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Evaluation of the chemical composition of fresh and dried pepper (*Piper nigrum*) produced in Côte D'Ivoire

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Abstract

In this study, we evaluate the chemical quality of fresh and dried pepper grown in Côte d'Ivoire. Sampling was carried out on the basis of pedological data provided by the Association of Côte d'Ivoire Pepper Producers. Samples were then collected over a period of two (2) years. The results show that the fresh and dried pepper samples with the highest water content came from Niablé (69.55%) and Assouba (14.32%) respectively. The highest total sugar values for fresh pepper samples were found in Guibéroua (6.44 mg). Dried pepper samples with the highest total sugar content came from Guibéroua (7 mg). The highest reducing sugar contents in fresh and dried peppers were found in samples collected successively in Niablé (2.86 mg) and Danané (3.20 mg). Fresh pepper samples collected in Lopou (5.58%) showed the highest ash content. Dried pepper samples with the highest ash content were recorded from PK 103 (5.63%). Fresh pepper samples from Maféré (14.33 g) and Azaguié (14.33 g) contained the highest values. The highest protein contents were found in dried pepper samples from Niablé (14.55 g) and Maféré (14.33 g/100g). The highest piperine values were found in fresh pepper samples from Maféré (7.05 g). Dried pepper samples from Maféré (7.36 g) showed the highest piperine content. Fresh pepper samples with the highest essential oil content were from Maféré (1.93 mL). Dried pepper samples from Maféré (7.36 g) had the highest piperine content.

Finally, the chemical parameters analyzed are very important for the development of the organism.

Keywords: *Piper nigrum*; chemical parameters; Fresh peppers; Dried peppers

1. Introduction

The pepper plant (*Piper nigrum L.*) is a perennial climber in the Piperaceae family. It belongs to the Piper genus, which comprises over 1,000 species [1]. It is generally grown at the beginning of the dry season, after clearing the plantation of weeds [2]. Pepper production can last up to twenty years, with the first seeds appearing from the third year onwards, peaking in the seventh year [3]. Worldwide, pepper production has fallen considerably in recent years. It has fallen from 633,000 to 497,000 tonnes successively in 2019 and 2021 [4]. Furthermore, world demand for pepper was estimated at around 505,000 tonnes, i.e. a deficit of 8,000 tonnes, which represents a loss for producers in 2021 [4]. Indeed, this drop in pepper production has had an impact on exports, which have fallen from 407,000 to 280,000 tonnes, with prices rising from $2,000 to $4,500 per tonne in 2019 and 2021 respectively [4]. Vietnam has been the world's leading pepper producer for several years, with production of 201,265 tonnes in 2021. It is followed in succession by Brazil, India, Indonesia and China, with production of 89,954, 66,000, 52,758 and 24,684 tonnes respectively [4]. In Africa, the biggest pepper producers are Madagascar, Ghana and Ethiopia, with 5,282.56 tonnes, 3,737.9 tonnes and 4,431.03 tonnes of

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pepper produced in 2021 [5, 4]. With national pepper production of 57.46 and 45.03 tonnes in 2020 and 2021 respectively, Côte d'Ivoire is classified as a low-production country [4]. Pepper's chemical composition confers numerous properties. The essential oil, which accounts for 1-3% of pepper composition, is used in the manufacture of perfumes and soft drinks. In addition, numerous studies have shown that this oil has antibacterial (against *Bacillus subtilis, Vibrion cholerae, Clostridium botulinum*) and antifungal (against *Aspergillus flavus, Alternaria alternata, Fusarium oxysporium*) properties [1, 6]. In addition, piperine, responsible for pepper's pungent flavour, is present in all parts of the plant, but is more abundant in the seeds (5-10%) [1]. In addition, research by Chikh and Rachem [7] shows that pepper is rich in starch (40-50%), lipids (5-10%) and proteins (10-12%). It has conquered gourmet tables all over the world, enhancing the taste of many dishes. In addition to its culinary properties, many other biological properties have been attributed to the various parts of the pepper plant, including its leaves, fruits and seeds [1, 6, 8].

In this study, chemical parameters such as water content, total sugars, reducing sugars, ash content, protein content, piperine content and essential oils of fresh and dried peppers from Côte d'Ivoire were determined.

2. Materials and methods

2.1. Plant material

The plant material consisted mainly of fresh and dried pepper (*Piper nigrum*) (Figure 1). They were purchased from growers in the localities of : Azaguié, Maféré, N'douci, Guibéroua, Danané, Niablé, Yakassé-Mé, Lopou, Assouba and Pk 103.

Figure 1 Fresh cluster pepper and destemmed dried pepper

3. Methods

3.1. Selection of fresh and dried pepper sampling sites

A survey of pepper growers in Côte d'Ivoire previously carried out by FIRCA [9] identified 38 pepper plantations in production. Taking into account the geographical location and soil distribution of Côte d'Ivoire, these plantations were grouped into 10 different localities. They are mainly located in the Azaguié, Maféré, N'douci, Guibéroua, Danané, Niablé, Yakassé-Mé, Lopou, Assouba and Pk 103 zones.

