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EFFECT OF ROASTING TEMPERATURE AND DURATION ON THE PHYSICO-CHEMICAL AND SENSORY PROPERTIES OF THE COFFEE-GUINEA PEPPER ROASTED BLEND

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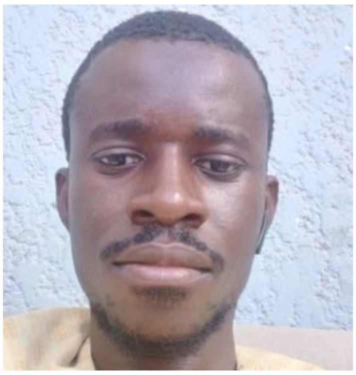

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ABSTRACT

Coffee is one of the most widely consumed products in the world. In Senegal, coffee-Guinea pepper roasted blend is consumed by over 70% of the population, making it the most widely consumed type of coffee. In view of its high consumption, coffee-Guinea pepper roasted blend is increasingly being marketed. The products on the Senegalese market often lack taste and aroma. Although the taste and aroma of the coffee-Guinea pepper roasted blend vary according to the species and origins of the coffee-Guinea pepper, an unmitigated roasting temperature and duration can alter their physico-chemical characteristics. To this end, the study of roasting temperature and duration on the physico-chemical characteristics of the coffee-Guinea pepper roasted blend is becoming an important area of research for all those involved in the sector. The effect of roasting temperature and duration on the physico-chemical characteristics of the coffee-Guinea pepper roasted blend is the subject of this study. To achieve this objective, four most popular samples on the Senegalese market were chosen. They were roasted at temperatures of 211 °C, 215 °C, 216 °C and 220 °C for 28, 25, 30 and 31 min, respectively. Fourier transform infrared spectroscopy (FTIR) in conjunction with energy dispersive spectrometry (EDXRF) were used to characterise the blend. The results showed the presence of more than 15 chemical elements, including nutrients such as calcium, potassium and magnesium, as well as heavy metals at trace levels. The results also show that roasting temperature and duration influence the concentration of these elements. Potentially toxic elements can appear at high temperatures. A relatively long roast at high temperatures leads to a darker coffee with richer, bitter notes. Low temperature and long duration lead to a more balanced blend of coffee-Guinea pepper roasted blend with less bitterness. Moderate temperature and duration result in a lighter coffee-Guinea pepper roasted blend with more subtle aromas. Optimal roasting conditions are determined at 215°C for 25 min, characterised by a balance between bitterness and more subtle notes.

Key words: Characterization, Coffee, Fluorescence, Guinea pepper, Infrared, Roasting, Spectroscopy, Temperature

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INTRODUCTION

Coffee is one of the most popular beverages. It is estimated that 400 billion cups of coffee are consumed worldwide every year, equivalent to around 12,000 cups of coffee per second [1]. In Senegal, the most widely consumed type of coffee is a blend of coffee-Guinea pepper roasted blend and is enjoyed by over 70% of the population [2]. Its characteristic taste and aroma are the result of a combination of chemical compounds produced by heat-induced reactions during roasting [3]. Parameters such as roasting time and temperature have a major impact on the physico-chemical properties of the coffee-Guinea pepper roasted blend.

The chemistry of taste and aroma development during roasting is complex and still poorly understood. However, the study of the effect of roasting time and temperature on the chemical elements (essential, non-essential and potentially toxic) of the coffee-Guinea pepper roasted blend is of considerable importance for its quality, taste and aroma [4]. The physico-chemical characterisation of the coffee-Guinea pepper roasted blend is, therefore, becoming an important area of research for all stakeholders in coffee-Guinea pepper roasted blend sector.

