NUTRITIONAL QUALITIES OF GERMINATED SESAME (*SESAMUM INDICUM* L.) SEEDS GROWN IN CÔTE D'IVOIRE

Kouamé Ikpé Aristide Didier, **Disseka** William kwithony, **Koné** Fankroma Martial Thierry, **Yao** Kouakou Adayé, **Faulet** Meuwiah Betty
Department of Food Science and Technology, Laboratory of Biocatalysis and Bioprocessing, University Nangui Abrogoua (Abidjan, Côte d'Ivoire), 02 BP 801 ABIDJAN 02
E-mail: ikpe@hotmail.fr

Abstract
Sesame is an under-exploited plant resource in Côte d'Ivoire, to the extent that it is classified as a minor crop. The objective of this study is to contribute to food valorization of sesame seeds by improving the nutritional quality of flours. For this, germination is applied to sesame seeds and derived flours was analyzed using standard methods. Result of enzymatic assays during germination revealed various enzymatic activities, where the most important were the xylan and lipase activities. As for biochemical characterization of sesame seed flours obtained, dry matter, protein and carbohydrate contents increased. In addition, potassium, phosphorus, calcium and iron were detected at increasing levels. Germination also increased content of some phytochemicals compounds (polyphenols, tannins and flavonoids) and promoted the vitamin C formation. Otherwise, treatment reduced lipid levels and those of antinutrients compounds such as phytates (67 %) on the second day and oxalates (17 %) on the first day of germination. In general, the highest concentrations of nutrients were obtained at 2 days of germination. Application of this treatment to raw sesame seeds has improved the nutritional value of flours for well-being of Ivorian populations. Therefore, the consumption of these flours could help reduce the problems associated with protein, mineral and certain phytonutrient deficiencies commonly encountered in population.

Keywords: *Sesamum indicum, Germination; Côte d'Ivoire, Proximate composition*

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1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is a food legume belonging to the order Turbiflorae, a Family of *Pedaliaceae*. The plant grown on relatively poor soils in climates generally unsuitable for other crops (Makinde and Akinoso, 2013). It is strongly used in food, pharmaceutical and cosmetics industries. Indeed, sesame seeds contain 19 to 25 % protein, 5 % ash, 57-63 % fat (Elleuch *et al.,* 2007). They are also rich in phosphorus, iron, magnesium, calcium and some potential of nutraceutical compounds such as phenolic and tocopherols with antioxidant activity that have significant effect on Human health (Hahm *et al.*, 2009).

In Côte d'Ivoire, sesame is one of several vegetable exploitable resources for food purposes however, it is a lesser known and under-exploited seed legume crop. Even if sesame seed is nutritionally important in some parts of the world, few little scientific information is currently available on its nutritional potential and uses in local foods. Indeed, sesame is produced and consumed by the local populations in traditional forms. Otherwise, sesame seeds undergo a number of pre-consumer treatments including cooking and roasting which contribute to reduce certain anti-nutritive compounds and facilitate oil extraction (Yaacoub 2009; Agiang *et al.,* 2010). However, these techniques have drawbacks including the nutrients losses in cooking water and formation of toxic compounds by Maillard reaction (Yaacoub 2009; Agiang *et al.,* 2010). Therefore, in order to optimize nutritional value of sesame seeds, it is necessary to look for other traditional treatment techniques that are applicable and easy to implement. Soaking, fermentation and germination are processing techniques aimed to improve the nutritional value and protein digestibility of foods (Brou *et al.,* 2008). Concerning germination, it has been suggested as an inexpensive and effective technology for

improving seed quality by enhancing their nutritional value (Vidal-Valverde *et al.,* 2002). In the process, considerable endogenous hydrolysis enzymes are formed, modifying the seed structure, which means macromolecules (lipids, carbohydrates, proteins) are breakdown into simple molecules (Joshi and Varma 2016). Therefore, there is an increase of simple sugars, free amino acids and organic acids (Brou *et al.*, 2008). Among other processes, it has been widely used for its ability to decrease the levels of antinutritional factors in plant seeds, at the same time improving the concentration and bioavailability of their nutrients (Mohammed *et al.,* 2016).

The purpose of the present study is to establish the nutritional quality of germinated sesame seeds grown in Côte d'Ivoire in view of contribute to their food valorization. Specifically, it will be to investigate some enzymatic activities, proximate, mineral, polyphenols and antinutritionals compositions.

2. MATERIALS AND METHODS

I. Vegetable material

Sesame (*Sesamum indicum* L.) seeds used for this study were purchased from Méagui market, a Bakwé locality in Soubré department, South-West potion of Côte d'Ivoire (West Africa).

II. Methods

2.1. Preparation of sesame flours

2.1.1. Preparation of raw sesame flour

The sesame seeds were sorted to get rid of post-harvest plant debris. Then, 200 g of seeds were weighed, washed and dried at room temperature (25°C) for 48 h and then crushed to obtain the raw sesame flour which was stored in a sealed jar for analyzes **(Fig. 1)**.