3.2. Sampling

Samples of fresh and dried pepper were collected from growers in ten (10) localities in Côte d'Ivoire. In these localities, five (05) samples were taken, each weighing 1.5 kg for fresh pepper and 1.5 kg for dried pepper. After collection, the fresh pepper samples were packed in 10 kg coolers containing carboglass. The samples were transported directly to the Laboratory for Industrial Processes, Synthesis, the Environment and New Energies (LAPISEN) of the Felix Houphouët-Boigny National Polytechnic Institute (INP-HB). Given that each sample weighs 1.5 kilograms, a total of forty-five (45) samples of fresh pepper and fifty (50) samples of dried pepper were collected. In Danané, samples of dried pepper were collected.

3.3. Determination of dry matter and water content in fresh and dried peppers

Dry matter content was determined using the AOAC method [10]. A 5 g mass of each fresh or dried pepper bean sample was weighed into metal crucibles of known mass M0 using the 0.001 g precision balance (Wunder Sa. Bi model NHB). The whole assembly (crucible and sample) was placed in an oven (Memmert, Germany) at 105°C for 24 h. After 24 h, the crucible was removed and placed in a desiccator for cooling and weighing. Dry matter content expressed as a percentage by mass was determined from equation (1). Results were obtained in triplicate. The water content (Te) was obtained as the difference between the total matter rate, i.e. 100%, and the dry matter rate (equation 2).

$$\mathbf{MS}\ (\%) = \frac{\mathbf{(M2-M0)}}{\mathbf{M1}} \times 100 \quad \mathbf{(1)}$$

Where:

MS % = dry matter content

M0 = mass in grams of empty crucible (g)

M1 = mass in grams of test sample before drying (g)

M2 = mass in grams of crucible and test sample after drying (g).

$$\boldsymbol{Te}\ (\%) = \mathbf{100}\ (\%) - \boldsymbol{MS}\ (\%) \quad \mathbf{(2)}$$

Where:

Te (%) = Water content

3.4. Determination of total sugars

Total sugar content was determined using the phenol-sulfuric method described by Dubois et al [11]. A volume of 100 µL of water-soluble sugar extracts was introduced into a test tube. Then, 1 mL of phenol (5%, w/v), 0.9 mL of distilled water and 5 mL of 95% concentrated sulfuric acid were added respectively. After shaking and cooling the tube in the dark, the optical density (OD) was read on a spectrophotometer (JASCO V-530) at 490 nm, against a blank without water-soluble sugar extract prepared under the same conditions as the assays. A standard range was prepared using a 1 mg/mL glucose stock solution. Trials were carried out in triplicate. The amount of total sugars in each fresh or dried pepper sample was obtained from the equation of the regression line established using the standard range.

3.5. Determination of reducing sugars

The determination of reducing sugars was carried out according to the method of Yadav and Prakash [12] using 3,5-dinitro-salicyclic acid (DNS). One (1) mL of fresh or dried pepper extracts was taken and placed in a test tube. To these different volumes was added 1 mL of DNS (3,5-dinitrosalicylic acid), then brought to a boil in a water bath for 5 min. Next, 10 mL distilled water was added to the reaction medium after cooling on the bench. Optical density readings were taken at 540 nm using a JASCO V-530 spectrophotometer against a blank. Trials were performed in triplicate. Optical density was converted to reducing sugars using calibration curves obtained from a glucose solution (1 mg/mL).

3.6. Determination of ash content in fresh and dried peppers

The method used for ash determination was described by AOAC [10], which involved incinerating a sample until whitish residues were obtained. 5 g of fresh, dried pepper (P0) were placed in porcelain incinerator capsules of known mass (P1). The whole assembly (capsule + pepper grind) was heated in a muffle furnace, then incinerated at 550°C for 12 h. The capsules were then removed from the oven and cooled in a desiccator. The mass (P2) of the crucible-ash assembly was determined by weighing. Trials were carried out in triplicate. The ash content (C) was obtained in g per 100 g of dry matter by the formula:

$$\mathbf{Ash}\ (\%) = \frac{\mathbf{P2 - P1}}{\mathbf{P0}} \times \mathbf{100} \quad \mathbf{(3)}$$

P0 = Mass of pepper powder (g)

P1 = Mass of empty capsules (g)

P2 = Mass of crucible + ash (g)

3.7. Determining the protein content of fresh and dried peppers

Protein determination was carried out using the Kjeldahl method [10]. Determination of protein content was reduced to the determination of total nitrogen in the sample by Kjeldahl. This method comprises a mineralization phase, a distillation phase and a hydrochloric acid titration phase.