Several studies have been carried out on the characterisation of roasted coffee. Marta *et al.* [5] and Krivan *et al.* [6] used flame atomic absorption spectrometry (FAAS) to characterise roasted coffee in order to determine its chemical elements. The results obtained show the presence of certain elements such as Calcium (Ca), Potassium (K), Magnesium (Mg), Sodium (Na), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Nickel (Ni) and Lead (Pb) Filho *et al.* [7] and Ramato *et al.* [8] used flame atomic emission spectrometry (FAES) to characterise roasted coffee. The results obtained show the potassium and sodium concentrations in roasted coffee. Grembecka *et al.* [9] and Santos *et al.* [10] used inductively coupled plasma optical emission spectrometry (ICP-OES) for the elemental analysis of roasted coffee. The results show that this method is more sensitive and faster than Flame Atomic Absorption Spectrometry (FASS), with lower detection limits and wider linear dynamic ranges. Direct Current Plasma Optical Emission Spectrometry (DCP-OES) is used to determine the presence of aluminium in roasted coffee [11]. Pawel *et al.* [12] used instrumental methods to determine the elemental composition of roasted coffee. They report that FAAS and FAES are generally used to determine trace and minor elements (Al, Co, Cr, Cu, Fe, Ni, Mn and Sr) in roasted coffee. They also state that DCP-OES is rarely used for coffee analysis. Haswell *et al.* [13] applied total reflection X-ray fluorescence spectrometry (TXRFS) to characterise roasted coffee. The results obtained show that TXRFS allows all the chemical elements in coffee to be studied with greater sensitivity and efficiency.

In addition to these methods, which study the chemical elements in roasted coffee, other methods such as mass spectrometry, gas chromatography and sensory instruments deal with the molecular composition of roasted coffee [14]. Niya *et al.* [15] used Fourier Transform Infrared Spectroscopy (FTIR) to study the effects of roasting time and temperature on the molecular composition of roasted coffee. The results obtained show that FTIR is simpler and more effective than the methods used by Rahn *et al.* [14]. Romain *et al.* [16] used FTIR to characterise roasted coffee and found this method to be simpler and more efficient in providing a global spectrum of roasted coffee. Donald *et al.* [17], Véronique *et al.* [18], Habtamu *et al.* [19] and Nadia *et al.* [20] also use this method to study the molecular composition of roasted coffee. Their results confirm the simplicity and effectiveness of FTIR for the molecular analysis of roasted coffee.

There are no known studies on the physico-chemical characterisation of the coffee-Guinea pepper roasted blend. The aim of this study was to determine the optimum roasting temperature and duration of the Guinea pepper-coffee blend using Fourier transform infrared spectroscopy and X-ray fluorescence spectrometry.

MATERIALS AND METHODS

The samples chosen represent the brands most present on the Senegalese market. A visit to the roasting facilities showed that the method used was translational. The master roasters had no standard norms for roasting times or temperatures. Their approach consisted of introducing around 16 kg of coffee beans into the roasting chamber, then manually stirring the roaster while observing the changes in colour of the beans to know when to stop roasting. To improve quality, taste and aroma and to establish the optimum roasting parameters, the temperatures were measured when the coffee beans were introduced and at the end of the roasting process. The roasting time for each sample of the coffee-Guinea pepper roasted blend was taken into account. These samples were named E1, E2, E3 and E4. All the samples had the same proportions (90% coffee beans and 10% Guinea pepper), but were exposed to different temperatures and roasting times, as shown in Table 1. The coffee and Guinea pepper were blended just after the coffee beans were roasted. The heat from the coffee beans leaving the roasting chamber roasts the Guinea peppers by simply stirring the roasted coffee-Guinea pepper mixture until the peppers are roasted. The temperature sensors used are shown in Figure 1.

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Figure 1: **Temperature sensors**

The samples are monitored throughout the roasting process to record temperature and time data as shown in Table 1. Samples of the roasted Guinea pepper-coffee blend are shown in Figure 2.

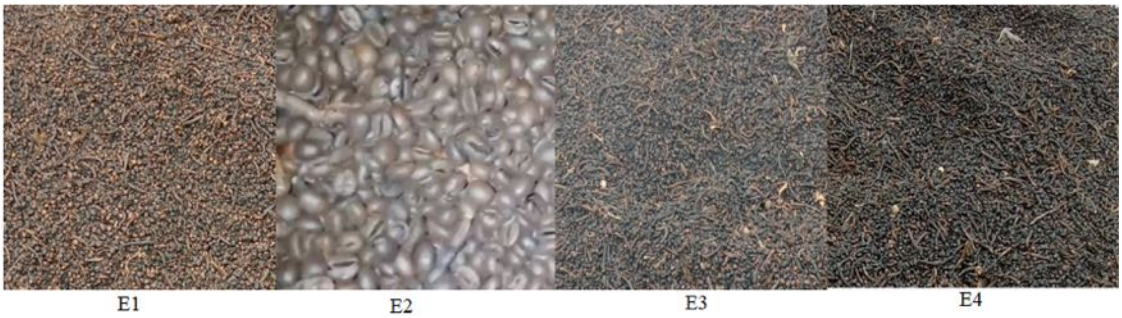

Figure 2: Samples of coffee-Guinea pepper roasted blend

After roasting, the coffee-Guinea pepper blend was ground in a grinding machine to obtain the coffee-Guinea pepper roasted blend powder. X-ray fluorescence spectrometry (EDXRF) and Fourier transform infrared spectroscopy (FTIR) were used.

