

Assessment of Minerals, Vitamins and Functional Properties of Flours from Germinated Yellow Maize (*Zea mays* L.) Seeds from Daloa (Côte D'Ivoire)

Mankambou Jacques Gnanwa¹, Jean Bedel Fagbohoun^{2,*},
Kouamé Claude Ya¹, Sika Hortense Blei¹, Lucien Patrice Kouame³

¹Laboratoire d'Agrovalorisation de l'UFR Agroforesterie, Université Jean Lorougnon Guédé, Daloa, Côte d'Ivoire

²Laboratoire de Biochimie-Génétique, Université Peleforo Gon Coulibaly, Korhogo Côte d'Ivoire

³Laboratoire de Biocatalyse et de Bioprocédés, Université Nanguy Abrogoua, Abidjan, Côte d'Ivoire

Abstract This study was proposed to assess the effect of germination on minerals, vitamins composition and some functional properties of sprouted yellow maize grains with a view to their valorization in the Ivorian diet. The mineral contents (Calcium, Magnesium, Iron, Sodium, Potassium) of sprouted yellow maize samples are statistically different from those of ungerminated maize. Then, it was found that germination resulted in a significant increase in the contents of vitamins (A, B1, C, D and E). The germination of corn kernels led to a significant increase ($p < 0.05$) in the contents of vitamin A (3.00 ± 0.02 to 6.00 ± 1.00 % DW), vitamin B1 (0.03 ± 0.01 to 0.05 ± 0.02 % DW), vitamin C (6.50 ± 0.10 to 9.20 ± 0.40 % DW), vitamin D (0.94 ± 0.03 to 1.86 ± 0.04 % DW) and vitamin E (1.80 ± 0.30 to 2.60 ± 0.20 % DW) from raw and germinated yellow maize respectively. Thus, germination is an effective processing method for increasing vitamins, mineral bio-availability, and for improving significantly functional properties after the yellow maize seeds germinate. Then, germination induced a significant increase in the water and oil absorption capacity (dinor and red) in the flour of the sprouted corn kernels. Therefore, sprouting improves the micronutrients value of corn kernels.

Keywords Maize, *Zea mays* L., Minerals, Vitamins, Functional properties

1. Introduction

Maize (*Zea mays* L.) is an annual monocotyledonous diploid belonging to the Poaceae family. It is an important cereal that serves as an important food ingredient around the world in the production of varieties of products such as canned corn, breakfast cereals and in the formulation of infant foods (Offia Olua et al., 2020). The genus *Zea* comprises four species of which *Zea mays* L. is economically important and is native to Mexico and Central America (Shah et al., 2016). Maize is one of the most widely cultivated plants in the world and the third most important cereal in the world after rice and wheat (Gwirtz & Garcia-Casal, 2014). In Africa, after cassava (*Manihot esculenta* Crantz) corn is the second most important food crop (Oluwaranti et al., 2015). In Côte d'Ivoire and most of West Africa, maize forms the staple of the diet of rural populations. It is used for human and animal food and is used as raw materials in certain industries (brewing, soap

and oil mills) (Hossain et al., 2016). According to Nuss et al. (2011) corn is the most energy-efficient cereal due to its nutritional and economic advantages. In addition, Maize provides more than 20 % of total calories in the human diet in 21 countries and more than 30 % in 12 countries which are home to a total of over 310 million people (Shiferaw et al., 2011; Hossain et al., 2016). In addition, corn is a very interesting and nutritionally edible plant due to its richness in protein as well as certain minerals, carbohydrates and vitamins (Shah et al., 2016). However, the presence of anti-nutritional compounds can affect the digestibility of proteins as well as other nutrients (Andriamasinandraina, 2012; Randrianasolo, 2013). In addition, certain anti-nutritional factors such as α -galactoside, whose fermentation in the colon is largely responsible for gas (Kasprowicz-Potocka et al., 2015; Barkiene et al., 2014; Sathya & Siddhuraju, 2015). This would justify one of the main reasons why people are turning away from the consumption of cereals (corn). However, all of this information on the nutritional potential of corn only concerns the edible portion, that is to say the kernels. Nevertheless, processing techniques such as sprouting improved the quality of cereals due to chemical changes that improve the organoleptic response, the content of free

