

Effect of Germination and Roasting Process on Biochemical and Functional Properties of Pigeon Pea (*Cajanus Cajan*) Seeds Cultivated in the Gontougo Region, Cote D'Ivoire

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Abstract Pigeon pea (*Cajanus cajan*) is an important source of protein, carbohydrates and minerals for many populations. However, its consumption can cause digestive problems due to its high content of anti-nutritional factors. Therefore, the aim of this study is to contribute to the improvement of the nutritional quality of pigeon pea by developing processing techniques for its use in different sectors. Flours were produced from germinated and roasted pigeon pea seeds. A control flour (no seed treatment) was also used. The nutritional, anti-nutritional and functional properties of the flours were evaluated using standard methods. The results showed that germination resulted in a significant ($p < 0.05$) increase in nutritional elements such as fibre (12.29%), protein (28.87%), total sugars (65.15%), polyphenols (654.43 mg) and flavonoids (9.49 mg) and a decrease in anti-nutritional factors in the flour, particularly oxalates (38.68 mg/100 g) and phytates (5.55 mg/100 g). Roasting showed a reduction in anti-nutritional factors such as oxalate (33.867 mg/100 g) and phytate (4.512 mg/100 g) and a significant increase in functional parameters such as water absorption capacity (55.33%) and oil absorption capacity (ACH). (22%). Analysis of these results shows that germination significantly improves the nutritional value of pigeon pea flour, while roasting improves the functional parameters of this vegetable.

Keywords: nutritional elements, anti-nutritional factors, functional properties

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1. Introduction

The nutritional value of pulses is considerable throughout the world, where demand for healthy food is high. Consumed regularly, they contribute to a healthy diet and help combat certain metabolic diseases. Rich in protein, fibre, vitamins and minerals, pulses are a food of choice. They contain a number of nutrients and bioactive compounds that may explain their protective effect. Pigeon pea is an important seed legume grown mainly in India [1].

It is a perennial legume native to tropical regions. In Côte d'Ivoire, it is grown in both savannah and forest areas to enrich the soil with nitrogen. It is drought and nitrogen tolerant and grows in tropical and subtropical regions. It should be noted that pigeon pea is widely regarded as an orphan crop, having been domesticated by humans [2]. These crops, which are common and widely accepted by

local farmers, are highly rich in nutritional profile, good for medicinal purposes, and well adapted to suboptimal growing conditions [3]. As a result, pigeon pea has attracted increasing interest in recent years. Unlike other legumes, pigeon pea is characterised by its tolerance to environmental stresses, unique nutritional profile, high biomass productivity and ability to conserve soil nutrients [4]. A perennial vegetable of the *Fabaceae* family, pigeon pea is a perfect source of protein for traditional cereal-based diets to prevent deficiencies. With an average protein content of 25g per 100g, it is one of the richest pulses. It also contains calcium, phosphorus, potassium and a variety of essential amino acids, making it a nutritious food of choice. Pigeon peas are also rich in polyphenols, which may also have health benefits. However, its consumption as a food, and therefore its use in the food industry, is very limited worldwide for a number of reasons. However, its consumption as a food, and therefore its use in the food industry, is very limited

worldwide for a number of reasons. The first and most important is that pigeon pea contains high levels of anti-nutrients [5] such as enzyme inhibitors, phytic acid and lectins [6].

As the name suggests, anti-nutrients are compounds that block the absorption of nutrients from food. Some of them are even toxic to the human body to a certain extent, in particular by inducing malnutrition and micronutrient deficiencies and by altering the integrity of the intestinal mucosa [6]. Of these inhibitors, trypsin and amylase inhibitors are of greatest concern. Trypsin inhibitors can reduce protein digestibility by forming a complex with trypsin and chymotrypsin. Similarly, amylase inhibitors can inhibit amylase activity, reducing the rate of carbohydrate digestion [7]. Phytic acid can inhibit the intracellular uptake of minerals and trap them. Lectins can also interfere with mineral absorption by binding to the intestinal mucosa, leading to intestinal inflammation [8].