X-ray fluorescence spectrometry is a global elemental analysis technique that can be used to identify and determine the chemical elements that make up a sample [21]. X-ray fluorescence spectrometry can be divided into wavelength-dispersive X-ray fluorescence spectroscopy (WDXRF) and energy-dispersive X-ray fluorescence spectroscopy (EDXRF). Unlike WDXRF, EDXRF allows the simultaneous detection of all the organic compounds and mineral elements (calcium, potassium, magnesium, iron, zinc and trace elements) present in the coffee-Guinea pepper roasted blend.

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The energy dispersive X-ray spectrometry (EDXRF) method was used in this work. Figure 3 shows the components of the portable X-ray fluorescence spectrometer that was used [22].

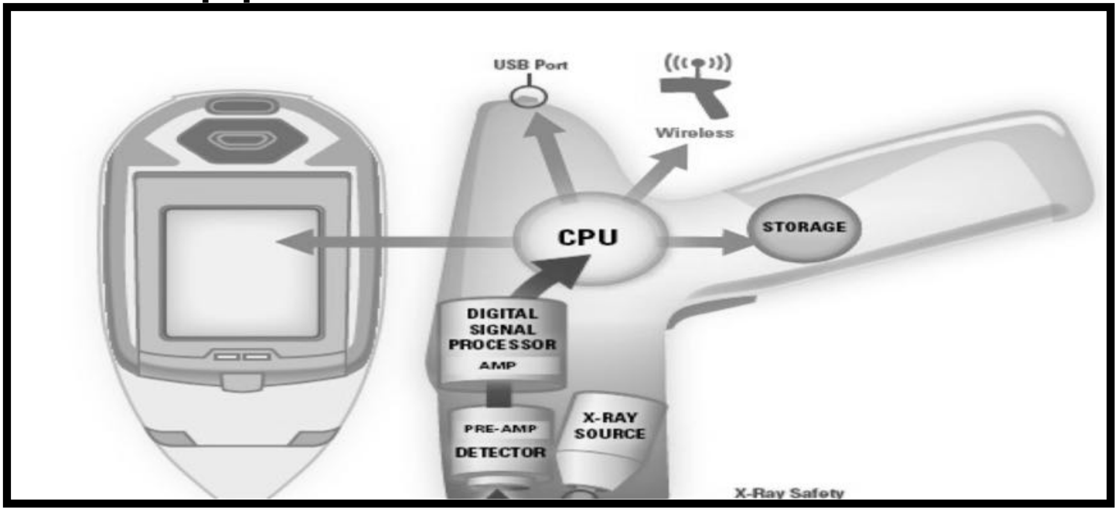

Figure 3: The various components of the "Niton XLT900s" portable X-ray fluorescence spectrometer

Self-absorption corrections between elements that are present in the sample but absent on the spectrum, known as the 'dark matrix', are carried out using the emission and transmission method. The presence of certain potentially toxic elements, such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As), in the coffee-Guinea pepper roasted blend powder led to a focus on the overlap of the cadmium line (Cd-L) with that of potassium (K) in the experimental study. Table 2 shows the specifications and operating conditions of the XLT900s Niton Spectrometer used to refine the excitation of the Cd-L line using silver (Ag) as the excitation source.

Fourier Transform Infrared Spectroscopy (FTIR) enables molecular bonds to be analysed by exposing the sample to a broad spectrum of light. It can also be used to study phenolic compounds (chlorogenic acid), alkaloids such as caffeine, as well as aromatic compounds and terpenes (limonene, sabinene, eucalyptol and caryophyllene) contained in the coffee-Guinea pepper roasted blend. The Perkin Elmer Lambda 365 spectrometer was used without traditional solvents such as KBr or Nujol, providing high-precision results with software that complies with regulations. Both techniques provided crucial information on the composition of the coffee-Guinea pepper roasted blend. Figure 4 shows the Perkin Elmer Lambda 365 brand used.