* Corresponding author:

fagbohounjb@gmail.com (Jean Bedel Fagbohoun)

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sugars, proteins and vitamins, as well as the bioavailability of minerals and leads to the breakdown of certain endogenous anti-nutritional compounds (Ahmed *et al.*, 2006; Ochanda *et al.*, 2010; Ijarotimi, 2012). Thus, there is constantly an information gap to be filled, especially in terms of the impact of germination technologies on the nutritional value of corn kernels (Vodouhe *et al.*, 2012). This is why the present study was carried out to evaluate the physicochemical composition, some functional properties and some enzymatic activities of sprouted maize grains with a view to their valorization in the Ivorian diet.

2. Materials and Methods

2.1. Raw Material

Dried grains of yellow maize (*Zea mays* L.), used as raw material (Figure 1), were purchased at the local market in Daloa (Côte d'Ivoire).



Figure 1. Yellow maize (*Zea mays* L.)

2.2. Germination Method

Three hundred grams of the sorted corn sample, disinfected with 1% (v/v) sodium hypochlorite for 10 minutes, is washed thoroughly in tap water and soaked for 24 hours in 500 milliliters of water contained in a 2 liters plastic bucket. They are then spread out on a 100% cotton cloth, and placed in a plastic pot in a room with humidity and temperature of around 85% and 28°C, respectively (Figure 2). Each day, the germinating grains are watered only once. The grains germinated for three days and were prepared for the flours and assay for enzyme activities.



Figure 2. Sprouted yellow maize kernels

2.3. Flour Production

The corn kernel samples were oven dried for 48 hours at 45°C. They were then ground in a MOULINEX brand mixer to obtain a flour. This flour was stored in pre-dried jars for possible analysis (Figure 3).

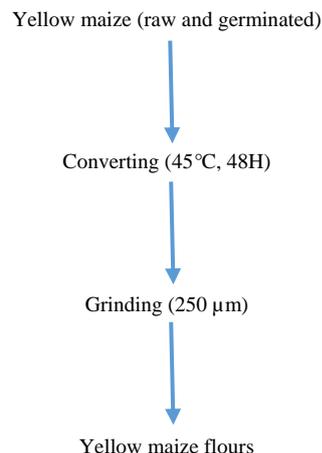


Figure 3. Flow diagram of the process for producing yellow maize (raw and germinated) flour

2.4. Mineral Analysis

The method described by AOAC (1990) was used for mineral analysis. Flours were digested with a mixture of concentrated nitric acid (14.44 mol/L), sulfuric acid (18.01 mol/L) and perchloric acid (11.80 mol/L) and analysed using an atomic absorption spectrophotometer.

2.5. Vitamins Dosage

Analytical technique used for determination of folate content is HPLC-method (AOAC, 2004).

Vitamin C (ascorbic acid) content was determined by the method of Pongracz *et al.* (1971) and Barros *et al.* (2007). Vitamin D, vitamin E (α -tocopherol, γ -tocopherol) and carotenoids (provitamin A = β -carotene,) were extracted from 500 mg of yellow maize flour using the following method: 2 mL of distilled water were added to sample. The internal standard (retinyl acetate) was added to the sample in 2 mL of ethanol. The mixture was extracted twice with 8 mL of hexane. After centrifugation (500 \times g, 10 min at 4°C), 2 mL of distilled water and methanol–dichloromethane (65/35, v/v). A final volume of 150 μ L for samples was used for HPLC analysis. The fat-soluble vitamins and carotenoids were separated as previously described (Gleize *et al.*, 2012; Goncalves *et al.*, 2014). All molecules were identified by retention time compared with pure standards.