2.1.2. Preparation of germinated sesame flours

Sesame seeds (1 kg) were carefully washed with tap water to remove the worn and immature seeds and soaked for 24 h in 5 L of water (ratio 1/5: w/v) contained in a plastic container seal. After soaking, the seeds were rinsed and then spread on a 100% cotton cloth, in a room whose humidity and temperature were respectively 85% and 28°C. Each day, the germinating seeds are watered once and samples are taken for the preparation of the crude enzymatic extracts as well as for the preparation of the flours. The germination process was done during 4 days (Fig. 1).

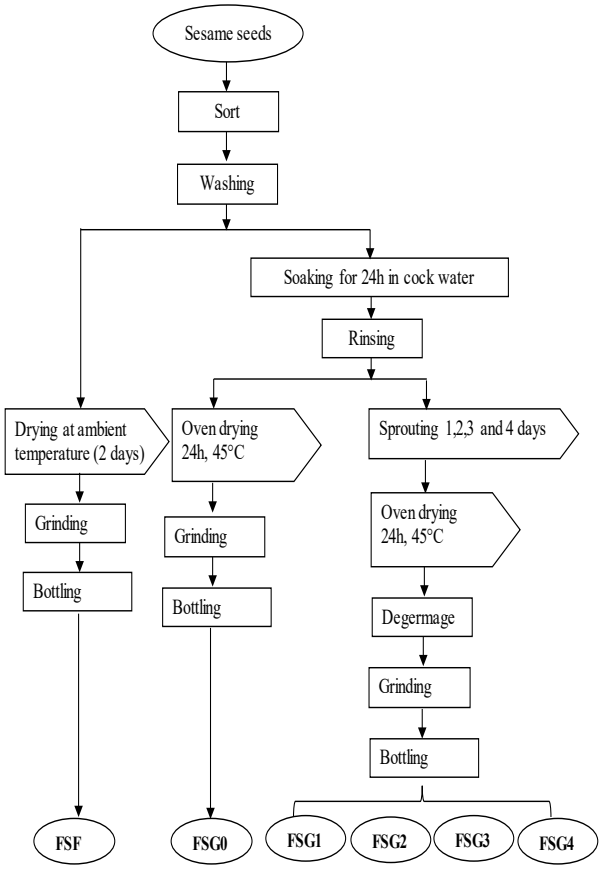

Fig. 1 Flow chart for the production of germinated and non-germinated sesame flour

FSF: Flour derived from raw sesame; FSG_0: Flour derived from germinated for 0 days; FSG_1: Flour derived from germinated sesame seeds for 1 day; FSG_2: Flour derived from germinated sesame seeds for 2 days; FSG_3: Flour derived from germinated sesame seeds for 3 days; FSG_4: Flour derived from germinated sesame seeds for 4 days

2.2. Determination of enzymatic activity during germination

2.2.1. Enzyme extraction

For polysaccharides activities

Thirty (30) grams of germinated seeds were ground in 60 mL of NaCl 0.9% (w/v) using a Moulinex-type mixer. The homogenate was filtered with a white cotton cloth and the filtrate was centrifuged at 8000 rpm for 10 min at 4°C in a refrigerated centrifuge. The gotten supernatant was used as the enzymatic crude extract of germinated sesame seeds. It was fractionated into eppendorf tubes and then stored in the freezer for further testing.

For lipase activity

The enzymatic crude extracts were prepared as reported previously with slight modifications (Abigor *et al.*, 2002). Twenty five (25) grams of germinated sesame seeds were ground with 30 mL of cold acetone using a porcelain mortar. The acetone extract was filtered through cheese cloth and washed four times, with 20 mL each time, of cold acetone (4°C). The residue was air dried at room temperature (20°C) for 20 min. It was finely milled using a Moulinex-type mixer and screened through a mesh of 0.5 mm. The meal obtained was stored in an airtight container at 4°C until required for assay.

2.2.2. Assay enzyme

Polysaccharide activities

Polysaccharide activities were assayed by 3.5-dinitrosalycilic acid (DNS) procedure using polysaccharide (1%, w/v) (soluble starch, sucrose, xylan and carboxymethylcellulose) as substrate. The enzyme (75 µL) was incubated for 30 min at 40°C with 125 µL sodium acetate buffer (100 mM, pH 5.0) and 100 µL of polysaccharide. The reaction was stopped by adding 300 µL of DNS solution and heating for 5 min in a steam bath (100°C) and then cooled to room temperature for 10 min. The absorbance was measured at 540 nm on a spectrophotometer after adding 2 mL of distilled water. The relative activities determined under the standard conditions were then expressed as a percentage of activity in relation to maximum activity.