3.7.1. Mineralization

A mixture consisting of 1 g fresh or dried pepper powder, 5 g catalyst (composed of 95% K_2SO_4, 1.5% $CuSO_4$ and 2% Selenium), 5 mL distilled water and 8 mL concentrated sulfuric acid (H_2SO_4) were successively introduced into a mineralization matras tube. The tube was covered with a steam collector and heated under a hood in a BUCHI (France) digester set progressively from 200 to 400°C. The end of digestion was marked by a limpid coloration of the mineralizate, which was left at room temperature (25°C). Two blank tubes containing all reagents were run simultaneously with the assays.

3.7.2. Distillation

After complete cooling, the mineralizate was transferred to a flask, taking care to rinse the inner wall of the tubes with 80 mL distilled water. Next, 10 mL of 40% NaOH was transferred to the tubes. The mixture was placed in the distillation tank. The extension of the distillation condenser was then immersed in a beaker containing 20 mL boric acid spiked with mixed indicator (methyl red + bromocresol green). Distillation was carried out for 10 min until a violet distillate was obtained.

3.8. Total nitrogen determination

The distillate was then titrated with a 0.1 N hydrochloric acid (HCl) solution in a digital burette. A blank was made with distilled water. The end of titration was marked by a change from violet to green. Trials were carried out in triplicate. The quantity of nitrogen (QN) was expressed in g/100 g of dry matter, calculated according to the formula :

$$QN\ (g/100g) = \frac{14 \times NHCl \times (VA - VB)}{PNet} \times 100 \quad (4)$$

NHCl = normality of HCl equal to 0.1 N ;

VA = volume of HCl solution required for blank titration (mL) ;

VB = volume of HCl solution required for sample titration (mL);

PNet = net weight of sample (g);

PNet = % MS × Sample Fresh Weight (g);

Protein content (PQ) was determined by applying the nitrogen-to-protein conversion coefficient [13] according to the relationship :

$$QP\ (g/100g) = QN \times 6{,}25 \quad (5)$$

3.9. Determination of piperine in fresh and dried pepper extracts

Piperine content was determined using the method described by Hassad [13]. A 0.5 g sample of fresh and dried pepper was weighed and transferred to a round-bottomed flask. Next, 50 mL of ethanol (96% solution) was added. The flask was heated for 3 hours on a PC401 hot plate. The resulting solution was allowed to cool, then filtered through whatman paper into a 100 mL volumetric flask. The extraction flask and filter paper were washed with 10 mL ethanol (96%). The washing liquid was used to make up the solution to the mark. A 5 mL aliquot was taken and made up to volume with ethanol (96%) in a 50 mL volumetric flask. Next, 5 mL of this solution was withdrawn and transferred to another 50 mL volumetric flask and topped up again to the mark with ethanol. The final solution was used to measure absorbance (A) at 343 nm on a spectrophotometer, using ethanol (96%) as the reference liquid. The vials were wrapped in aluminum foil to prevent piperine denaturation. Trials were performed in triplicate. Piperine content (Tp) expressed as a percentage was obtained by the formula :

$$Tp = \frac{A}{Ad} \times \frac{50}{5} \times \frac{50}{5} \times \frac{100}{m} \times \frac{100}{100 - Te} \quad \textbf{(6)}$$

m = test sample mass (g).

Te = water content of sample (%).

A = absorbance at 343 nm of final test solution.

Ad = absorbance at 343 nm of a 1% piperine solution in a cell with an optical path of 1 cm, equal to 1238.

3.10. Principle and processes of essential oil extraction from fresh and dried peppers

The essential oil was extracted by steam distillation using a Clevenger-type device for 3 hours, according to the method described by Cyrille et al [14]. A 100 g mass of each fresh and dried pepper sample was introduced into a pressure cooker (SEB, France) containing 2 L of distilled water and topped with a Clevenger-type device. The whole unit was brought to the boil (350°C) for 3 hours after the first drop appeared. The essential oil is recovered after decanting and drying with magnesium sulfate. Trials were carried out in triplicate.

3.11. Extraction yield of essential oils from fresh and dried peppers

According to the AFNOR standard [15], essential oil yield (EOY) is defined as the ratio between the mass of essential oil (Me) obtained after extraction and the mass of plant material (Mv) used. Trials were carried out in triplicate. It is given by the following formula :

$$R\,(\%) = \frac{Me}{Mv} \times 100 \quad \textbf{(7)}$$

R (%) = yield in %.

Me = mass of essential oil extracted (g).

Mv = mass of plant material used for extraction (g).

3.12. Statistical analysis

The results obtained were processed using STATISTICA version 7.1 software. A probability threshold of less than or equal to 0.05 was chosen for the significance of all data analyses. Data are expressed as mean plus or minus standard deviation. For multiple comparisons, the ANOVA test is used. Means are compared using Duncan's test.