Pigeon peas are also extremely hard, making them difficult to cook. In particular, it takes up to 24 hours to produce pigeon pea flour from its dried seeds using traditional heat treatment methods [9]. In addition, pigeon pea has a characteristic taste that distinguishes it from other pulses. This particular taste certainly limits its use in our daily diets [2]. Given the economic and nutritional potential of pigeon pea, it makes sense to look for practical strategies to improve its edibility and take full advantage of the beneficial functions of its bioactive components. It is therefore essential to process this crop using appropriate methods, not only to reduce the levels of anti-nutrients and toxins, but also to improve the bioavailability of nutrients [10]. In recent years, various treatment methods have been used to pave the way for the use of pigeon pea in food products, mainly targeting anti-nutrients. These methods include physical, chemical and biological treatments. By using these methods alone or in combination, it is possible to reduce the levels of anti-nutrients and improve undesirable flavours and hard textures. Thus, the aim of this work is to determine the effect of the germination and roasting process on the biochemical and functional properties of pigeon pea seeds.

2. Material and Methods

2.1. Materials

2.1.1. Sampling and Pre-treatment of Pigeon Pea Seeds

pigeon pea seeds were purchased at an open market in Tanda, in the Gontougo region of Côte d'Ivoire, and transported to the biochemistry laboratory at Peleforo Gon Coulibaly University in Korhogo.

2.1.2. Preparation of Pigeon Pea Meal

2.1.2.1. Pre-treatment

Unprocessed, roasted and germinated pigeon pea flour was obtained using the method described by [11] with slight modifications. Prior to sample treatments, two kilograms (2kg) of seed were weighed, sorted and winnowed. They were then divided into three batches of 500 (g) and each batch was washed with tap water. One (1)

of the batches was subjected to germination and the other to roasting, with one batch serving as a control. The control was oven dried at 45°C for 1 to 2 hours and then ground into flour.

2.1.2.2. Germination

The sorted and shelled pigeon pea seeds (500g) were sterilized for 5 to 10 minutes in a bleach solution at 8°. The grains were then washed in tap water until the smell of bleach had disappeared and then soaked in tap water at a ratio of 1:3 for 24 hours at room temperature. The grains are spread out on a white cotton sheet placed on a cardboard box in a dark room. The temperature of the room is 31°C and the humidity is 37%, measured with a thermometer. The seeds were watered with tap water once or twice a day for three (3) days. (Figure 1).



Figure 1. Sprouted pigeon pea seeds

2.1.2.3. Roasting

The third portion of pigeon pea seeds was roasted in a stand-alone oven with a temperature probe at 120 °C for 10 minutes, ground and sieved through a 250 µm mesh sieve to obtain roasted pigeon pea flour (Figure 2).



Figure 2. Roasted pigeon pea seeds

2.2. Methods

2.2.1. Physicochemical characterization of the Different Types of Pigeon Pea Flour Produced

2.2.1.1. Proximate Analysis

Moisture was determined after drying 5 g of the sample at 105°C for 24 h [12]. The protein content was determined by the Kjeldahl method, and the nitrogen content of the samples was multiplied by a factor of 6.25 [13]. Ash was determined by combustion of 5 g of the sample at 550°C for 6 h.

2.2.1.3. Mineral Content

The mineral content was analyzed according to the

method of [14]. Briefly, pea flour (0.5 g) was dissolved in 31 mL of acid and heated until thick white fumes were produced. After cooling and dilution with 50 mL of distilled water, the sample was boiled for 30 minutes and filtered (Whatman No. 42) into a volumetric flask. After the addition of water, the solution was used for the determination of minerals. phosphorous was quantified after mineralization (2 g at 550°C) and treatment with a vanadate-molybdate solution

2.2.1.2. Fiber Content

The determination of the crude fiber content was carried out according to [15]. One gram (1 g) of the sample (Ws) was boiled under reflux in 50 mL of 0.25 N sulfuric acid for 30 min. Then 50 mL of 0.31N NaOH was added, and the sample was boiled again for 30 min under the same conditions. After filtration and washing with several portions of hot water, the residue was allowed to dry and quantitatively transferred to a preweighed crucible. The residue was dried at 105°C for 8 hours, cooled in a desiccator, weighed (W2), and then incinerated in a muffle furnace at 500°C for 3 hours. After cooling, the sample was reweighed (W3) and the percentage of fiber was calculated as follows: % crude fiber = $[100 (W2-W3) / Ws]$.