2.6. Functional Properties Of Samples

2.6.1. Water Absorption Capacity and Solubility Index in Water

The water absorption capacity (WAC) of ungerminated and germinated yellow maize flour were determined according to the method of Claver *et al.* (2010). Distilled

water (10ml) was added to 1g of sample, and the mixture was mixed thoroughly using a vortex mixer for 30 min and centrifuge at 4000 rpm for 15 min. The mass of water absorbed was expressed as g/g starch on a dry weight basis. The water absorption capacity and solubility index in water were expressed as percentage increase of the sample weight.

2.6.2. Oil Absorption Capacity

Oil absorption capacity of the flour samples was determined by the centrifugal method elicited by Eke & Akobundu (1993) with slight modifications. One gram of sample was mixed with 10 ml of oil, the mixture was allowed to stand for 30 min at room temperature, centrifuged at 4000 g for 15 min and the oil that separated was carefully decanted and the tubes were allowed to drain at 45° angle for 10 min and then weighed. Oil absorption was expressed as percentage increase of the sample. And the hydrophilic-lipophilic ratio (HLR) as defined by Njintang et al. (2001).

2.6.3. Foaming capacity and stability

The procedure of Coffman & Garcia (1977) was used. Three grams of flour sample and 50 mL distilled water were mixed in a Braun blender at room temperature. The suspension was mixed and shaken for 5 minutes at 1600rpm. The content along with the foam was poured into a 100ml graduated measuring cylinder. The total volume was recorded after 30 seconds. Then the content was allowed to stand at room temperature for 30 minutes and the volume of foam only was recorded.

2.6.4. Bulk Density

Bulk density of the starch was determined according to the method of Musa et al. (2008). Flour (20 g) was weighed into a 50 mL measuring cylinder and the volume occupied was measured and recorded. The cylinder was gently tapped on the bench top 10 times from a height of 5cm. The bulk density was calculated as weight per unit volume of sample.

2.6.5. Dispersibility

The dispersibility of yellow maize (ungerminated and germinated) flours were measured according to the method of Mora-Escobedo et al. (1991). One gram of the flour was dispersed in distilled water in a 50 mL stoppered measuring cylinder. Then distilled water was added to reach a volume of 30 mL, the mixture was stirred vigorously and allowed to settle for 20 min, the volume of settled particles was subtracted from 30 and multiplied by 100 and reported as percentage dispersibility.

2.6.6. Emulsification Properties

2.6.6.1. Emulsification Capacity

Emulsification capacity was calculated by the modified method of Naczek et al. (1985). 2.0g of sample was taken and blended with 25 mL distilled water. Corn oil was taken in

burette and added to the mixture with continuous blending until the break point was reached (i.e. separation of oil from aqueous phase). The emulsification capacity (EC) was expressed as mL of oil emulsified by 1.0 g of the sample.

2.6.6.2. Emulsification Activity

Emulsification activity was calculated by the method of Naczek et al. (1985). 3.5 g of flour sample was homogenized in 50 mL water and re-homogenized by adding 50 mL corn oil for 90s. Emulsion was then transferred to two centrifuge tubes equally and centrifuged for 5 min at 1100×g.

2.6.6.3. Emulsion stability

Emulsion stability was calculated using the above sample after calculating emulsifying activity (Naczek et al., 1985). Sample was heated at 85 ± 2 °C, for 15 minutes and then centrifuged at 1100g for 5 min. Emulsion stability was expressed in percentage as the emulsifying activity remaining after heating using formula for the calculation of emulsion activity (%).

2.7. Statistical Analysis

All measurements were performed in triplicate. Statistical analyzes of the data were performed using STATISTICA 7 software (Statsoft Inc, Tulsa-USA Headquarters). Comparisons between dependent variables were determined using analysis of variance (one-way ANOVA) and Duncan's test according to the general linear model. The difference between two variables is significant if $p \leq 0.05$.