Lipase activity

Lipase activity was assayed using the modified titrimetric method of Khor *et al.* (1986). The assay mixture (standard assay procedure) contained 5 g of coconut oil, 2.5 mL of hexane to solubilize oil, 5 mL of Tris-HCL buffer (100 mM, pH 8) and 1 g of crude extract. The mixture was incubated for 45 min at 45°C with continuous stirring, using a magnetic stirrer. At the end of the incubation, 25 mL of acetone-ethanol (1:1, v/v) were added to stop the reaction and to extract the free fatty acids (FFAs). The FFAs in the mixture were then estimated by direct titration with 0.1 N NaOH using phenolphthalein as indicator. Lipase activity was expressed as the percent FFAs liberated after 45 min incubation.

2.3. Biochemical Characterization of sesame flours

2.3.1. Proximate analysis

The proximate composition of the samples was determined by AOAC (1990). The moisture contents were determined by drying in an oven at 105°C during 24 h to constant weight and Dry Matter was obtained by formula: 100 – Moisture. The crude protein contents were calculated from nitrogen contents (Nx6.25) obtained using the Kjeldahl method. The crude fat contents were determined by continuous extraction in a Soxhlet apparatus for 8 h using hexane as solvent. The ash contents were determined by incinerating flour (2 g) in a furnace at 550°C for 6 h, then weighing the residue after cooling to room temperature in a desiccator. For crude fibers, 2 g of sesame flour sample were digested with 50 mL of sulphuric acid (0.25 N) and 50 mL sodium hydroxide (0.3 N) solution. The insoluble residue obtained was washed with hot water and dried in an oven at 100°C until constant weight. The dried residue was then incinerated (550°C), and weighed for the determination of crude fibres content. While the carbohydrate contents were determined by difference as follows: % carbohydrate = 100 % – (% moisture + % crude protein + % crude fat + % ash).

2.3.4. Vitamin C content

The vitamin C content of samples was determined by titration (Pongracz, 1971). Sesame flour (20 g) were soaked for 10 min in 40 mL metaphosphoric acid-acetic acid (2%, w/v). The mixture was centrifuged at 3000 rpm for 20 min and the supernatant obtained was diluted and adjusted with 50 mL of bi-distilled water. Ten (10) mL of this mixture was titrated to the end point with dichlorophenol-indophenol (DCPIP) 0.5 g/L.

2.3.5. Determination of polyphenols

Phenolic compounds were extracted using the method reported by Singleton *et al.* (1999). Sample of sesame flour (1 g) was soaked in 10 mL of methanol 70% (w/v) and centrifuged at 1000 rpm for 10 min. The pellet was collected in 10 mL of methanol 70% (w/v) and

centrifuged again. A third extraction was carried out under the same conditions. The three (3) supernatants were pooled in a 50 mL vial and the volume was adjusted with distilled water to the mark. This mixture constituted the total phenolic extract.

Total Polyphenols

Total polyphenol content was determined using the Folin-Ciocalteu reagent-based colorimetric essay as described by Singleton *et al.* (1999). An aliquot (1 mL) of supernatant was oxidized with 1 mL of Folin–Ciocalteu's reagent and neutralized by 1 mL of Na_2CO_3 (20%, w/v). The reaction mixture was incubated for 30 min at ambient temperature and absorbance was recorded at 745 nm by using a spectrophotometer. The polyphenol content was obtained using a calibration curve of gallic acid (1 mg/mL) as standard.

Determination of tannins

Tannins contents of sesame flour samples were quantified by the spectrophotometric method of Broadhurst and Jones (1978). About 1 mL of the methanolic extract was mixed with 5 mL of vanillin reagent and the mixture was allowed to incubate at ambient temperature for 30 min. Thereafter, the absorbance was read at 500 nm by using a spectrophotometer. Tannin content of samples was estimated using a calibration curve of tannic acid (2 mg/mL) as standard.

Determination of flavonoids

The total flavonoids were evaluated using the spectrophotometric method reported by Meda *et al.* (2005). Briefly, 0.5 mL of the methanolic extract was mixed with 0.5 mL methanol, 0.5 mL $AlCl_3$ (10%, w/v), 0.5 mL potassium acetate (1 M) and 2 mL distilled water. The absorbance was measured using a spectrophotometer at 415 nm after 30 min. The total flavonoids were calculated using a calibration curve of quercetin (0.1 mg/mL) as standard.

2.3.6. Anti-nutritional factors determination

Determination of phytates

The colorimetric method of Latta and Eskin (1980) was used for the determination of phytates content. About 1 g of sesame flour sample was mixed with 20 mL of hydrochloric acid (0.65 N) for 12 h under continuous stirring and the mixture was centrifuged at 12,000 rpm for 40 min. An aliquot (0.5 mL) of the supernatant obtained was then mixed with 3 mL of Wade's reagent. The reaction mixture was incubated for 15 min and absorbance was read at 490 nm by using a spectrophotometer (PG Instruments, England). Phytate content was estimated using a calibration curve of sodium phytate (10 mg/mL) as standard.

Determination of oxalates

The titrimetric method described by Day and Underwood (1986) was performed to determine the oxalate content. Two (2) g of sesame flour sample were weighed into a 100 mL beaker. A quantity (75 mL) of H_2SO_4 (3 M) was added and stirred for 1 h with a magnetic stirrer. The mixture was filtered through Whatman paper and 25 mL of the filtrate was titrated while hot against $KMnO_4$ solution (0.05 M) to the end.