4. Results

4.1. Water content of fresh and dried peppers

The results for the moisture content of fresh and dried pepper grains are shown in figure 2. The highest values for fresh pepper were observed in the localities of Niablé (69.55%), Maféré (66.7%) and Yakassé-Mé (65.07%), while fresh pepper samples collected in the localities of Lopou (60.52%) and Azaguié (60.8%) had relatively low values. Dried pepper samples with the highest water content were collected in Assouba (14.32%), PK 103 (13.68%) and Niablé (13.34%), while the lowest water content was observed in dried pepper samples collected in N'douci (9.68%), Lopou (10.61%), Yakassé-Mé (10.73%) and Danané (11.02%). Overall, the fresh and dried pepper samples with the highest water content came from Niablé (69.55%) and Assouba (14.32%) respectively. However, the lowest water contents were observed in samples collected in the localities of Lopou (60.52%) for fresh pepper and N'douci (9.68%) for dried pepper.

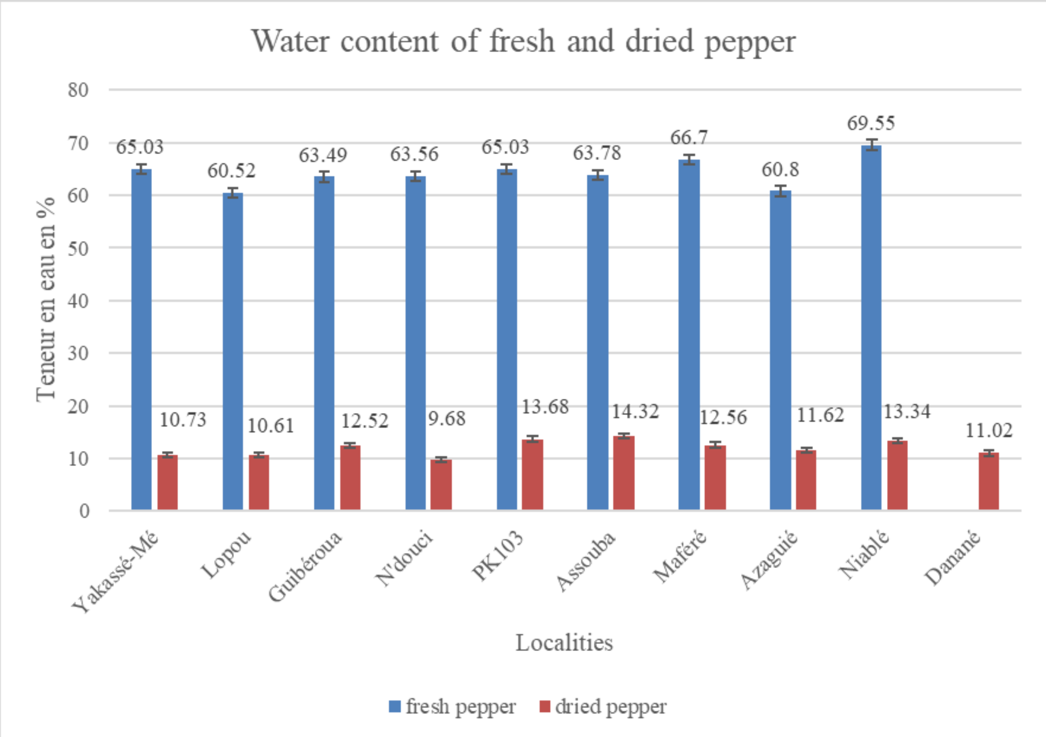

Figure 2 Water content of fresh and dried peppers

4.2. Total sugars in fresh and dried peppers

The total sugar contents of fresh and dried pepper samples collected from the different plantations are listed in Table I. Statistical analysis of the data shows a significant difference between the total sugar contents of fresh and dried peppers ($p < 0.05$). The highest total sugar values were found in fresh pepper samples from Guibéroua (6.44 ± 0.24 mg/100g) and Niablé (6 ± 0.44 mg/100g). Those with the lowest total sugar content were fresh pepper samples from Maféré (3.33 ± 0.5 mg/100g), Yakassé-Mé (3.22 ± 0.5 mg/100g) and Azaguié (3.88 ± 0.3 mg/100g). The dried pepper samples with the highest total sugar contents came from Guibéroua (7 ± 0.5 mg/100g) and Azaguié (7 ± 0.39 mg/100g), while the lowest total sugar contents were obtained with dried peppers sampled in Danané (5.88 ± 0.32 mg/100g).