3. Results and Discussion

Mineral Composition

One of the main reasons for processing foods is to make sure that their nutritional value is maintained over long periods and, where possible, improved. Phytic acid is one of the antinutritional factors common in cereals, which is responsible for binding minerals thus making them not readily bioavailable (Liang et al., 2008). Thus, it should be remembered here that mineral elements are an important group of nutrients necessary for the human body for optimal functioning. The germination of corn kernels significantly increased ($p < 0.05$) the levels of micronutrients such as calcium (47.00 ± 4.00 to 58.00 ± 4.00 % DW), magnesium (90.00 ± 3.00 to 108.00 ± 3.00 % DW), iron (0.50 ± 0.02 to 1.25 ± 0.01 % DW), potassium (2.10 ± 0.30 to 4.30 ± 0.20 % DW) and sodium (0.50 ± 0.10 to 0.70 ± 0.02 % DW) presented in table 1. This same observation was observed by Sadawarte et al. (2018) on germinated malt. This finding is believed to be due to the increase in phytase activity during germination which promotes the reduction of phytic acids which bind to minerals and leading to an increase in mineral availability (Luo et al., 2014). In addition, when the seeds are germinated, the minerals chelate or fuse with the proteins, which increases their content (Mostafa, 2013).

Moreover, according to Lemmens *et al.* (2019) the significant increase in the bioaccessibility of minerals attests to the decrease in the content of antinutritional compounds. Thus, one could infer that the germination process is useful in the preparation of nutrient-rich corn. Consequently, the consumption of the present germinated yellow maize seeds would then be recommended for the prevention of certain diseases (Boislève, 2016; Rosique-Esteban *et al.*, 2018; Sadawarte *et al.*, 2018).

Table 1. Mineral content in ungermed and sprouted corn

Parameters	Values (% DW)		Percentage Increase (%)
	Flour from ungerminated maize	Flour from germinated maize	
Ca ²⁺	47.00 ± 4.00 ^a	58.00 ± 4.00 ^b	123.40
Mg ²⁺	90.00 ± 3.00 ^a	108.00 ± 3.00 ^b	120.00
Fe ²⁺	0.50 ± 0.02 ^a	1.25 ± 0.01 ^b	250.00
K ⁺	2.10 ± 0.30 ^a	4.30 ± 0.20 ^b	204.76
Na ⁺	0.50 ± 0.10 ^a	0.70 ± 0.02 ^b	133.33

Vitamins composition

Table 2. Vitamin content in ungermed and sprouted corn

Parameters	Values (% DW)		Percentage increase (%)
	Flour from ungerminated maize	Flour from germinated maize	
Vitamine A	3.00 ± 0.02 ^a	6.00 ± 1.00 ^b	200.00
Vitamine B1	0.03 ± 0.01 ^a	0.05 ± 0.02 ^b	166.67
Vitamine C	6.50 ± 0.10 ^a	9.20 ± 0.40 ^b	141.54
Vitamine D	0.94 ± 0.03 ^a	1.86 ± 0.04 ^b	197.87
Vitamine E	1.80 ± 0.30 ^a	2.60 ± 0.20 ^b	144.44

Germination increases various vitamins present in cereals and legumes such as vitamin A, tocopherols (α -, β -, and γ -tocopherols), thiamine (Vitamin B1), riboflavin (Vitamin B2), and total niacin (Vitamin B3) (Kim *et al.*, 2012) due to synthesis of these vitamins by the new sprouts (Zilic *et al.*, 2015). Therefore, the germination of corn kernels led to a significant increase ($p < 0.05$) in the contents of vitamin A (3.00 ± 0.02 to 6.00 ± 1.00 % DW), vitamin B1 (0.03 ± 0.01 to 0.05 ± 0.02 % DW), vitamin C (6.50 ± 0.10 to 9.20 ± 0.40 % DW), vitamin D (0.94 ± 0.03 to 1.86 ± 0.04 % DW) and vitamin E (1.80 ± 0.30 to 2.60 ± 0.20 % DW) (Table 2). The results obtained corroborate those reported by Hiran *et al.* (2016) in their work on maize grains. Indeed, according to various authors, certain pre-treatments of corn kernels, such as sprouting, help to increase their nutritional value, especially in terms of vitamins (Okorie & Ekwe, 2017; Chaves-López *et al.*, 2020; Rico *et al.*, 2020). In addition, Vitamin C accumulation in sprouted edible seeds may be newly formed because most seeds have little or no availability of vitamin C before germination (Idowu *et al.*, 2020). On the other hand, the high value of vitamin B1 in germinated maize may be due to the reason why

microorganisms under stress conditions (fermentation or germination) could synthesize thiamine pyrophosphate (Hiran *et al.*, 2016).