2.3.7. Mineral content

Minerals of sesame seed flours, such as calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P), potassium (K), sodium (Na) and zinc (Zn) were determined using AOAC(1990) method. Flour was acid-digested with a mixture of concentrated perchloric acid (11.80 mol/L), nitric acid (14.44 mol/L) and sulfuric acid (18.01 mol/L), and analyzed using a flame atomic absorption spectrophotometer (VARIAN, model AA-20).

2.4. Statistical analysis

All measurements were carried out in triplicate. Statistical analyzes of the data were carried out using STATISTICA 7.1 software. Comparisons between the dependent variables were determined using the one-factor ANOVA and the Duncan test. Statistical significance was defined at $P < 0.05$.

3. RESULTS AND DISCUSSION

1. Enzymatic activities during germination

Degradation of polysaccharides and lipids by crude enzymatic extract during seed germination showed various enzymatic activities (Fig. 2 and 3). These activities are significantly ($P<0.05$) different during germination. The presence of all these activities suggests that germ derive a significant portion

of his energy from the macromolecule degradation in seeds under the enzyme action.

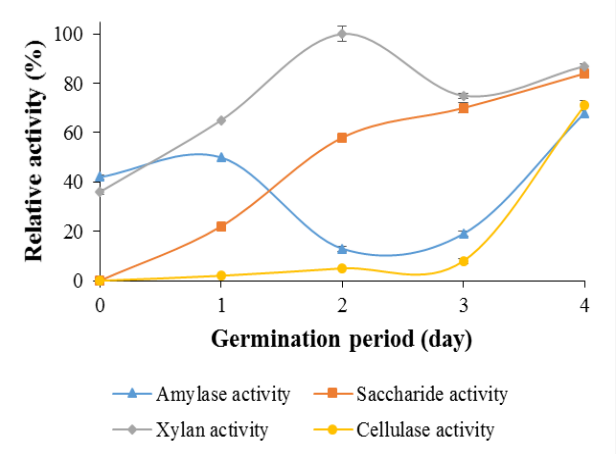

Fig. 2 Evolution of polysaccharides activities in sesame seeds during germination

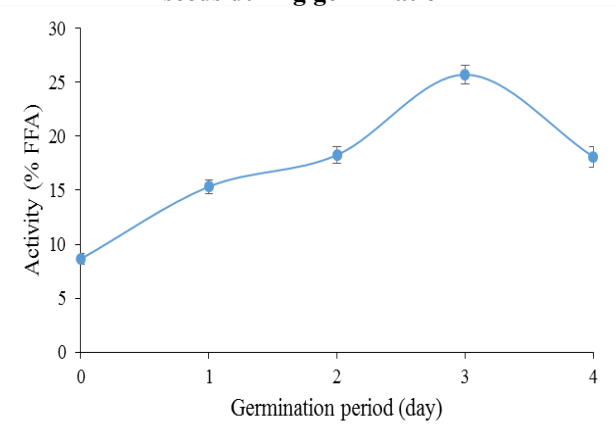

Fig. 3 Evolution of lipase activities in sesame seeds during germination

Polysaccharide activities: In Fig. 2, the peak of xylanosic activity (100%) observed after 2 days of germination is due to an important hydrolysis of xylan into simple elements (xylose) necessary for the formation of the secondary cell walls of the growing germ. Indeed, after starch and cellulose, xylan is the most abundant polysaccharide in plants and forms part of the secondary walls of the latter.

An increase in amylase activity from 40 to 50% was obtained after 1 day of germination, and after that a decreased was observed (Fig. 2). This increase could be explained by starch hydrolysis of seeds into simple products easily assimilated by the developing germ to ensure its growth towards autotrophy (Vidal-Valverde *et al.,* 2002; Chinma *et al.*, 2009). Moreover, the decrease observed after 1 day is due to starch depletion as substrate, especially since sesame is not a starch source (less than 1%) (Elleuch et al. 2007; Rizki *et al.*, 2015). This hypothesis is in agreement with Tian *et al.* (2010) who showed a decrease in starch content (59.80 to 20.87 %) from oat seeds during germination.

With regard to saccharide activity, the work of Dué *et al.* (2008) showed that high amylase activity is associated with high α-glucosidase activity, both of which are amylolytic enzymes involved in starch saccharification. In this regard, the increase in saccharide activity (16 to 84%) observed in Fig. 2 for sesame seeds could be α-glucosidic and/or β-fructosidic. Indeed, the hydrolysis of sucrose is provided by two types of enzymes (α-glucosidase or β-fructosidase). Thus, sesame seeds during germination have been the site of significant α-glucosidic activity, which has been active in the degradation of carbohydrates into readily assimilated simple sugars. This result, which also explains the increase in amylase activity after 3 days of germination, was in concordance with the work of Brou *et al.* (2008) who showed increase levels of sugars (total and reducing) during germination and fermentation of millet (*Pennisetum glaucum*).