2.2.1.4. Determination of Total and Reducing Sugars Extraction of the Sample Sugars

The ethanol-soluble sugars were extracted according to [16]. One gram of sample was mixed in 10 mL of ethanol (80% v/v), followed by the addition of 2 mL of zinc acetate (10% w/v) and 2 mL of oxalic acid (10% w/v). The mixture was then centrifuged at 3000 rpm for 10 minutes. The pellet obtained was resuspended in 10 mL ethanol (80% v/v) and centrifuged again. The pooled supernatant was transferred to a 50 mL flask and the excess ethanol was evaporated in a sand bath for 10 min. The resulting solution was made up to 50 mL with distilled water.

Quantification of total sugars

The method described by [17] was used to determine the total sugars of the extract. To a test tube containing 100 μ L of ethanol soluble extract, 0.9 mL distilled water, 1 mL phenol (5 % w/v), and 5 mL concentrated sulphuric acid were added. After standing for 10 min, the optical density (OD) was read against a blank using a spectrophotometer (PG Instruments) at 490 nm. A glucose solution (1 mg/ml) was used to construct a calibration curve and the amount of total sugar in the sample was expressed in g/ 100 g of dry sample.

Quantification of reducing sugars

Reducing sugars were determined according to [18]. To a test tube containing 150 μ L of extract, 300 μ L of DNS (3,5-dinitrosalicylic acid) solution was added and the tube was heated in a boiling water bath for 5 minutes. After cooling to room temperature for 5 minutes, 2 mL of distilled water was added, and the optical density was read at 540 nm using a JASCO V 530 spectrophotometer against a blank prepared in the same way. The amount of reducing sugars, expressed in g /100 g of dry sample, was determined from a calibration curve plotted using 2 mg/ml

glucose solution.

2.2.2. Phytochemicals Analysis

2.2.2.1. Extraction of Phenolic Compounds

Phenolic compounds were extracted with methanol according to the method of [19]. One (1) gram of pigeon pea flour was homogenized in 10 mL of 70% (v/v) methanol. The resulting mixture was centrifuged at 1000 rpm for 10 min and the resulting pellet was re-extracted. The pooled supernatant was transferred to a 50 mL flask and made up to volume with distilled water.

2.2.2.1.1. Estimation of Total Phenolic Content

Total polyphenols were determined by the method reported by Assoi [20] using 1 mL of the methanolic extract to which 1 mL of Folin-Ciocalteu reagent was added. After 3 min of standing, 1 mL of 20% (w/v) sodium carbonate solution was added to the mixture. After the addition of distilled water to a final volume of 10 mL, the sample was stored in the dark for 30 min and the OD was read at 745 nm against a blank. Gallic acid (1 mg/ml) was used to construct a standard curve and the amount of phenolics was expressed as mg / 100 g of dry sample.

2.2.2.1.2. Estimation of Flavonoid Content

In a 25 mL volumetric flask, 0.75 mL of 5% (w/v) sodium nitrite (NaNO₂) was added to 2.5 mL of extract. Then 0.75 mL of 10 % (w/v) aluminium chloride (AlCl₃) was added and the mixture was incubated in the dark for 6 minutes. Then, 5 mL of sodium hydroxide (1N NaOH) was added, and the volume was made up to 25 mL. The mixture was shaken vigorously, and the absorbance was read against a blank at 510 nm using a UV-visible spectrophotometer. Flavonoid content was expressed in grams per 100 g of quercetin equivalent [21].

2.2.2.1.3. Estimation of Tannin Content

Tannins were determined according to the method described by [22] with slight modifications. After adding 5 mL of vanillin reagent. To 1 mL of methanolic extract, test tubes were left in the dark for 20 minutes and the optical density was read at 500 nm against a blank. Tannic acid was used as standard (2 mg/ mL) and the tannin content was expressed in g /100 g of dry sample

2.2.3. Anti-nutritional Factor

2.2.3.1. Estimation of Phytate Content

Phytic acid content was determined as described by [20] on 0.5 g of flour, and the absorbance was read at 470 nm against a blank. A standard curve of different concentrations of Mohr's. salt treated under similar conditions was plotted to calculate the amount of phytic acid in g /100 g of dry sample.

2.2.3.2. Estimation of Oxalate Content

The oxalate content was determined according to the [13] method as described by [23] after heating a mixture of 2 g of sample, 200 mL of distilled water, and 20 mL of hydrochloric acid for 1 h in a boiling water bath. Titration was performed with 0.05N potassium permanganate solution.