Functional Properties

Functional properties state to the physicochemical properties, which show the relations of numerous constituents of food. This comprises the relationship among composition, structure, spatial arrangement of components and physico-chemical properties, with respect to the conditions they are associated and measured. Thus, the water absorption capacity of corn flour varies between 205.36 ± 2.85 % and 304.90 ± 2.05 % for sprouted corn and there is a significant difference ($p < 0.05$) in values (table 3). Germination increases the water absorption capacity of the maize sample, which is in agreement with the work of Siddiqua *et al.* (2019) for cereals. Indeed, according to (Adedeji *et al.*, 2014), the observed increase could be due to the production of compounds with good water retention capacity such as soluble sugars. Also, the increase in water absorption capacity could be attributed to the hydration of the corn kernels during soaking and germination, which in turn unfolds the protein, thereby increasing their hydrophilic binding sites and exposing them to the aqueous phase (Akaerue & Onwuka, 2010; Offia Olua *et al.*, 2020). Therefore, the high water absorption capacity of sprouted corn flour can be useful in manufacturing products where good viscosity is required.

Bulk density was reported lower in the germinated yellow maize flour sample and observed higher in raw grain flour (table 3). This change could be attributed to decrease in mass per unit volume as a result of germination. Germination lowers the bulk density of yellow maize flour. Decrease in bulk density with germination might be due to lowering of heaviness and dispensability of flour particles. Similar observations have also previously been reported by Udensi & Okoronkwo (2006).

Foaming capacity corresponds to the ability of proteins to form foam and its surface activities. Germination in yellow maize caused higher surface activity of protein and thus resulted in increase in the foaming capacity (Njintang & Mbofung, 2006). Foaming capacity of yellow maize flour varied from 22.08 ± 0.30 to 26.74 ± 0.20 %.

Sedimentation value of germinated yellow maize flour was lowered as compared to raw yellow maize flour. Sedimentation value decreased from 60.46 ± 1.70 to 52.39 ± 1.62 mL. Decrease in the sedimentation value might be attributed to the breakdown of particularly gluten protein as a result of protease activity during germination.

Emulsification properties like emulsification activity, emulsification capacity and emulsification stability varied significantly as a result of germination. Emulsification activity percentage of raw yellow maize flour was reported as 29.01 ± 0.10 %, which increased to 37.08 ± 0.40 % as a result of germination. Emulsification capacity of germinated yellow maize flour was high and reported as 28.35 ± 0.04 (mL oil/g), whereas emulsification capacity of raw sample

was 21.48 ± 0.03 (mL oil/g). Emulsification stability of yellow maize flour varied from 19.23 ± 0.01 to $21.75 \pm 0.03\%$ as a result of germination. Enhancement in the emulsification properties of yellow maize flour after germination could be attributed to the interaction of fats and protein content (Makri et al., 2005).

Table 3. Effect of germination on the functional properties from maize flours

Functional Parameters	Values	
	Flour from Raw maize	Flour from germinated maize
Water absorption capacity (%)	205.36 ± 2.85^a	304.90 ± 2.05^b
Solubility Index in Water (%)	28.05 ± 0.58^a	41.45 ± 2.32^b
Bulk density (g/mL)	0.88 ± 0.03^b	0.76 ± 0.02^a
Emulsification activity	29.01 ± 0.10^a	37.08 ± 0.40^b
Emulsification capacity (mL Oil/g sample)	21.48 ± 0.03^a	28.35 ± 0.04^b
Emulsification stability	19.23 ± 0.01^a	21.75 ± 0.03^b
Foaming capacity	22.08 ± 0.30^a	26.74 ± 0.20^b
Sedimentation value (mL)	60.46 ± 1.70^b	52.39 ± 1.62^a