Cellulase activity was also found to increase from 2 to 71% (Fig. 2). According to Dicko *et al.* (2006), this increase would be due to degradation of structural carbohydrates such as lignin and cellulose during seeds germination.

Lipase activities: Lipase activities increased during seed germination from 8.65 to 25.71% (Fig. 3). This increase would be relate to lipid content of seed, which are the major source of energy during germination and the early periods of seedling growth (Shirvani *et al.,* 2016). Oil, main biochemical component of these seeds, is mainly composed of triacylglycerol (substrate of lipases). So, during this metabolic process, lipases catalyze hydrolysis of triacylglycerol into fatty acids and glycerol (Chinma *et al.,* 2009). The glycerol produced is phosphorylated and subjected to glycogenesis after its conversion to dihydroxyacetone phosphate (Quettier *et al.,* 2008). However, the free fatty acids are activated into acetyl-CoA to initiate β-oxidation and takes part in glycogenesis to produce the sugar required by the embryo as an

energy source during germination (Mora-Lopez *et al.,* 2018).

2. Proximate composition of raw and germinated sesame seed

Results of this study indicated a significant difference in proximate composition of raw and germinated sesame seeds (Table 1).

Dry matter (DM) increased significantly ($P<0.05$) from 94.93% in raw sesame to 96.48% in germinated sesame seeds. During the germination bioprocess, a considerable breakdown of seed-storage compounds, and synthesis of cell wall components, structural proteins, vitamins and secondary compounds take place. So, increasing in DM could be explained by the strong enzymatic activity (hydrolases such as proteinases, lipases, etc.) which will promote the synthesis or hydrolysis of macromolecules into easily assimilated simple elements by the germ during germination. After the first day of germination, there was a significant decrease ($P<0.05$) in the DM, which would due to intense cellular respiration and biogenesis of mitochondria (Tian *et al.,* 2010). During this period, reserve substances are degraded and generally used for respiration and synthesis of new cells to ensure development of embryo (Joshi and Varma 2016). Increase in DM content consequently leads to a decrease in moisture content of the flours which would enhance their shelf lives by preventing the growth of micro-organisms during storage and deterioration due to insect and fungal attacks (Rizki *et al.,* 2015).

Protein content of raw sesame flour (FSF) increased from 21.88% to 24.30% after 2 days of germination (FSG_2) and then decreased at the end of germination (FSG_4). The relatively high protein may confer nutritional advantage of germinated sesame flours and makes them an important source of protein that can be used to complement other sources of protein. The desirable nutritional changes that occur during soaking and germination are mainly due to the breakdown of complex compounds into a more simple form, transformation into essential constituents and breakdown of nutritionally undesirable constituents. The most probable reason for this increase in protein content could be attributed to the synthesis of cell constituents and enzymes, which lead to the degradation of other constituents (Bau *et al.*, 1997). Indeed, during germination, metabolic enzymes such as proteinases are activated, which may lead firstly to the release of some amino acids and peptides; and secondly, their use to synthesize or form new protein molecules (Chinma *et al.*, 2009; Devi *et al.*, 2015). This is also due to the degradation of other nutrients such as carbohydrates and lipids to synthesize amino acids necessary for biochemical activities and the growth of germinating seeds (Ijarotimi, 2012).

Table 1 Effect of germination on biochemical properties of raw and germinated sesame flour

	FLOURS					
PARAMETERS	**FSF**	**FSG_0**	**FSG_1**	**FSG_2**	**FSG_3**	**FSG_4**
Dry matter (%)	94.93 ± 0.13^{a}	95.81 ± 0.18^{b}	96.48 ± 0.15^{c}	95.47 ± 0.27^{b}	95.46 ± 0.48^{b}	94.70 ± 0.33^{a}
Protein (%)	21.88 ± 0.12^{d}	21.83 ± 0.05^{d}	21.24 ± 0.18^{c}	24.30 ± 0.20^{e}	20.75 ± 0.18^{b}	18.40 ± 0.10^{a}
Fat (%)	55.25 ± 0.05^{d}	57.8 ± 0.18^{f}	55.7 ± 0.04^{e}	54.25 ± 0.03^{c}	52.89 ± 0.14^{b}	51.42 ± 0.06^{a}
Ash (%)	$4.85\pm0.07^{a.b}$	4.93 ± 0.05^{b}	5.25 ± 0.02^{c}	4.75 ± 0.02^{a}	$4.83\pm0.05^{a.b}$	4.95 ± 0.7^{b}
Fibers (%)	5.98 ± 0.01^{f}	5.74 ± 0.04^{e}	5.44 ± 0.04^{d}	5.34 ± 0.00^{c}	4.73 ± 0.02^{b}	4.28 ± 0.01^{a}
Carbohydrate*(%)	12.96 ± 0.09^{c}	11.25 ± 0.34^{a}	14.29 ± 0.19^{d}	12.17 ± 0.31^{b}	17.99 ± 0.32^{e}	19.93 ± 0.14^{f}
Vitamin C (mg/100g DM)	0.00 ± 0.00^{a}	2.60 ± 0.82^{b}	6.78 ± 0.51^{c}	13.81 ± 0.61^{d}	24.31 ± 0.82^{e}	20.92 ± 0.55^{f}
Total polyphenol (mg/100g DM)	342.94 ± 4.23^{a}	537.82 ± 5.87^{b}	561.57 ± 5.00^{c}	586.02 ± 6.74^{d}	811.76 ± 8.42^{e}	874.34 ± 8.49^{f}
Tannins (mg/100g DM)	229.52 ± 4.37^{a}	265.21 ± 4.23^{b}	268.24 ± 1.78^{b}	284.56 ± 5.40^{c}	368.28 ± 3.34^{d}	445.07 ± 2.23^{e}
Flavonoid (mg/100g DM)	6.45 ± 0.17^{a}	11.92 ± 0.29^{b}	19.56 ± 0.41^{d}	18.77 ± 0.27^{c}	20.75 ± 0.17^{e}	25.29 ± 0.31^{f}