Figure 4: The Perkin Elmer Lambda 365 brand

The LAMBDA ™ 365 offers both IR and UV-Vis performance. It meets the needs of pharmaceutical laboratories, analytical chemistry laboratories, geneticists and QA/QC production analysts. Table 3 illustrates the specification and operating conditions of the Perkin Lambda 365 spectrometer.

RESULTS AND DISCUSSION

Analysis of the coffee-Guinea pepper roasted blend using X-ray fluorescence spectroscopy revealed the presence of more than 15 chemical elements. The elements listed in Table 4 can be classified into majority elements, minority elements and macroelements.

Temperature and roasting time modified the concentrations of these elements by reducing the moisture content and increasing the relative density of the coffee beans. Analysis of the results shows the presence of heavy metals such as lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) at trace levels. Under the temperature and roasting time conditions, the chemical element S was the most concentrated, followed by P, Cl, Mn, W, Rb and Ti. The presence of mineral elements such as K, P, Mg, S, Ca and Na shows the nutritional and dietary value of the coffee-Guinea pepper roasted blend. It can be interpreted as a substantial source of certain elements that are important for consumers' well-being. This blend is also made up of chemical elements (Ca, Cu, Cr, Fe, K, Mg, Mn, Ni, Sr and Zn) in insufficient quantities (see table 4) to make a significant contribution to nutritional and physiological intake. High roasting temperatures over a long period of time can lead to the presence of certain toxic elements (Al, Cd, Ni, Sb, Sn, Pb) in the coffee-Guinea pepper roasted blend. Chemical elements such as As, Ba, Cd, Ce, Co, Cr,

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Dy, Eu, Gd, Hf, La, Lu, Mo, Ni, Pb, Sb, Sc, Se, Sm, Sr, Ta, Tb, Th, Ti, Tm, U, V and Yb are often not detected in roasted coffees or are present at very low levels. Although ED-XRF spectroscopy is useful for elemental analysis, it has limitations in the detection of light elements, sensitivity for low concentration elements and resolution of complex organic compounds in the coffee-Guinea pepper roasted blend.

Determining the elemental composition of the coffee-Guinea pepper roasted blend is insufficient to fully characterise the chemical interactions between the components of this blend. The infrared spectrum provides information on the molecular composition of the coffee-Guinea pepper roasted blend. Each absorption band in the spectrum is associated with a chemical bond that characterises a molecule. Infrared spectroscopic analysis of the four samples of coffee-Guinea pepper roasted blend showed the infrared spectra illustrated in Figure 5.