2.2.4. Technofunctional Properties

2.2.4.1. Water / Oil Absorption Capacity

In preweighed centrifuge tubes, 1 g of flour was added to 10 mL of water or vegetable oil and mixed, then the tube was left undisturbed for 1 h at room temperature [20]. After centrifugation at 2500 rpm for 30 min, the supernatant was discarded and drained at 45 degrees for 10 minutes before the tube was weighted. The water or oil capacity was calculated and expressed as g /g of dry flour.

2.3. Statistical Analysis

The STATISTICA software (version 7.1) carried out statistical analyses of the various results of physicochemical and mineral parameters. Significant statistical differences were highlighted by a one-factor analysis of variance (ANOVA) followed by the Duncan test. Statistical significance was defined at the 5% threshold.

3. Results and Discussion

3.1. Results

3.1.1. Nutritional Properties of Pigeon Pea Flours

The dry matter, ash, fibre, protein, total sugars and reducing sugars content of germinated, roasted and control pigeon pea seed flours is shown in Table I. The dry matter content varies from 89.27% (roasted flour) to 95.83% (sprouted flour). Statistical analysis shows that these contents are significantly different. The dry matter content of the control flour is lower than that of the sprouted flour; in addition, the sprouted flour has a higher content than the roasted flour. The ash content varied from 3.637% (roasted flour) to 5. control). Statistical analysis shows that the contents obtained are significantly different. The ash content of the control flour was higher than that of the sprouted and roasted flours. The ash content of the sprouted seed flours was also higher (4.450 ± 0.3) than that of the roasted seeds (3.637 ± 0.038). Fibre content varied from 10.893% (roasted flour) to 12.290% (sprouted flour). Statistical analysis shows that the fibre contents obtained are significantly different. Sprouted flour has the highest fibre value compared with the control and roasted. In addition, the control flour had a higher fibre content than the roasted flour. Protein content ranged from 20.44% (roasted flour) to 28.87% (sprouted flour). Statistical processing shows that the protein contents obtained are significantly different. The protein content of the control flour (23.62 ± 0.01) is higher than that of the roasted flour, but lower than that of the sprouted flour. In fact, sprouted flour had the highest protein content. The analysis shows that the total sugar contents obtained are significantly different. The total sugar content of the control flour is lower than that of the sprouted flour and the roasted flour. Sprouted flour has the highest total sugar content, followed by roasted flour. The reducing sugar content ranged from 16.988% (roasted flour) to 25.420% (sprouted flour). The analysis shows that the reducing sugar contents are significantly different. The reducing

sugar content of the control flour is higher than that of the roasted flour, but lower than that of the sprouted flour, which has the highest value compared with the control and the roasted flour.

Table 1. Nutritional properties of pigeon pea flours

Parameter	Control	Germination	Rôtiy
Dry matter (%)	92.20 ± 0.40^b	95.83 ± 1.26^a	89.27 ± 1.14^c
Ash (%)	5.230 ± 0.080^a	4.450 ± 0.3^b	3.637 ± 0.038^c
Fiber (%)	11.100 ± 0.050^b	12.290 ± 0.040^a	10.893 ± 0.461^b
Protein (%)	23.62 ± 0.01^b	28.87 ± 0.01^a	20.44 ± 0.03^c
Total sugars (%)	35.890 ± 0.360^c	65.150 ± 4.100^a	57.265 ± 2.151^b
Reducing sugars (%)	23.590 ± 0.150^b	25.420 ± 0.220^a	16.988 ± 0.113^c

Mean deviations, assigned different letters on the same line are significantly different at the 5% threshold according to the Duncan test. With a < b < c < d < e.

3.1.2. Minerals Content

Table 2 shows the results for the minerals in the different pigeon pea meals. The statistical analysis shows that the content of certain minerals such as nitrogen (N), potassium (K), copper (Cu) and iron (Fe) increases progressively in the flours. In fact, the control has the lowest levels of these minerals compared to the germinated and roasted seeds, which have the highest levels. The results in the table also show a decrease in the content of phosphorus (P) and magnesium (Mg) in the flours of sprouted and roasted seeds compared to the control. An increase in the content of zinc (Zn) and sodium (Na) is observed in the roasted flour compared to the control flour and the sprouted flour. The flour from sprouted seeds has a high content of calcium (Ca) compared to the control and roasted flour