The different letter averages on the same line are significantly different at $P<0.05$. FSF: Flour derived from raw sesame; FSG_0: Flour derived from germinated 0 days; FSG_1: Flour derived from germinated sesame seeds for 1 day; FSG_2: Flour derived from germinated sesame seeds for 2 days; FSG_3: Flour derived from germinated sesame seeds for 3 days; FSG_4: Flour derived from germinated sesame seeds for 4 days

*Carbohydrate= 100-(Moisture + Protein + Fat + Ash)

In summary, the breakdown of seed reserves and the increase in enzyme activity during seed germination results in a total dry matter loss and an increase in total protein. The decrease in protein may be due to utilization of protein for growth process. Protein is one of the major sources of energy for the developing embryo. Proteins are hydrolyzed to form simple peptides and amino acids due to protease activity and are then transported to the developing axis (Nonogaki *et al.,* 2010). In sum, to obtain a high protein level in sesame flour, it is advisable not to sprout seeds beyond 2 days.

Fat content of sesame seeds was 55.25% in raw flour (FSF) and 51.42% in germinated flour during 4 days (FSG_4). These values were found to decrease significantly ($P<0.05$) with increasing germination time. This reduction would be related to biochemical and physiological changes occurring during germination. Indeed, fat was used as the major source of carbon for seed growth (Bau *et al.*, 1997; Joshi and Varma 2016). Therefore, the decrease in fat content observed in sesame seeds might be attributed to the increase activities of lipolytic enzymes during germination, as shown in Fig. 3. These enzymes hydrolyze fat compounds into free fatty acids and glycerol for carbohydrate synthesis.

Ash content increased significantly ($P<0.05$) during germination from 4.85% (for raw sesame flour, RSF) to 5.25% (for 24 h germinated sesame flour, FSG_1), indicating that germination, particularly 24 h period is a good method to increase ash content of sesame. This increase was due to endogenous enzyme hydrolysis of complex organic compounds to release more nutrients leaving the antinutrients to leach into the germination medium. During germination there is activation of phytases which will hydrolyze phytates and release the minerals in seeds (Azeke *et al.,* 2010). Indeed, phytates are mineral chelating agents and subsequently they thus form complexes that are indigestible to humans, which reduces their bioavailability. Also, during germination the increase in ash content is correlated with dry matter content and varies proportionally.

Crude fiber content decreased significantly ($P<0.05$) as germination time increase. It is would be due that part of the seed fiber may be solubilized enzymatically during seed germination. In fact, as germination progressed, partial utilization of cell wall carbohydrate can occur and consequently, the content of structural carbohydrates such as lignin and cellulose can be affected negatively with the germination time (Dicko *et al.*, 2006; Shirvani *et al.*, 2016).

Significant differences ($P<0.05$) were observed between the carbohydrate contents (11.25 to 19.93 %) of the raw and germinated sesame seed flours. The carbohydrate contents of soaking and 2nd day of germinated sesame flours were lower than those of raw flour sample. This decreasing could be due to their use during cellular metabolism. Indeed, according to Vidal-Valverde *et al.* (2002), embryo uses carbohydrates as essential source of energy for its development during germination. The carbohydrate degradation is the consequence of activation of the enzymes during soaking of the seeds and is in consistent of polysaccharides activities in this study. Thus, starch and other carbohydrate constituents contained in the seeds are degraded into simple elements (glucose, fructose and sucrose) to provide energy necessary for cell division during germination (Nonogaki *et al.*, 2010). Otherwise, increase of carbohydrates in FSG_3 and FSG_4 flours is probably due to lipid degradation (under action of lipases as showed in Fig. 3) for carbohydrate synthesis (Mora-Lopez *et al.,* 2018).