Oil absorption capacity (OAC)

Oil absorption capacity was determined to measure the ability of the flour protein to physically (Table 4) bind fat by capillary attraction. Oil absorption capacity is important since oil acts as flavour retainer and increases the palatability of foods (Kinsella, 1976). Thus, the oil absorption capacity varied significantly ($p \leq 0.05$) among the non-germinated and germinated samples (table 4). Germination increased the oil uptake capacity of cornmeal, consistent with previous work by Siddiqua et al. (2019). The higher oil retention capacity could be due to protein solubilization and dissociation during germination (Agrawal et al., 2013). It should be remembered here that seed germination increases oil uptake capacity due to oil entrapment bound to non-polar side chains of proteins (Giani & Bekebain, 1992; Adedeji et al., 2014). Thus a greater oil retention capacity improves the taste, flavor and lipophilicity of food products (Siddiqua et al., 2019).

Oil absorption capacity was also reported high in yellow maize flour of germinated grains. The results obtained show that the OAC ranged between 115.54 ± 2.75 to $156.40 \pm 4.00\%$ and between 126.00 ± 3.00 to $176.00 \pm 2.00\%$ of raw and germinated yellow maize flour respectively with different oils. The highest values were found with red oil (156.40 ± 4.00 and $176.00 \pm 2.00\%$) and the lowest with refined oil (115.54 ± 2.75 and $126.00 \pm 3.00\%$) respectively of germinated and raw yellow maize flour. Chinma et al. (2009) reported the similar observations in tiger nut flour as a result of germination. The high oil retentions (Table 4) which were observed in sprouted maize flour would be due to an availability of lipophilic groups and to the ability of the proteins of this flour to retain oil (Suresh & Samsher, 2013). Therefore, the high oil absorption capacity of the

present sprouted maize meal makes it suitable for facilitating the improvement of flavor and mouthfeel when used in food preparations (Appiah et al., 2011). Thus, the major chemical component affecting OAC is protein which is composed of both hydrophilic and hydrophobic parts. Non-polar amino acid side chains can form hydrophobic interaction with hydrocarbon chains of lipids (Jitngarmkusol et al., 2008). The oil absorption capacities obtained in the present study are superior to those mentioned by Aguemon et al. (2019) on ackea (*Blighia sapida*) seed meal with values of 107 ± 0.03 and $97.90 \pm 0.06\%$ for red oil and refinedoil respectively. However, the oil retentions obtained are lower than those reported by Ratnawati et al. (2019) on certain legume flours, the proportions of which varied from 303 to 360%.

Table 4. Oil Absorption Capacity and Hydrophilic-Lipophilic Ratio

Different Oils	Values		Hydrophilic-Lipophilic Ratio (HLR)	
	Flour from Raw Maize	Flour from germinated Maize	Flour from Raw Maize	Flour from germinated Maize
Redoil	156.40 ± 4.00^a	176.00 ± 2.00^b	1.31	1.73
Refinedoil	115.54 ± 2.75^a	126.00 ± 3.00^b	1.77	2.42
Oliveoil	125.46 ± 1.52^a	132.00 ± 1.00^b	1.63	2.31
Tournesoloil	142.00 ± 3.00^a	151.00 ± 1.98^b	1.45	2.02

Dispersibility and Foam stability

The dispersibility of a mixture in water indicates its reconstitutability (Kulkarni et al., 1991). The better temperature, ionic composition, pH and agitation degree of the solvent are major factors affecting dispersibility (Kinsella, 1976). This property is a mean of comparing the solubility of a protein in water, and this property is widely used in the flour and powder studies. The dispersibility of full-fat raw and germinated yellow maize flour is shown in Figure 4a. The results indicated that dispersibility increased with time for both raw and germinated flour. The highest values were 80 and 95% at 20 min respectively for raw and germinated yellow maize flour. These results indicated that protein concentration was favourable for a better dispersibility of yellow maize flour. The higher the dispersibility, the better the reconstitution property (Kulkarni et al., 1991). Higher dispersibility enhances the emulsifying and foaming properties of proteins, which was observed during making of bread, macaroni and cookies (Kinsella, 1979).