Table 2. Minerals content

Parameter (mg/100g)	Control	Germination	Rôtiy
(N)	2184.33 ± 0.58^c	2492.67 ± 1.15^b	3269.87 ± 4.03^a
(P)	1020.00 ± 0.00^a	259.33 ± 0.58^c	771.60 ± 0.00^b
(K)	1013.00 ± 0.00^c	1232.67 ± 1.15^b	1603.00 ± 0.00^a
(Ca)	878.00 ± 1.00^b	1127.33 ± 0.58^a	183.60 ± 0.00^c
(Mg)	241.27 ± 0.12^a	205.97 ± 0.12^b	116.90 ± 0.00^c
(Cu)	0.33 ± 0.01^c	1.23 ± 0.00^b	2.18 ± 0.00^a
(Fe)	0.22 ± 0.00^c	0.29 ± 0.00^b	11.61 ± 0.00^a
(Zn)	0.36 ± 0.00^b	0.29 ± 0.00^c	4.28 ± 0.00^a
(Na)	1.27 ± 0.00^b	0.82 ± 0.00^c	21.20 ± 0.00^a

Mean deviations, assigned different letters on the same line are significantly different at the 5% threshold according to the Duncan test. With a < b < c < d < e..

3.1.3. Antioxidant or Bioactive Compounds of Flour

Table 3 presents the results of the phytochemical compounds of pigeon pea. Indeed, these contents increase from 416.340 ± 2.290 mg/100 g (control) to 762.566 ± 1.515 mg/100 g (roasting) for polyphenols. In addition, the flavonoid content varies between 4.490 ± 0.060 and 9.490 ± 0.11 mg/100 g, with a higher content (9.490 ± 0.11) in the flour from sprouted seeds. The tannin content ranged from 43.840 ± 0.370 (control) to 71.600 ± 0.49

mg/100 g (germinated), with the control having the lowest tannin content and the flour from the germinated grains having the highest content compared to that of the flours from the roasted seeds. The analysis of the results showed a significant decrease in all these factors. The results show respectively that the content of oxalates and phytates in pigeon pea flour gradually decreases from 55.370 ± 0.640 mg/ 100g (Control) to 33.867 ± 2.975 mg/ 100g (roasting) and from 8.010 ± 0.030 mg/ 100g (control) to 4.512 ± 0.051 mg/ 100g (roasting). In general, the contents of anti-nutritional factors in the different flours from treated pea seeds have significantly decreased

Table 3. Phytochemicals and Anti-nutritionals content

Parameter	Control	Germination	Rôtiy
Polyphénols (mg EAG /100 MS)	416.340 ± 2.290^c	654.430 ± 4.99^b	762.566 ± 1.515^a
Flavonoides (mg EQ /100 MS)	4.490 ± 0.060^c	9.490 ± 0.11^a	7.745 ± 0.034^b
Tanins (mg EAT g /100 MS)	43.840 ± 0.370^c	71.600 ± 0.49^a	50.065 ± 0.258^b
Oxalates (mg/100g)	55.370 ± 0.640^a	38.680 ± 0.84^b	33.867 ± 2.975^c
Phytates (mg/100g)	8.010 ± 0.030^a	5.550 ± 0.09^b	4.512 ± 0.051^c

Mean deviations, assigned different letters on the same line are significantly different at the 5% threshold according to the Duncan test. With $a < b < c < d < e$.

3.1.4. Functional Properties of Pigeon Pea Flours

Figure 3 and Figure 4 present the results of the functional properties of pigeon pea

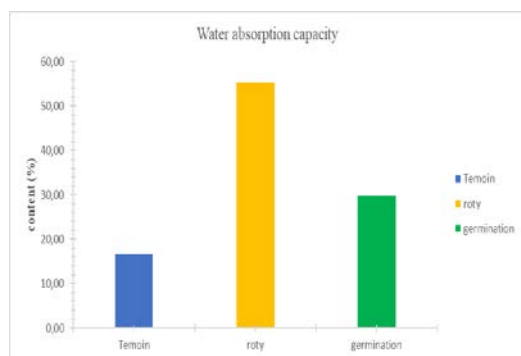


Figure 3. Effect of roty and germination on Water Absorption Capacity (WAC)

