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The influence of roasting conditions on volatile flavour compounds in raw and roasted cashew kernels (*Anacadium ocidentale*) grown in Nigeria

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ABSTRACT

The use of inappropriate temperature-time combinations during the roasting of nuts could lead to quality defects, such as burnt taste, short shelf-life, rancidity, and poor flavour. In this study, cashew kernels were roasted in a forced airflow-drying oven for 20, 40, and 60 min at 100, 120, 140, and 160 °C. The products were evaluated for volatile flavour compounds and the sensory evaluation of the roasted cashew kernels at different roasting conditions. The volatile fraction was isolated using the combined steam distillation–extraction procedure and identified by gas chromatography–flame-ionization detection (GC-FID). The consumer acceptability test was carried out by 100 panellists using nine point hedonic scales to assess preferences for like or dislike, colour, taste, texture, flavour, and overall acceptability. It was found that there were significant differences in flavour compounds between the different conditions of roasting. Twenty-nine volatile compounds were identified in both fresh and roasted cashew kernels comprising five main classes, which consist of 12 hydrocarbons, eight aldehydes, four ketones, three alcohols, and one acid. The volatile compounds (mg/100 g) ranged from 5.03×10^{-2} to 1.20 (2-butanone), 7.46×10^{-6} to 1.85 (hexanal), 8.91×10^{-6} to 1.94 (acetone), 6.74×10^{-1} to 2.24 (benzaldehyde). The amount of generated volatile compounds increased as the roasting temperature and time increased. The consumer acceptability test revealed that samples roasted for 40 or 60 min at 140 °C produced the most acceptable product in terms of all the measured attributes. The study showed that the roasting conditions produced acceptable cashew kernels of desirable colour and superior flavour quality that enhance direct and commercial utilization.

Introduction

The cashew plant, *Anacadium occidentale* is native to central and South America, with its main centre of variation in Eastern Brazil. The name cashew is derived from ACAJU, a Portuguese word. It is a member of the genus *Anacadium* of the family *Anacardiaceae*. It contains about 400 species made up of shrubs and trees which are now grown in many parts of the world, where its growth and production is not limited by the cold, over 50% of the annual cashew production of 400,000 tonnes comes from South Asia and East Africa, especially Indians and Tanzania, while West Africa produces small quantities of cashews (Opeke, 2005). The cashew industry ranks third in the world production of edible nuts with products – the raw cashew nut as the main commercial product of the cashew tree, though yields of the cashew apple are eight to ten times the weight of the raw nuts. Raw nuts are either exported or processed prior to export. The primary product of cashew nuts is the kernel, the edible portion of the nut, which is consumed either directly by the consumer, as roasted and salted nuts, in confectionery

or as bakery products, as finely chopped kernels, used in the production of sweets, ice creams, cakes and chocolates, both at home and industrially, and as paste to spread on bread. Also, cashew kernels are consumed as an appetizer to cocktail drinks (Azam-Alli and Judge, 2001). It is estimated that 60% of cashew kernels are consumed in the form of snacks, while the remaining 40% are included in confectionery, breakfast cereals, health food, salads, and baked goods (Nagabhusana and Ravindranath, 1995; Akinwale, 1996; Intermediate Technology Development Group, 2005). The effects of heat treatment on the behaviour of some agricultural materials during handling and processing have been studied by other researchers (Elmastry et al., 2006; Irtwange, 2006; Akinoso et al., 2006). Commercial cashew nut processing is done by drum roasting, oil bath roasting, and steam roasting, which result in cashew kernels, testa, and cashew shell liquid. Processing of raw cashew nuts into kernels involves the heat treatment of the nuts, shelling, peeling, grading, and packaging. Though, several papers have been done on cashew nut shelling and a number of appropriate technologies have been developed (Ajav, 1996; Thivavarnvongs et al., 1995). Roasting is one of the most important processes that provides important product attributes. One of the several objectives of nut roasting is to alter and significantly enhance the flavour, texture, colour, and appearance of the product. Roasting gives nuts a variety of textures and colours, increases their crispness and makes them crunchier (Demir and Cronin, 2004; Özdemir and Devres, 2000; Özdemir et al., 1999; Saklar et al., 2003). As a result of roasting, the moisture level in nuts decreases from the initial value in the range of 4-6% down to 1-3%. Moisture reduction helps to create a desirable crisp texture. Roasting improves the flavour of raw nutmeats from their green taste. If nuts are heavily roasted, the sugars in the cashew nut can decrease, therefore, exposure to high temperatures for longer periods decreases the quality of nuts. Roasting is the most important step in cashew nut processing, the improvement of the roasting process shall contribute to the improvement of processed cashew nut products. The use of inappropriate temperature and time combinations leads to quality defects such as short shelf life, discoloration, rancidity, and poor flavour. Therefore, a more precise determination of roasting conditions (temperature-time combinations) and adhering to the best conditions for roasting would ensure the production of good quality cashew nuts. The effects of the time-temperature profile on cashew aroma properties have not been reported. Currently, integrated studies offer lacking explanations regarding the effects of the roasting degree of cashew nuts under different time-temperature conditions on the physical and chemical properties of cashew nuts. Flavour, as well as the crispy and crunchy texture, are not usually monitored by the industry but are sometimes required by the customers. Since the moisture content is a quality indicator of the roasting process. The aim of this study was to determine the effect of time-temperature conditions on volatile flavour compounds in cashew nuts at different stages of roasting and determine the sensory attributes of roasted cashew nuts at different temperature-time combinations.