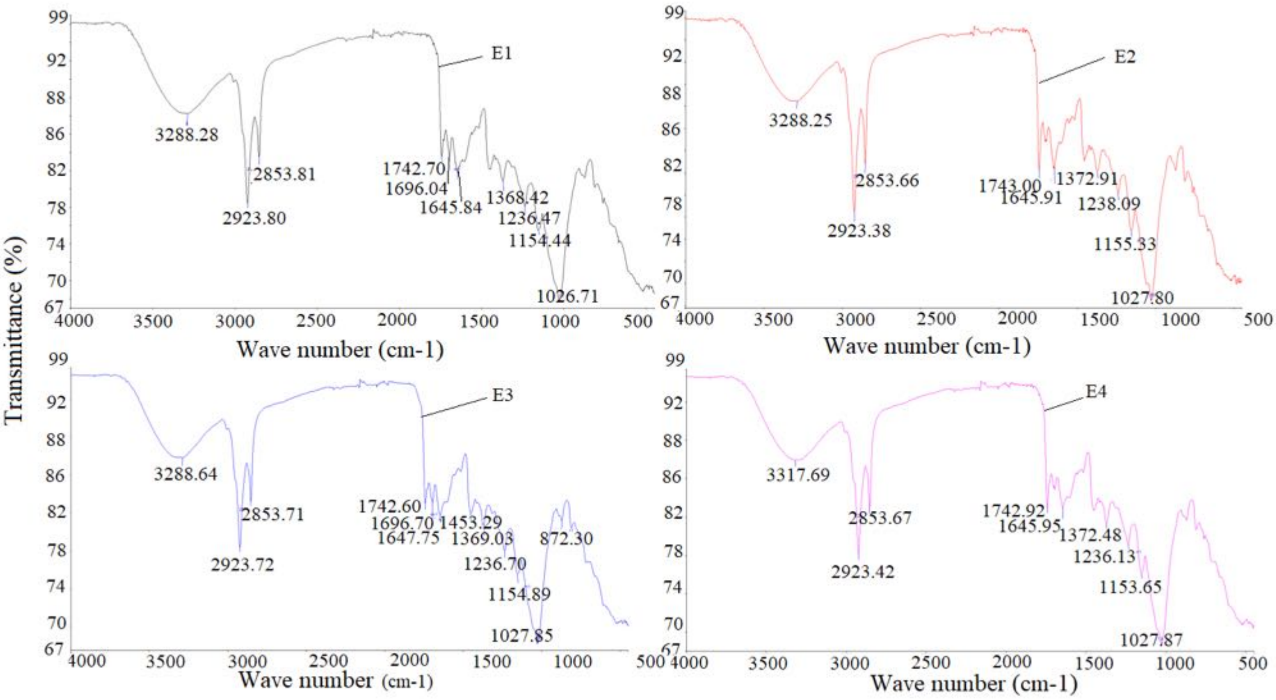

Figure 5: **Infrared spectra of the coffee-Guinea pepper roasted blend**

Analysis and interpretation of the above spectra is based on the position, intensity and shape of the peaks in each sample. The spectra in Figure 5 are identical and show the presence of medium and broad bands at 3288.28, 3288.25, 3288.64 and 3288.28 cm^{-1} from E1, E2, E3 and E4, respectively. These broad bands belong to the infrared region of the vibrations of the hydroxyl group (-OH). These bands may be associated with the presence of O-H bonds in certain molecules. The hydroxyl groups of water molecules can produce absorption bands in the 3288 cm^{-1} region. The presence of water in the mixture could contribute to these bands.

Carbohydrates, such as sugars, contain O-H bonds in their molecular structure. The presence of carbohydrates in coffee may contribute to absorption bands in this region. Certain phenolic compounds in coffee, such as chlorogenic acid, may also contain hydroxyl groups. These compounds can contribute to the bands in the -OH region. Absorption bands in the 2800-3000 cm^{-1} region are associated with vibrations of C-H functional groups in organic molecules. C-H bonds from methyl (CH_3), methylene (CH_2) and methine (CH) groups may be present. Coffee oils often contain fatty acids with characteristic C-H bonds in this region. Certain phenolic compounds, such as chlorogenic acid, can also contribute to these bands. Aromatic compounds present in Guinea pepper may also contain CH bonds that contribute to these bands. The fine bands present at 1743, 1742.60, 1742.92 and 1742.70 cm^{-1} are in the region of carbonyl compounds and illustrate the CO bonds of organic compounds, namely aliphatic esters. Around 1650-1600 cm^{-1}, see vibrations of C=O bonds linked to the chemical structure of chlorogenic acid, a phenolic compound naturally present in coffee, confirming its presence and interaction with other compounds in the coffee-Guinea pepper roasted blend. Carbohydrates, such as sugars, can also contribute to absorption bands in the 1650-1600 cm^{-1} region due to C=O bonds in their structure. Other organic compounds present in coffee and Guinea pepper, such as fatty acids, may also contain C=O bonds and contribute to these bands. The fine bands around 1697 cm^{-1} characterise aromatic acids. These organoleptic compounds play a key role in coffee quality. At 1368.42, 1372.91, 1369.03 and 1372.48 cm^{-1}, we observed peaks indicating a CO bond characteristic of phenol and/or an epoxide structure, aromatic ethers and lactone groups. Peaks at 1026.71, 1027.80, 1927.80 and 1027.87 cm^{-1} are attributed to C-O-C bonds in polysaccharides. The bands present between 1650 and 1500 cm^{-1} can be associated with caffeine, trigonelline and pyridines. The weak bands between 650 and 950 cm^{-1} may characterise the carbohydrates and chlorogenic acids in the coffee. Fourier transform infrared spectra obtained from four samples of the coffee-Guinea pepper roasted blend show identical molecular characteristics, revealing the presence of around ten chemical particles. Higher roasting temperatures accentuate bitterness, while lower temperatures preserve the blend's natural acidity and brighter notes. The molecule responsible for the bitterness of the coffee-Guinea pepper roasted blend is mainly caffeine. The bitterness of Guinea pepper is characterised by the amides, alkaloids and flavonoids present in the pepper.