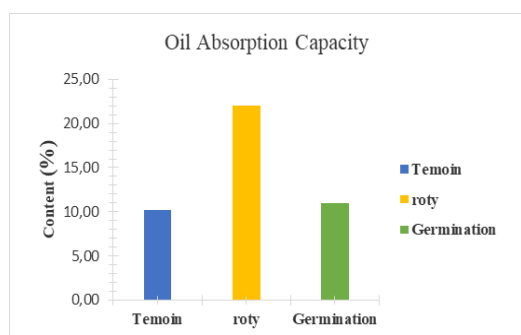


Figure 4. Effect of roty and germination on Oil Absorption Capacity (ACH)

3.2. Discussion

The proximate composition of foods includes moisture, ash, lipid, protein and carbohydrate contents. These food components may be of interest in the food industry for product development, quality control (QC) or regulatory purposes [24]. In this regard, the proximate composition of sprouted and roasted pigeon pea flour was compared with that of raw pigeon pea flour. Thus, biochemical analyses showed that germination of pigeon pea seeds has a significant effect on the measured biochemical parameters. Indeed, Germination is a process that activates enzymes in the seeds, increasing the digestibility and bioavailability of nutrients. Germination can reduce the levels of phytic acid, an antinutrient that inhibits mineral absorption [25]. The study showed that this process can increase the protein (28.87%) and fiber (12.290%) content. These results are similar to those of [26] who showed that the fiber content of pigeon pea increased significantly ($P \leq 0.05$) from 4.75 to 6.13% during germination. The slight decrease in ash content in the sprouted pigeon pea flour samples in this study could be due to soaking the grains in water before the germination process as it was found that during soaking, there was leaching of minerals. According to a work by [27], sprouting pigeon pea significantly increased its digestible protein content by up to 25% while reducing the content of non-digestible complex carbohydrates. The increase in crude protein content of the sprouted pigeon pea flour samples in this study confirms other previous studies. For example, an increase in crude protein content due to sprouting has also been reported in chickpea [28]. The increase in crude protein can be attributed to the synthesis of proteases required for certain amino acids during protein synthesis [29]. Germination is known for the breakdown of macromolecules such as starch into glucose and other monosaccharides, which involves complex metabolic changes mainly due to the activation of enzymes such as α - and β -amylases [30]. This was well illustrated by the increase in total sugars (65.150%) and reducing sugars (25.420%) observed after sprouting treatment. Roasting, which involves dry heat, also induces significant changes in nutritional composition. This treatment resulted in a decrease in matter, protein and reducing sugars content, with a variable impact on fiber, this could be due to the times and temperatures applied. A research by [31] noted a decrease in total protein of up to 15% after high-temperature roasting, due to protein denaturation. Roasting also has the ability to reduce ash content. Experiments have shown that roasting can decrease ash due to the volatilization of some minerals, but this depends on the specific process conditions [32]. On the other hand, this treatment is often used to increase total sugars content, as it can cause caramelization, which increases reducing sugars on the surface of the beans.

According to a study by [33], sprouting results in a significant increase in nitrogen, phosphorus, and potassium levels in pigeon pea, leading to an increase in protein and mineral content in the flour. Furthermore, work by [26] showed that sprouting could also improve iron and zinc content in legumes. This is often attributed to the reduction of phytates that inhibit the absorption of these nutrients. It was observed that sprouts contained sufficient moisture to require solubilization of mineral

elements bound to the cotyledons to facilitate their extraction during analysis [34]. Roasting involves exposure to high temperatures, which could lead to significant changes in mineral components such as Nitrogen (N), Potassium (K), Copper (Cu), Iron (Fe), Zinc (Zn), and Sodium (Na). Although some losses are possible, the reduction in moisture during roasting can also lead to a relative concentration of the remaining minerals in the flour [35]. It is noted that calcium and magnesium can be relatively stable under heat treatment. The effects of roasting on different minerals are often complex and depend on the duration and temperature of treatment. A study by [36] showed that copper and iron content can vary considerably depending on the roasting conditions.

Germination of pigeon pea seeds showed an increase in polyphenol levels. The results corroborate those of [29], who show that pigeon pea germination results in increased release of polyphenols, which contributes to an increase in antioxidant activity. Germination also promotes the accumulation of flavonoids. The results obtained are similar to those of [26] who reported an increase in the flavonoid content of sprouted pigeon pea grains. During germination, the phenylpropanoid metabolic pathway is activated, leading to the production of acetylcoenzyme esters that are converted into flavonoids, thereby increasing the total flavonoid content of sprouted grains. In addition, the tannin concentration may also decrease or remain stable, depending on the germination time and environmental conditions [37]. Indeed, enzymatic modifications and hydrolysis of complex polysaccharides contribute to the release of these compounds during the germination process, thus promoting the increase in the bioavailability of phytonutrients [38].