Table 1 Total sugar content of fresh and dried peppers

Localities	**Total sugars of fresh pepper (mg/100 g)**	**Total sugars of dried pepper (mg/100 g)**
Maféré	$3,33 \pm 0,5^{a}$	$6,22 \pm 0,01^{a}$
Assouba	$3,33 \pm 0,71^{a}$	$6,44 \pm 0,46^{a}$
Guibéroua	$6,44 \pm 0,24^{b}$	$7 \pm 0,5^{c}$

Azaguié	3,88 ± 0,3[a]	7 ± 0,39[c]
Pk 103	3,88 ± 0,78[a]	6,88 ± 0,32[b]
Yakassé-Mé	3,22 ± 0,5[a]	6,88 ± 0,07[b]
Lopou	3,22 ± 0,87[b]	6 ± 0,87[a]
Niablé	6 ± 0,44[b]	6,22 ± 0,13[a]
N'douci	5,88 ± 0,17[b]	6,22 ± 0,32[a]
Danané	-	5,88 ± 0,32[a]

Values in the same column with the same letter are not significantly different from each other according to Duncan's multiple comparison test at the 5% threshold. Values are expressed as mean ± standard deviation (n = 3 determinations).

4.3. Reducing sugars in fresh and dried peppers

The reducing sugar contents of fresh and dried pepper from different localities were recorded in Table II. Statistical analysis of the fresh pepper data showed no significant difference between the reducing sugar contents of fresh pepper (p>0.05). Thus, reducing sugar contents of fresh pepper samples ranged from 2.71 ± 0.33 to 2.86 ± 0.01 mg/100g. Statistical analysis of the dried pepper data shows a significant difference between the reducing sugar contents of dried peppers (p<0.05). Dried pepper samples collected in the Danané locality (3.20 ± 0.5 mg/100g) showed the highest reducing sugar contents. The lowest levels of reducing sugars were found in dried pepper samples from PK 103 (2.71 ± 0.5 mg/100g). All fresh and dried pepper samples showed the highest levels of reducing sugars. These reducing sugar contents were observed with fresh and dried pepper samples collected in the localities of Niablé (2.86 ± 0.5 mg/100g) and Danané (3.20 ± 0.5 mg/100g). However, the lowest levels of reducing sugars were recorded in fresh and dried pepper samples from N'douci (2.71 ± 0.33 mg/100g) and KP 103 (2.71 ± 0.5 mg/100g) respectively.

Table 2 Reducing sugar content of fresh and dried peppers

Localities	**Reducing sugars of fresh pepper (mg/100 g)**	**Reducing sugars of dried pepper (mg/100 g)**
Maféré	2,82 ±0,5[a]	2,76 ± 0,01[a]
Assouba	2,76 ± 0,5[a]	2,76 ± 0,01[a]
Guibéroua	2,76 ± 0,01[a]	2,84 ± 0,5[a]
Azaguié	2,84 ± 0,01[a]	2,82 ± 0,44[a]
Pk 103	2,82 ±0,5[a]	2,71 ± 0,5[a]
Yakassé-Mé	2,84 ± 0,33[a]	2,82 ± 0,5[a]
Lopou	2,86 ± 0,01[a]	2,76 ± 0,5[a]
Niablé	2,86 ± 0,5[a]	2,76 ± 0,5[a]
N'douci	2,71 ± 0,33[a]	3,17 ± 0,5[b]
Danané	-	3,20 ± 0,5[b]

Values in the same column with the same letter are not significantly different from each other according to Duncan's multiple comparison test at the 5% threshold. Values are expressed as mean ± standard deviation (n = 3 determinations).

4.4. Ash content of fresh and dried peppers

The ash contents of fresh and dried pepper samples from the different localities were recorded in Table III. Statistical analysis of the data shows a significant difference between the ash contents of fresh and dried pepper samples (p<0.05). Fresh pepper samples collected in the localities of Lopou (5.58 ± 0.03%) and PK 103 (5.63 ± 0, 02%) showed the highest ash contents, while the lowest ash contents were observed with fresh pepper samples collected in the localities of Maféré (3.54 ± 0.01%), Assouba (3.59 ± 0.01%) and Azaguié (3.59 ± 0.01%). Dried pepper samples with the highest ash content were recorded for PK 103 (5.63 ± 0.01%) and Lopou (5.58 ± 0.03%). Those with the lowest ash content came from Maféré (3.54 ± 0.01%), Azaguié (3.59 ± 0.01%) and Assouba (3.59 ± 0.01%).

Table 3 Ash content of fresh and dried pepper (in % of dry matter)

Localities	Ash content of fresh pepper	Ash content of dried pepper
Maféré	3,54 ± 0,01[a]	3,54 ± 0,01[a]
Assouba	3,59 ± 0,01[a]	3,59 ± 0,01[a]
Guibéroua	4,26 ± 0,05[b]	4,33 ± 0,05[cd]
Azaguié	3,59 ± 0,01[a]	3,59 ± 0,01[a]
Pk 103	5,63 ± 0,02[d]	5,63 ± 0,01[e]
Yakassé-Mé	4,19 ± 0,06[b]	4,19 ± 0,06[bc]
Lopou	5,58 ± 0,03[d]	5,58 ± 0,03[e]
Niablé	4,37 ± 0,01[c]	4,37 ± 0,01[d]
N'douci	4,28 ± 0,05[bc]	4,28 ± 0,05[bc]
Danané		4,05 ± 0,05[b]

Values in the same column with the same letter are not significantly different from each other according to Duncan's multiple comparison test at the 5% threshold. Values are expressed as mean ± standard deviation (n = 3 determinations).