This experimental study of coffee roasting highlights the importance of roasting temperature and duration and their impact on the sensory characteristics of coffee. A relatively long roasting time with high roasting temperatures leads to a darker coffee with richer, bitter notes. A low temperature and long roasting time results in a more balanced and less bitter coffee-Guinea pepper roasted blend. A moderate

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temperature and roasting time indicate a milder roast, giving a lighter coffee with more subtle aromas. Optimum roasting conditions are 215°C for 25 min.

The spectrum of coffee roasted by Habtamu *et al.* [19] was chosen for the comparative study between the coffee-Guinea pepper roasted blend and roasted coffee alone. Figure 6 shows the infrared spectra of roasted coffee alone and the roasted coffee-Guinea pepper blend.

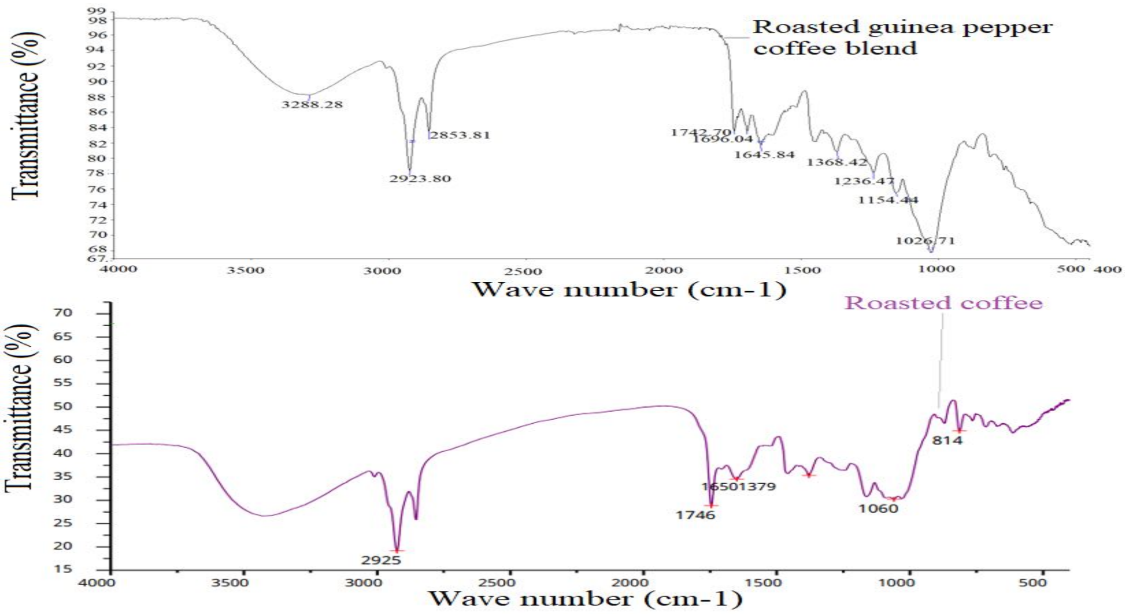

Figure 6: Infrared spectra of coffee-Guinea pepper roasted blend and roasted coffee

For wave numbers between 3500 cm^{-1} and 1746 cm^{-1}, the bands present in the two spectra are identical. This means that their molecular composition is virtually the same in this range. A difference is observed at wave numbers between 1700 and 500 cm^{-1}. The peaks between 1700 and 1154.44 cm^{-1} correspond to the zone of aromatic compounds. They are more intense in the coffee-Guinea pepper roasted blend than in the roasted coffee alone. This is due to the aromatic characteristics of Guinea pepper. The latter is composed of alkylamides, limonene, sabinene, eucalyptol, linalool, caryophyllene and other terpenes in smaller quantities, less than 5%, contributing to the unique aromatic and sensory properties of Guinea pepper. This explains the difference between the two spectra, as well as the sensory and organoleptic characteristics observed between the coffee-Guinea pepper roasted blend and the roasted coffee.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