Roasting resulted in a significant increase in polyphenols. Thus, the results are inconsistent with those of [35], who illustrate that heat treatment can degrade some heat-sensitive polyphenols, leading to a reduction in antioxidant activity. Roasting also modified the flavonoid content. Although some studies indicate that roasting can reduce the concentration of flavonoids, others suggest that chemical transformations can improve their bioactive availability after heat treatment [39].

All treatments reduced the level of tannins in the seed, but sprouted pigeon pea exerted a greater effect. Tannins are water soluble compounds and can be destroyed by heat and reduced by the leaching process.

Results revealed that processing, sprouting and roasting methods inactivated heat-sensitive antinutritional factors and reduced their concentrations to safe levels [26] found a significant ($P \leq 0.05$) decrease in phytic acid content of pigeon pea from 8.40 to 3.53 mg/100 g (72 h sprouted grains). The reductions in antinutrients could result from degradation by microbial enzymes released during sprouting [40].

Oxalates, on the other hand, can bind to calcium and reduce its absorption. According to a study by [41], sprouting can have a variable effect on oxalate levels, which can either reduce or remain constant depending on the sprouting time and pigeon pea variety.

Roasting can lead to partial degradation of phytates, although it is generally not as effective as proper germination. Work by [35] has shown that phytate content can decrease by up to 10–15% after roasting, but this

reduction is often small compared to that observed after germination. At high roasting temperatures, oxalates can be relatively stable, and their concentration may not be significantly affected [36].

Germination is a process that activates enzymes and changes the chemical composition of the seeds. This process can lead to an increase in EAC and HAC through the degradation of macromolecules into smaller molecules, such as soluble sugars and amino acids, which can interact more effectively with water and oil. The results showed a slight increase in EAC and HAC contents in flours with sprouted grains compared to the control. Studies have shown that significant improvement in EAC and HAC can be observed in pulse flours after germination [42]. During germination, solubilization of polysaccharides and degradation of proteins can increase the availability of hydration sites and adsorption sites for oil [43]. These changes increase the hydrophilic and lipophilic properties of flour, making it more capable of absorbing larger amounts of water and oil.

Water absorption capacity is the amount of water absorbed by flour to achieve the desired consistency and create a quality food product [44]. The increase in WAC of A1 and B1 could be attributed to thermal dissociation of proteins, gelatinization of carbohydrates, and swelling of crude fiber in flour [45]. Furthermore, roasting is a heat treatment that modifies the starch structure and protein grain size, thereby influencing the absorptive capacity. However, the results regarding the effects of roasting on CAE and CAH have been significant. According to a study by [46], roasting can reduce CAE by denaturing proteins and making starch less soluble. Conversely, research has indicated that moderate temperatures may promote better protein cross-linking, thereby increasing CAH [47]. It has been reported that the oil absorption capacity of flour is mainly influenced by the amount of hydrophilic and lipophilic amino acids and their spatial arrangements [48]. Thus, oil uptake capacity is a function of fat, binding nonpolar side chains of proteins affected by the number of hydrophobic sites and protein-lipid-carbohydrate interactions. An increase in oil uptake capacity after germination has been previously reported in germinated wheat, brown rice, and triticale [48]. Roasting temperature and duration are key factors affecting the uptake properties. Over-roasting can lead to reduced EAC due to protein denaturation, while light roasting can improve EAC by facilitating the interaction between lipids and flour surfaces [49].

4. Conclusion

The process of germination and roasting of pigeon pea seeds significantly modifies their biochemical and functional properties. Germination and roasting promote the development of bioactive compounds, such as antioxidants, which may have beneficial effects on health. In addition, germination leads to a significant increase in nutritional compounds in pigeon pea flour. On the other hand, roasting improves the functional properties of pigeon pea flour. These processes can also reduce the content of anti-nutritional, making nutrients more accessible and thus increasing the nutritional quality of the

final product. The combination of germination and roasting represents a strategic approach to improve the functional and biochemical properties of pigeon pea, thus promoting its use in various food products. These transformations could enrich the nutritional value and optimize the organoleptic acceptability, opening the way to new industrial applications in the agri-food sector.

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