4.5. Fresh and dried pepper proteins

The protein contents of the various samples of fresh and dried peppers taken from the different localities were listed in Table IV. Statistical analysis of the data shows a significant difference between the protein contents of fresh and dried peppers ($p < 0.05$). Table analysis shows that protein contents range from 12.44 ± 0.05 to 14.56 ± 0.01 g/100g dry matter. Fresh pepper samples from Maféré (14.33 ± 0.03 g/100g) and Azaguié (14.33 ± 0.03 g/100g) contained the highest values. Those sampled in Yakassé-Mé (12.44 ± 0.05 g/100g) had the lowest protein content. The highest protein contents were found in dried pepper samples from Niablé (14.55 ± 0.09 g/100g) and Maféré (14.33 ± 0.03 g/100g). Those with the lowest protein content came from Assouba (13 ± 0.01 g/100g).

Table 4 Protein content of fresh and dried peppers (g/100 g dry matter)

Localities	Protein content of fresh pepper	Protein content of dried pepper
Maféré	14,33 ± 0,03[c]	14,33 ± 0,03[c]
Assouba	14,56 ± 0,01[c]	13 ± 0,01[a]
Guibéroua	13 ± 0,01[ab]	14,22 ± 0,03[c]
Azaguié	14,33 ± 0,03[c]	13,55 ± 0,01[ab]
Pk 103	13,77 ± 0,02[bc]	14 ± 0,06[bc]
Yakassé-Mé	12,44 ± 0,05[a]	13,44 ± 0,01[ab]
Lopou	13 ± 0,01[ab]	13,55 ± 0,01[ab]
Niablé	14,11 ± 0,02[c]	14,55 ± 0,09[c]
N'douci	14,33 ± 0,03[c]	13,44 ± 0,01[ab]
Danané	-	13,44 ± 0,01[ab]

Values in the same column with the same letter are not significantly different from each other according to Duncan's multiple comparison test at the 5% threshold. Values are expressed as mean ± standard deviation (n = 3 determinations).

4.6. Piperine from fresh and dried peppers

The piperine contents of fresh and dried pepper samples collected from different localities are presented in Table V. Statistical analysis of the data shows a significant difference between the piperine contents of fresh or dried peppers ($p < 0.05$). The highest piperine values are observed with the fresh pepper samples taken in the locality of Maféré (7.05 ± 0.02 g/100 g) of dry matter while those sampled in Guibéroua (4.61 ± 0.07 g/100 g) and N'douci (4.59 ± 0.16 g/100 g) showed the lowest piperine contents. Dried pepper samples from Maféré (7.36 ± 0.92 g/100 g) and Assouba (6.51 ± 0.05 g/100 g) showed the highest piperine contents compared to dried pepper samples collected from the localities of N'douci (4.48 ± 0.04 g/100 g) and Guibéroua (4.61 ± 0.09 g/100 g) which showed the highest piperine contents.

Table 5 Piperine content of fresh and dried peppers (g/100 g of dry matter)

Localities	Piperine content of fresh pepper	Piperine content of dried pepper
Maféré	7,05 ± 0,02^{c}	7,36 ± 0,92^{c}
Assouba	6,41 ± 0,01^{ab}	6,51 ± 0,05^{ab}
Guibéroua	4,61 ± 0,07^{a}	4,61 ± 0,09^{a}
Azaguié	6,21 ± 0,03^{ab}	6,4 ± 0,06^{ab}
Pk 103	5,64 ± 0,14^{ab}	5,6 ± 0,09^{ab}
Yakassé-Mé	6,33 ± 0,32^{ab}	6,33 ± 0,04^{ab}
Lopou	6,38 ± 0,07^{ab}	6,41 ± 0,08^{ab}
Niablé	4,74 ± 0,02^{a}	4,75 ± 0,03^{a}
N'douci	4,59 ± 0,23^{a}	4,48 ± 0,02^{a}
Danané	-	6,52 ± 0,05^{ab}

Values in the same column with the same letter are not significantly different from each other according to Duncan's multiple comparison test at the 5% threshold. Values are expressed as mean ± standard deviation (n = 3 determinations).

