorption capacity (%)	**92.96±0.53[a]**	**93.06±0.47[a]**	**92.98±0.00[a]**	**93.02±2.02[a]**
Oil absorption capacity (%)	72.33±4.04[d]	81.33±1.05[b]	74.06±0.00[c]	**82.16±1.55[a]**
Water solubility index (%)	**11.33±0.57[a]**	02.67±0.00[c]	**11.06±0.00[a]**	03.27±0.02[b]
Foam stability (%)	38.67±2.31[c]	**47.50±0.25[a]**	36.45±0.00[d]	44.39±1.54[b]

Each value is the mean of triplicate analyses. Different letter in the same line Indicate statistical difference ($p < 0.05$).

Legend: In bold, highest values; underlined, the weakest. GSF: germinated sorghum flour; USCF: germinated sorghum shea caterpillar composite flour; GSF: germinated sorghum flour; USF: ungerminated sorghum flour; GSSCF: germinated sorghum shea caterpillar flour and USSCF: ungerminated sorghum shea caterpillar flour

Indeed, the traditional sorghum flours, germinated and ungerminated seeds, exhibited foaming capacity values ranged from 05.75 to 05.64 %, respectively and the enriched one values ranged from 05.47 and 05.37 %, respectively (Table 3). Similarly, the emulsifying capacity of the different studied flours was not influenced since the traditional sorghum flours showed emulsifying capacity values of 41.87 % for the ungerminated flour and 41.12 % for the germinated flour, which were significantly similar to those obtained with the enriched sorghum flours (41.74 and 41.06 % for the germinated and ungerminated flours, respectively). These values were lower than those obtained by Mezajoug (2010) in protein concentrates of *R. heudelotii* (63.25%) and *T. conophorum* (87.68%). These parameters related to the solubility of proteins would favour the formation of emulsions, which would contribute to provide desirable properties to foods (Mezajoug, 2010). The low values of foaming and emulsifying capacity obtained by the studied composite flours especially by the enriched one could be explained by the high resistance of the globular proteins of these flours to surface tension. As for the bulk density, the obtained values were 0.88 to 0.86 g/ml for USF and GSF flours, respectively and 00.86 g/ml (USSCF) to 00.84 g/ml (GSSCF) flours (table 3). These values are lower (1.04 g/mL) than that of *Imbrasia oyemensis* larvae flour (Akpossan *et al*., 2015). This suggests that the studied flours were less heavy; therefore, they would occupy less space and would require relatively less packaging materials. Since bulk density is an excellent indicator of product porosity and influences packaging design, this parameter is useful in food industry to determine the type of packaging material required the handling of the material and the different wet process application (Mezajoug, 2010).

Concerning wettability, results revealed that the enrichment of sorghum flour improved wettability independently of germination. Indeed, the 10% shea caterpillar enriched sorghum flour exhibited the lowest wettability times 02.44 and 02.75 s for germinated and ungerminated sorghum, respectively compared to traditional sorghum flours with wettability values of 03.28 s (germinated flour) and 03.51

s (ungerminated flour). A flour is considered wettable when the wetting time is less than 60 seconds and very wettable if it is less than 30 seconds (Schuck, 2011). The high wettability of the enriched sorghum could be due to its high protein content. It has been reported that the higher the level of protein present, the quickly it takes to get wetted (Schuck, 2011). Water absorption capacity is an important factor indicating the maximum amount of water absorbed and retained by the food flour (Echendu *et al*., 2004),). Germination and addition of shea caterpillar flour did not significantly alter the water absorption capacity of sorghum flours with values of 92.96% (GSF), 93.06% (USSCF) and 92.98% (GSSCF) and 93.02% (USSCF). However, these values for enriched sorghum flours are higher than those displayed by Koffi *et al.* (2019) with full fat flour (71.17 %) and defatted flour (77.96 %) of dry *Cirina butyrospermi* larvae flours. The high protein content in sorghum-enriched flours was not sufficient to significantly increase their water absorption capacity because of their low starch content. According to Echendu *et al*. (2004), the water absorption capacity of composite flours would be directly influenced by both protein and starch contents. These authors indicated that any increase of this parameter is correlated with the increase of both protein and starch density. On the other hand, the low content of one of these parameters (starch in our case) would be a limiting factor that would reduce any increase in this capacity. However, this relatively high level of water absorption capacity obtained by enriched sorghum flours, ideal for reducing viscosity in food products (Echendu *et al*., 2004) could justify their use as ingredient in infant food preparation. The oil absorption capacity of flour is an indicator of food quality and taste (Echendu *et al*., 2004). The oil absorption capacity of the studied flours decreased from 81.33 to 72.33 % during germination and increased with the incorporated shea caterpillar flour 74.06 % (GSSCF) and 82.16 % (USSCF) (Table 3). This could be explained by the availability of protein and fat in the caterpillar flour. Indeed, the oil absorption capacity of the studied flours is related not only to the hydrophobic group of the proteins but also to the availability of lipophilic groups of the lipids. The higher the oil absorption capacity, the better the organoleptic characteristics of the flours. This capacity would also be important for food storage by preventing the development of oxidative rancidity (Mezajoug, 2010).

The water solubility index of the studied flours increased significantly during germination from 2.44 for GSF flour to 11.33 % for UGSSF flour, but was not significantly influenced by the enrichment of the sorghum flours USSCF (03.27 %) and GSSCF (11.06 %). These high values obtained by sorghum-germinated flours enriched with shea flour could justify their selection as thickener in food industries in the formulation of composite flours (Schuck, 2011). As for foam stability, it decreases during germination from 47.50 to 38.67 % for traditional USF and GSF flours, respectively and during enrichment from 44.39 to 36.4 5% in USSCF and GSSCF flours. Despite these decreases, values remain higher than those do (2.09 % for full-fat flour and 30.52 % for defatted flour) obtained with dry *Cirina* butyrospermi larvae flours by Koffi *et al*. (2019). Indeed, this high foam stability over time would be due to the maintaining of flours protein compounds stability after milling. With this potential, sorghum enriched flours could be useful in the food industry where they would improve the texture, consistency and appearance of foods (Koffi *et al*., 2019).

CONCLUSION AND APPLICATION OF RESULTS

The present study revealed, based on physical and chemical standard analysis, some important nutritional and functional benefits resulting from the combination of germinated sorghum with shea caterpillar in complementary food. The decrease in antinutritional factors of sorghum after germination coupled with the beneficial effects of protein-rich larvae could contribute to the suitability and macro-nutrients enhancement of complementary foods. This highlighted the possibility of using shea caterpillars as a new ingredient in the development of complementary feeds; and this use could be an alternative to fill the protein deficiency of plant sources. In this case, using shea larvae at 10 % level with staple seeds as component of complementary food is appropriate to enhance the attainment of adequate nutrients for infants and young children. However, further in-depth studies should be carried out on the intrinsic qualities to ensure that this enriched formulation with protein rich substances boost limiting amino acid, improves vitamin profile, functional and antioxidant properties necessary for a balanced diet and maintaining the health of the consumer.

ACKNOWLEDGEMENTS

The present work was supported by the Ph.D. to the first author

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