Materials and methods

Materials

Freshly harvested and sun dried "Brazilian Jumbo" cashew nuts *(Anacardium occidentale* L.*)* were purchased at maturity from the plantation of the Cocoa Research Institute of Nigeria (CRIN), Ibadan, Nigeria. The dried raw cashew nuts were sorted, and the diseased and immature nuts were discarded and spread on the floor until further processing is required.

Cashew nut processing

Raw cashew nuts were steam boiled using a steam boiler at a pressure of 0.62 MPa for a contact time of 40 min between steam and cashew nuts, using the modified method of Kosoko et al. (2009). The steamed nuts were cooled for 24 h and shelled using a foot-pedalled shelling machine. It makes use of a pair of knives, each shaped into the contour of a half nut. When the knives come together by means of a foot operated lever, they cut through the shell around the nut, leaving the kernel untouched. The kernel was then removed from the shell using a small metal tool resembling a pen knife to remove the kernel from the nuts. The kernels were then pre-dried in a cabinet drier (Model LEEC F2, LEEC Ltd, Colwick, Nottingham), at a temperature of 60 °C for 3 h to allow the easy removal of the peels from the Kernel. The peeled kernels were then packaged in glass bottles for the roasting process.

Roasting process

The cashew kernels were roasted using a convective scale (forced air pilot scale roaster with internal size 450 by 450 by 350 mm (Model-HRDH-71 laboratory oven, temperature precision ±0.1 °C, temperature range 50 to 250 °C, temperature stability of ±0.5 °C, power 1300 W, voltage/frequency of 220 V/50 Hz) at the roasting air temperature of 100, 120, 140, and 160 °C for 20 – 60 min, which represents the range commonly

used in the nut industry. The oven consisted of a heater, a centrifugal fan for generating an air stream, and a drying chamber. Each nut sample was held in a rectangular tray (10 cm by 15 cm), air velocity was kept constant at 1.0 m/s throughout the experiment to avoid affecting the drying rate. Prior to placing the sample in the roasting chamber, the roaster was allowed to run for at least 2 h to obtain the steady state condition. The kernel was placed in the roasting chamber as a single layer in a Pyrex petri dish (8.0 cm diameter). Then, every 20 min for a period of 1 h, one petri-dish was removed from the roasting chamber in less than 10 s so that the steady state conditions could be maintained during sampling. After the completion of roasting, the roasted cashew nuts were cooled to room temperature immediately by blowing ambient air with minimum fan capacity. This was necessary to prevent after cooking and further moisture loss due to the residual heat content.

Determination of volatile organic compounds

Ground roasted cashew nuts (150 g) were placed into a 2 L round-bottom flask containing 1 L of boiling deionized water (pH=5.6) and connected to a combined steam distillation and extraction apparatus. The mixture was heated to boiling in a heating mantle (Electromantle, Stafford, UK). The extraction was allowed to proceed for 1 h using 30 mL of *n*-pentane as the extraction solvent. The extract was neutralized with an aqueous solution of sodium carbonate, dried with anhydrous sodium sulphate, and then gently concentrated by Vigreux-column (PLT Puchong, Malaysia) distillation to 1 mL by heating at 40 °C in a water bath. The concentrated extract was then transferred into glass ampules, sealed, and stored at cold room temperature (5 °C). The volatile components in the extracts were analysed using a Hewlett-Packard 6890 gas chromatograph equipped with a mass selective detector (HP 6890 GC/FID). The gas chromatography (GC) conditions were as follows: detector temperature set at 280 °C; injector 200 °C; column (HP-INNOwax–cross-linked polyethylene glycol, 30 m ¥ 0.32 mm i.d., 0.25 mm, HP-INNOwax, Agilent Technologies, Palo Alto, CA) set at conditions of temperature programming as follows: 50 °C for 5 min and then the temperature was increased to 200 °C for 5 min at 4 °C/min. The temperature was then kept constant at 200 °C for 5 min. The sample (1 mL) was injected into the GC using helium as the carrier gas at the flow rate of 1.3 mL/min. Injections were conducted with a split ratio of 1:20. Fragmentation was performed by electro thermal impact, with ionization voltage at 70 eV and scan mode between 50 and 450 mass units. Quantification was carried out from peak areas of components.