4.7. Essential oils of fresh and dried peppers

The essential oil contents of fresh and dried pepper samples collected from different localities are presented in Table VI. Statistical analysis of the data shows a significant difference between the essential oil contents of fresh and dried pepper ($p < 0.05$). The fresh pepper samples with the highest essential oil contents are those collected from the localities of Maféré (1.93 ± 0.07 mL/100 g) and Azaguié (1.89 ± 0.06 mL/100 g) of dry matter. Those with the lowest essential oil contents come from N'douci (1.6 ± 0.02 mL/100 g), Guibéroua (1.69 ± 0.00 mL/100 g) and Lopou (1.58 ± 0.05 mL/100 g). Dried pepper samples from Maféré (1.93 ± 0.05 mL/100 g) and Azaguié (1.89 ± 0.05 mL/100 g) showed the highest essential oil contents while the lowest essential oil contents were found with dried pepper samples collected from the localities of N'douci (1.6 ± 0.12 mL/100 g), Lopou (1.58 ± 0.05 mL/100 g) and Guibéroua (1.69 ± 0.01 mL/100 g).

Table 6 Essential oil content of fresh and dried peppers (mL/100 g of dry matter)

Localities	Essential oil content of fresh pepper	Essential oil content of dried pepper
N'douci	1,6 ± 0,02^{a}	1,6 ± 0,12^{a}
Guibéroua	1,69 ± 0,01^{ab}	1,69 ± 0,01^{ab}
Niablé	1,74 ± 0,14^{bc}	1,74 ± 0,10^{abc}
Pk 103	1,83 ± 0,05^{cd}	1,83 ± 0,02^{bcd}
Azaguié	1,89 ± 0,06^{cd}	1,89 ± 0,05^{cd}
Yakassé-Mé	1,84 ± 0,12^{cd}	1,84 ± 0,08^{bcd}
Lopou	1,58 ± 0,05^{a}	1,58 ± 0,05^{a}
Assouba	1,84 ± 0,03^{cd}	1,84 ± 0,03^{bcd}
Maféré	1,93 ± 0,07^{e}	1,93 ± 0,05^{d}
Danané	-	1,59 ± 0,002^{a}

Values in the same column with the same letter are not significantly different from each other according to Duncan's multiple comparison test at the 5% threshold. Values are expressed as mean ± standard deviation (n = 3 determinations).

5. Discussion

The moisture contents of fresh pepper samples are lower than those observed by Dhas and Korikanthimath [16] whose moisture contents of fresh pepper samples were between 70 and 80%. These low moisture contents are related to the variety of fresh peppers analyzed. According to the International Pepper Community (IPC) standards, the ideal dried pepper profile should contain a maximum of 13% moisture. Referring to this limit, the water content of samples of dried peppers from Guibéroua (12.52%), Maféré (12.56%), Niablé (13.34%) meet the ideal criterion [17]. The five (5) other samples of dried peppers analyzed (Yakassé-Mé, Azaguié, Danané, Lopou, N'douci) whose water contents do not exceed 12% are both compliant with the standard prescribed by the joint FAO/WHO committee [18] and with the standards set by the European Spices Association [19]. Dried peppercorns with a higher moisture content (> 14%) such as those from Assouba (14.32%) are a priori due to insufficient drying. This could lead to mold attacks and insect infestations in ambient storage conditions given the hygroscopic nature of pepper and its high starch content [20]. A point of honor goes to the N'douci pepper sample which recorded a water content of 9.74%. This water content is consistent with the moisture standards for dried peppers that range from 10 to 12% described by Juliani et al. [21]. This implies that it can be stored in airtight containers for many years without losing its taste and aroma [22]. Regarding the total sugar contents of fresh and dried peppercorns, the maximum total sugar content which is 7 mg/100g of dry matter recorded with the samples of Guibéroua and Azaguié remains clearly lower than those obtained in dried pepper reported by Surthi et al. [23] varying from 41.54 to 57.34 mg/100g of dry matter concerning 11 different localities of origin of the same pepper cultivar. The contents found are very variable (at the threshold of 5%) from one sample to another. Furthermore, the quantities measured ranging from 3.22 to 7 mg/100g of dry matter in the present study remain low compared to those found in the literature which is 67.59 mg/100g in *Piper guineense* from Nigeria [24]. According to Zachariah et al. [25] the total sugar contents vary from 38.6 to 51.2 mg/100g for dried peppercorns of various origins. This variation in the results obtained could be explained by the fact that the total sugar contents vary depending on the harvest locations [26].

The high reducing sugar contents of the fresh and dried pepper samples obtained could be explained by the influence of environmental and agro-climatic factors (soil, temperature and altitude). The results obtained remain consistent with those of Somashekar et al. [27] varying between 2.74 and 9.90 mg/100g for different black pepper genotypes analyzed. However, this study took into account the black pericarp and not the seed which is known to be much richer in non-reducing sugar such as starch. Indeed, it is interesting to note that this starch, mainly located in the perisperm, represents the major element in the composition of black peppercorns with a content of up to 49% of the total weight of the grains [28, 29]. In the same study context, Sruthi et al. [23] reported reducing sugar contents that vary from 0.71 to 4.19 mg/100g in eleven (11) samples of dried peppers of the same variety. While the reducing sugar contents of the local samples analyzed are distributed in a wider range of values, between 2 and 8 ± 1.52 mg/100g.