Consumption of the coffee-Guinea pepper roasted blend has risen sharply in recent years. The taste and aroma of coffee-Guinea pepper roasted blend products on the market are deficient. A study of the effect of roasting temperature and duration on

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the physico-chemical characteristics of these commercial products is necessary to improve the quality, taste and aroma of coffee-Guinea pepper roasted blend. Four of the most popular samples on the Senegalese market were analysed. Fourier transform infrared spectroscopy (FTIR) and energy dispersive spectrometry (EDXRF) were used. The results show that the temperature and duration of roasting influence not only nutrients such as calcium, potassium and magnesium, but also the appearance of toxic elements at high temperatures. Long roasts at high temperatures accentuate bitter notes, while moderate temperatures and roasting times produce a milder, more subtle coffee. The optimum conditions were determined to be 215°C for 25 min, offering a good balance between aroma and bitterness. This could serve as a benchmark for improving the quality, taste and aroma of coffee-Guinea pepper roasted blend.

This work thus opens up interesting prospects for the sector. It directs practices towards a controlled roasting to preserve the organoleptic and nutritional characteristics of the coffee-Guinea pepper roasted blend. It would also be relevant to further research on the concentration of different elements and chemical compounds present in green coffee and unroasted Guinea peppers. In addition, determining the optimal proportion of Guinea peppers in the coffee-Guinea pepper roasted blend would also be of crucial importance.

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Table 1: Roasting temperatures and times

Samples	Initial temperature (°C)	Roasting temperature (°C)	Time (min)
E1	142	211	28
E2	150	215	25
E3	152	216	30
E4	150	220	31

Table 2: Specifications and operating conditions for the XLT900s Niton Spectrometer

Resolution	178 eV at Mn Kα
Window thickness	12.7 µm Be
Excitation tube	50KV, 40 µA maximum power 2 W
Beam diameter	7 mm
Filtres	List of targeted items
Source of Excitement Ag	Sb, Sn, Cd, Pd, Ag, Mo, Nb, Zr, Sr, Rh, Bi, As, Se, Au, Pb, W, Zn, Cu, Re, Ta, Hf, Ni, Co, Fe, Mn, Cr, V, Ti, Th, U
Sandwich from	Al, Ti et Mo, Ba, Sb, Sn, Cd, Pd, Ag
Filtre Cu	Cr, V, Ti, Ca, K
No Filtre	Al, P, Si, Cl, S, Mg

Table 3: Specification and operating conditions of the Perkin Lambda 365 spectrometer

Characteristics	Specifications	Applications
Dual beam, Peak performance, Compact Versatile, Easy to use	21 CFR Part 11 compliant, Interface : Tungsten-halogen and Deuterium. Max. temperature: 35 °C, Min. temperature: 15 °C. Operating range: 400 - 4000 cm-1. Weight: 20.0 kg	Pharmaceuticals, Analytical chemistry, Genetics

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Table 4: Chemical components of the roasted Guinea pepper-coffee blend

Majority chemical elements				
Chemical elements	Concentration (µg/g)			
	E_1	E_2	E_3	E_4
Cl	717.03	14.25	756.98	759.84
Mn	257.84	229.5	245.2	218.68
P	959.16	1100.5	1125.04	959.16
Rb	72.72	76.70	106.48	111.83
S	3226.22	3235.84	3298.28	111.83
Ti	28.65	< LOD	54.12	51.72
W	142.42	178.98	158.11	143.55
Minority chemical elements				
Chemical elements	Concentration (µg/g)			
	E_1	E_2	E_3	E_4
Cu	78.43	77.10	73.85	63.01
Sr	20.99	13.56	17.76	20.96
Zn	78.43	17.30	18.99	16.70
Zr	19.18	17.31	16.30	39.93
Macronutrients				
Chemical elements	Concentration (µg/g)			
	E_1	E_2	E_3	E_4
AS	< LOD	< LOD	1.21	<LOD
Ca	0.51	0.40	0.52	0.57
Cd	5.37	<LOD	4.31	3.31
Fe	0.15	0.04	0.63	0.46
K	5.62	5.17	5.09	4.62
Mo	3.09	2.58	2.13	2.16
Nb	8.66	7.56	7.20	7.12
Pb	8.57	10.22	8.39	7.75
Si	4.51	4.16	4.33	4.42

LOD : Limit of detection

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