The foam stability (FS) refers to the ability of protein to stabilize against gravitational and mechanical stresses (Fennema, 1996). Also, the foam stabilities of yellow maize flour decrease with increase in treatment time (100 - 63.50% and 100 - 52%) respectively for raw and germinated flour

(Figure 4b). It was noticed that the time increases, the values for foam stability kept decreasing. This suggests that yellow maize flour is more stable. Protein foams are important in many processes in the beverage and food industries and this has stimulated interest in their formulation and stability. Foams are used to improve texture, consistency and appearance of foods. In other hand there was an inverse relationship between foam capacity and foam stability. Flours with high foaming ability could form large air bubbles surrounded by thinner a less flexible protein film. This air bubbles might be easier to collapse and consequently lowered the foam stability (Jitngarmkusol *et al.*, 2008).

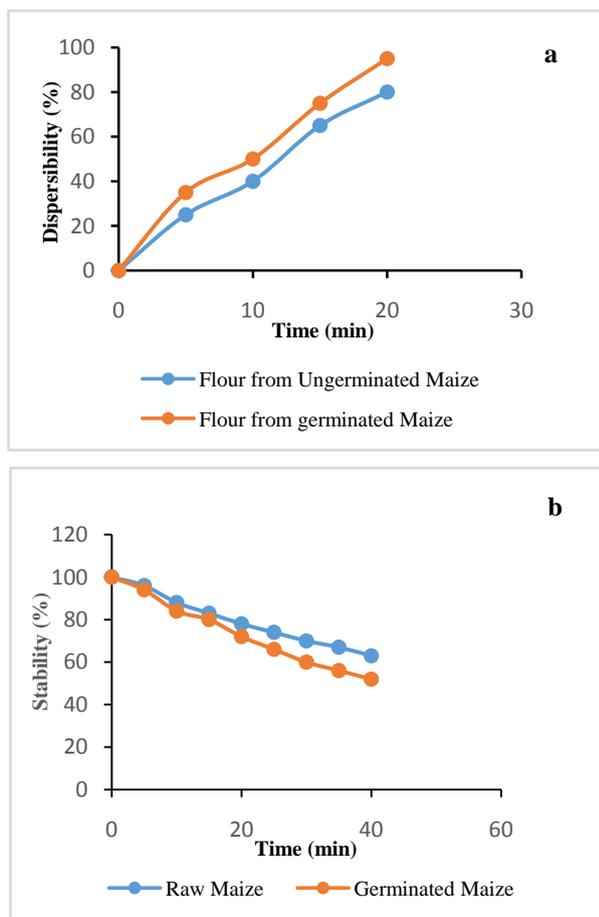


Figure 4. (a): Dispersibility determination; (b): Foam stability determination of yellow maize flour

4. Conclusions

The present study was carried out for the assessment of minerals, vitamins and some functional properties of sprouted maize grains with a view to their valorization in the Ivorian diet. The results of this study revealed that processing techniques such as germination improve levels of certain minerals and vitamins and functional properties of corn kernels. However, flour made from sprouted corn kernels should be supplemented with local fruits and vegetables, which are rich in other vitamins and minerals. With relatively high levels of good functional properties that

may be useful in food systems where they can play many functional roles. For example, the water absorption capacity WAC and oil absorption OAC of yellow maize flour make it useful for various products that require water and oil retention for their textural integrity like oil retention capability helps retain flavor and provides good mouth feel. Therefore, the improved functional properties of the germinated yellow maize seed flour could be utilized in food systems where natural modified flour is required rather than chemically or thermally modified white bean seed flour.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Review

This study does not involve any human or animal testing.

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