The ash contents of dried peppers are lower than those reported by Lepengue et al. [30] on *Piper guineense* (14.5%) in the Democratic Republic of Congo. In addition, the ash values of fresh and dried pepper samples collected in the locality of Maféré (3.54 ± 0.01%) are consistent with those of Lepengue et al. [30] in the Democratic Republic of Congo who found an ash content of local wild pepper (*Piper guineense*) which is 3.48% of dry matter. The ash contents are similar to those of Dhas and Korikanthimath [16] who obtained ash contents ranging from 3.6 to 5.7% of dry matter in pepper. According to ESA [19] and Weil et al. [31], the ash contents of fresh and dried pepper should be less than 7%. Overall, the ash contents of fresh and dried pepper are in agreement with the various standards. Proteins are one of the three major families of macronutrients (carbohydrates, lipids and proteins) essential for the functioning and structure of the body. Our results are low compared to those obtained by Lepengue et al. [30] in the Democratic Republic of Congo who found protein contents of 26.04 g/100 g of dry matter in wild pepper (*Piper guineense*). Moreover, these values are lower than those reported by Tchatchambe [32] on Piper umbellatum (30.9 g/100 g dry matter) in Cameroon. The fresh and dried peppers studied contain a low protein content. However, the protein contents of fresh and dried peppers from the different selected localities are close to those of Jayashree et al. [33] who obtained protein values between 9.6 and 14.1 g/100 g dry matter in pepper (*Piper nigrum*). The protein contents of fresh and dried peppers are higher than those of Zachariah et al. [25], who obtained values ranging from 2.1 to 6 g/100 g of dry matter in pepper.

As for the piperine contents, they are close to those of Dhas and Korikanthimath [16], who obtained piperine contents that varied from 1.7 to 7.4 g/100 g of dry matter in pepper (*Piper nigrum*). The piperine contents of the fresh pepper samples collected in N'douci are close to those of Jayashree et al. [33], who found quantities ranging from 2.8 to 4.4 g/100 g of dry matter in pepper (*Piper nigrum*). The piperine contents of fresh and dried pepper samples are similar to the results reported by IPC [17], which states that piperine contents can range from 5 to 8 g/100g dry matter for black pepper and from 5 to 6 g/100g dry matter for white pepper. In addition, the results obtained are higher than those described in the Codex Alimentarius [18], which range from 2 to 3.5 g/100g in black pepper. The piperine contents of fresh and dried pepper samples collected from different localities are higher than those obtained by Zachariah et al.

[25], who found piperine contents of 1.8 to 4.2 g/100g dry matter in pepper (*Piper nigrum*). The essential oil contents of peppers are consistent with those of the European Spice Association [19], which reported essential oil contents of 2 mL/100 g for black pepper and 1.5 mL/100 g for white pepper. In addition, the essential oil contents of fresh and dried pepper samples are similar to those of the ESA [19] in turmeric (1.5 mL/100 g), ginger (1.5 mL/100 g), anise (1 mL/100 g), cumin (1.5 mL/100 g), bay leaf (1 mL/100 g). The essential oil contents of the samples analyzed are close to those of François et al. [34] in Cameroon who found contents of 1.51 mL/100 g in *Piper capense* grains and 1.1 mL/100 g in *Piper nigrum* grains. However, the essential oil contents are higher than those of *Piper umbellatum* grains (0.02 mL/100 g) grown in Cameroon [34]. According to You et al. [35], the essential oil contents of black pepper evaluated in China can vary from 0.6 to 2.6 mL/100 g.

6. Conclusion

The study of the chemical composition of fresh and dried pepper is very important. Samples of fresh and dried pepper from the ten production areas showed significant differences in their chemical compositions. Pepper has very important amounts of total sugars (3.22-7 mg/100g), proteins (13-14.56 g/100g) and reducing sugars (2.71-3.20 mg/100g) for the growth and development of the organism. High ash contents (3.54-5.63%) show a good presence of minerals in fresh and dried pepper. In addition, fresh and dried pepper is very rich in essential oils (1,591.93 ml/100g) and piperine (4.48-7.36 g/100g) which is responsible for the spicy taste of pepper. Fresh and dried peppers have a high protein content as in most dried peppers because peppers in general are potential sources of protein. The majority of piperine contents of fresh and dried peppers are higher and reflect a very spicy taste of the fresh and dried peppers analyzed. Thus, fresh and dried peppers are very important sources of piperine in essential oils.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper

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