3. Phytochemical compounds and vitamin C

Table 1 shows the presence of vitamin C whose content increases significantly ($P<0.05$) from 2.60 (FSG_0) to 20.92 mg/100g DM (FSG_4) during germination time. Indeed, ascorbic acid has been directly implicated in the modulation of plant growth, including the early stage of embryos (Shirvani *et al.,* 2016). The increase in vitamin C content during germination was related to the increase in activity of key enzymes in ascorbic acid biosynthesis pathway such as L-galactono-γ-lactone dehydrogenase (GLDH, EC 1.3.2.3) as shown by Xu *et al.*

(2005). Moreover, according to Sangronis and Machado (2007), during germination, the respiration process is triggered by the ascorbic acid. This could explain the observed increase as a consequence of germination. Results of this study corroborate with those of Devi *et al.* (2015) from germinated cowpea (*Vigna unguiculata*).

Significant increase ($P<0.05$) were observed between the level of phenolic compounds of sesame seed flours during germination (Table 1). This would be due to the resumption of the metabolic activities of seeds which led to a large consumption of oxygen and resulting in the formation of free radicals called reactive oxygen species (ROS) (Mora-Lopez *et al.*, 2018). Thus, phenolic compounds act as antioxidants to protect cells against the stress induced by oxidation of these free radicals (Shirvani *et al.*, 2016). Their synthesis is enzymatically from phenylalanine ammonia lyase (Diaz-Sanchez *et al.*, 2018). This would explain the increase in levels during germination of sesame seeds. The increase of phenolic compounds improves the antioxidant potential of flour derived from germinated sesame seeds.

4. Antinutritionals compounds

Phytate contents in this study decreased significantly ($P<0.05$) from 134.66 for raw sesame (FSF) to 48.96 mg/100g DM for germinated sesame during 4 days (FSG_4) (Fig.4). The decrease in phytate content could be attributed initially to leaching in the soaking water. Indeed, during the soaking of the seeds, phytate ions are diffused into the soaking water under the influence of the concentration gradient which governs the diffusion rate (Mohammed *et al.*, 2016). Several studies have reported that this decrease is due to the activation of the intrinsic phytases present in seeds and to the increase of their activity during germination (Azeke *et al.*, 2010). Phytases hydrolyze the phytate to phosphate and myo-inositol phosphates during germination of the seeds. Moreover, decrease phytate content may be due to action of neo-synthesized phytase in addition to other proteins (Azeke *et al.*, 2010). Phytates represent about 89% of the total phosphorus in food seeds. Therefore, their hydrolysis during sesame seed germination would increase phosphorus levels.

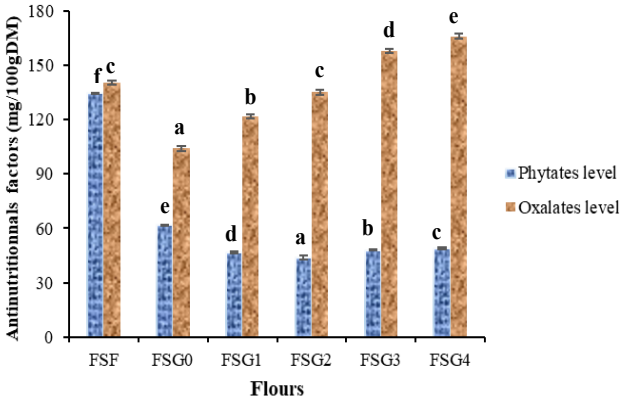

Fig. 4 Phytates and oxalates contents of raw and germinated sesame flours

Histograms surmounted by different letters have significantly different averages at $P<0.05$. FSF: Flour derived from raw sesame; FSG_0: Flour derived from germinated for 0 days; FSG_1: Flour derived from germinated sesame seeds for 1 day; FSG_2: Flour derived from germinated sesame seeds for 2 days; FSG_3: Flour derived from germinated sesame seeds for 3 days; FSG_4: Flour derived from germinated sesame seeds for 4 days

Germination of sesame seeds caused a significant ($P<0.05$) reduction in oxalate contents of flours (Fig. 4). Maximum reduction is observed after soaking of sesame seeds during 24 h before proceeded for germination (FSG_0). This reduction could be attributed to leaching out during hydration (Makinde and Akinoso, 2013), because 50-75 % of oxalates were present in the water-soluble form (Noonan and Savage, 1999). After soaking and during germination, we assist to an increase of oxalate level from 104.12 to 165.98 mg/100g DM. This increasing may be due to the biosynthesis of oxalate in seeds during germination. Indeed, studies have indicated that photorespiration contributes to the biosynthesis of oxalates (Noonan and Savage, 1999). Moreover, oxalate (oxalic acid) is involved in the metabolism of carbohydrates, lipids and proteins, especially since its precursors (glycolate, glyoxylate, oxaloacetate and citrate) are involved in different metabolic cycles (Briens, 1977). Oxalate is also involved in plant defense system, which explains the increase in rates during germination.

5. Mineral composition of raw and germinated sesame flour

Mineral contents of flours from raw and germinated sesame seeds varied significantly ($P<0.05$) as reported in Table 2. These results showed that mineral contents of flours from germinated sesame seeds were higher than those of raw sesame sample. This observation could be attributed to biosynthesis during germination process (Ijarotimi, 2012). The seed flours from Ivorian sesame studied would represent potential sources in mineral and notably in calcium, potassium, phosphorus, sodium and magnesium, the scarcity of which constitute a problem in public health. Indeed, potassium (498.75-1154.51 mg/100g) was found to be the predominant mineral followed by phosphorus (290.84-331.17 mg/100g) and calcium (70.07-166.36 mg/100g). The potassium and calcium contents increased during 2 days of germination (FSG_2) before decreasing. However, after 4 days of germination (FSG_4), these values remained higher than those of raw sesame (FSF). Sesame after germination could serve as a good source of potassium and calcium. The phosphorus content increased to 3rd day of germination, since phosphate translocation plays a significant role in sesame metabolism during germination (Hahm *et al.,* 2009).

Micronutrients, such as iron (1.98 to 10.72 mg/100g), copper (2.62 to 8.79 mg/100g) and zinc (0.95 to 3.14 mg/100g) are essential components of the body's antioxidant defense that play an important role in prevention of free radical-induced damage. Values of these micronutrients were found to increase during germination. This could be explained by their involvement in various reactions. Indeed, iron and copper are involved in oxygen transport in the cells, while zinc participates in enzymatic reactions.

It was observed in this study that germination processing technique improved the mineral composition of the flour samples. Most of quantified minerals have higher contents at 2 days of germination.

Table 2 Effect of germination on the mineral contents of raw and germinated sesame flour

MINERAL	FLOURS					
	FSF	FSG_0	FSG_1	FSG_2	FSG_3	FSG_4
Mn	6.00 ± 0.07^{c}	3.87 ± 0.04^{b}	13.01 ± 0.14^{e}	6.61 ± 0.11^{d}	4.00 ± 0.00^{b}	3.23 ± 0.18^{a}
Na	14.07 ± 0.13^{a}	21.83 ± 0.18^{c}	15.64 ± 0.15^{a}	$17.24\pm0.20^{a,b}$	31.73 ± 3.75^{d}	$21.00\pm1.41^{b,c}$
K	544.81 ± 1.36^{b}	498.75 ± 0.50^{a}	652.99 ± 4.35^{d}	1154.51 ± 6.82^{f}	855.74 ± 9.73^{e}	560.17 ± 3.30^{c}
Mg	12.62 ± 0.08^{a}	12.49 ± 0.48^{a}	13.38 ± 0.27^{b}	13.35 ± 0.21^{b}	13.47 ± 0.08^{b}	13.52 ± 0.12^{b}
Cu	2.62 ± 0.01^{a}	3.89 ± 0.06^{c}	2.76 ± 0.00^{a}	3.57 ± 0.00^{b}	6.70 ± 0.14^{d}	8.79 ± 0.04^{e}
Zn	0.95 ± 0.01^{b}	0.18 ± 0.00^{a}	1.69 ± 0.00^{c}	3.14 ± 0.20^{e}	2.91 ± 0.11^{d}	1.52 ± 0.04^{c}
P	293.39 ± 2.74^{a}	307.83 ± 2.36^{b}	290.84 ± 0.97^{a}	313.92 ± 5.54^{b}	331.17 ± 2.36^{c}	293.52 ± 6.11^{a}
Fe	1.98 ± 0.01^{a}	3.35 ± 0.87^{b}	7.71 ± 0.06^{d}	10.72 ± 0.62^{e}	5.80 ± 0.07^{c}	$2.95\pm0.07^{a,b}$
Ca	70.07 ± 0.11^{a}	77.79 ± 0.20^{c}	91.03 ± 0.70^{d}	166.36 ± 1.17^{f}	134.55 ± 0.29^{e}	75.82 ± 0.95^{b}

The different letter averages on the same line are significantly different at $P<0.05$. FSF: Flour derived from raw sesame; FSG_0: Flour derived from germinated 0 days; FSG_1: Flour derived from germinated sesame seeds for 1 day; FSG_2: Flour derived from germinated sesame seeds for 2 days; FSG_3: Flour derived from germinated sesame seeds for 3 days; FSG_4: Flour derived from germinated sesame seeds for 4 days

4. CONCLUSION

The outcome of the present studies indicates that germination significantly ($P<0.05$) improved nutritional attributes (proteins, vitamin C, polyphenol and mineral) in 2 days, except crude fat and carbohydrates in sesame seed flours. However, antinutritional factors like phytate decreased to a significant ($P<0.05$) level during germination. Germination generally improved the biochemical properties of flours and could be employed to potentially improve nutritional quality and digestibility of sesame seeds, and their utilization as complementary food formulations. Present study showed that germination is an effective method for removing anti-nutritional factors in sesame seeds without application of heat processing methods, which may reduce content of heat sensitive nutrients.

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