Consumer acceptability test

The employed panellists were members of the university staff, who have no previous experience in sensory evaluation. 100 panellists, 50 males and 50 females, of the age between 20 and 59 participated in the consumer acceptance test. Education levels varied from secondary school to university. The samples were presented to a panellist in a glass jar with a three-digit number. The panellists were provided with water between tests. They were asked for a judgment on how much they like or dislike the colour, flavour, texture, taste, and overall acceptability of the samples. A 9-point hedonic scale was used. All sessions were held in a sensory panel room kept at 22 °C and equipped with partitioned booths and cold white fluorescent lights. The panellists were each provided with 50 mL of water at room temperature to rinse their mouths after each sample. Every treatment was evaluated in three replications. The ratings were given a numerical value from 1 (extremely inferior to R) to 9 (extremely better than R) and 5 (no difference), while R is the reference sample.

Statistical analysis

Data collected from all experiments was in triplicates and the data was expressed as means ± standard deviations. The data was subjected to one-way analysis of variance (ANOVA) and the differences between the treatment means were separated using the Duncan's Multiple Range Test (DMRT) to assess the significant differences between means ($p<0.05$). All statistical procedures were carried out according to the methods of Steel and Torrie (1990), while computation was done using the SAS software package

Results and discussion

Changes in volatile organic compounds in cashew nuts during roasting

Tables 1, 2, and 3 show the volatile organic compounds present in raw and roasted cashew nuts. Twenty-nine (29) volatile organic compounds present in the cashew kernel were identified and they belong to the chemical classes of aldehydes, ketones, alcohols, and aromatic hydrocarbons. Raw cashews have a lower concentration of volatiles than roasted cashews, with the concentration of most volatiles increasing with the increased roasting time. Some of the identified compounds included a compound adding the stale attribute (acetaldehyde) compound with a sweet odour (toluene and styrene), and 2 lipid oxidation compounds (nonanal and octanal).

Table 1. Mean concentration (mg/100 g) of the volatile content of cashew nuts roasted from 100 $^\circ$C to 160 $^\circ$C for 20 min

Peak No.	Name of Compound	Amount (mg/100 g)				
		Control	100 °C	120 °C	140 °C	160 °C
1.	Acetaldehyde	4.70×10^{-2}	4.68×10^{-2}	1.20×10^{-1}	1.82×10^{-1}	2.17×10^{-1}
2.	Methanethiol	9.35×10^{-2}	9.78×10^{-2}	3.71×10^{-1}	2.93×10^{-1}	2.28×10^{-1}
3.	Acetone	8.91×10^{-1}	8.29×10^{-1}	9.81×10^{-1}	9.43×10^{-1}	1.14
4.	Pentane	2.36×10^{-1}	2.45×10^{-1}	7.05×10^{-1}	6.10×10^{-1}	6.40×10^{-3}
5.	2-methyl-pentane	3.67×10^{-2}	4.08×10^{-2}	1.12×10^{-1}	1.21×10^{-1}	1.46×10^{-1}
6.	Ethanoic acid	8.57×10^{-2}	9.30×10^{-2}	2.39×10^{-1}	2.20×10^{-1}	1.43×10^{-1}
7.	2-butanone	5.03×10^{-2}	4.75×10^{-2}	3.17×10^{-1}	2.77×10^{-1}	1.03
8.	Hexane	2.24×10^{-1}	2.30×10^{-1}	4.73×10^{-1}	4.64×10^{-1}	2.34×10^{-1}
9.	3-methylbutanol	1.01×10^{-4}	1.14×10^{-4}	1.02×10^{-4}	1.14×10^{-4}	1.00×10^{-3}
10.	1-heptane	1.40×10^{-1}	1.51×10^{-1}	2.65×10^{-1}	1.77×10^{-1}	2.15×10^{-1}
11.	Heptane	1.441×10^{-1}	1.45×10^{-1}	4.46×10^{-1}	1.07×10^{-1}	5.62×10^{-1}
12.	1-pentanol	1.96×10^{-1}	1.98×10^{-1}	3.18×10^{-1}	1.78×10^{-1}	1.60×10^{-1}
13.	Toluene	1.38×10^{-1}	1.20×10^{-1}	1.25×10^{-1}	1.20×10^{-1}	3.81×10^{-1}
14.	3-hexanone	4.65×10^{-2}	4.23×10^{-2}	$4.28 10^{-2}$	5.36×10^{-2}	2.25×10^{-1}
15.	2-hexanone	1.27×10^{-2}	1.09×10^{-2}	4.25×10^{-2}	4.53×10^{-2}	1.09×10^{-1}
16.	1-octene	1.28×10^{-2}	1.26×10^{-2}	4.44×10^{-2}	3.84×10^{-2}	6.38×10^{-2}
17.	Hexanal	7.46×10^{-1}	8.23×10^{-1}	8.34×10^{-1}	9.23×10^{-1}	1.28
18.	Hexanol	3.76×10^{-3}	3.54×10^{-3}	7.23×10^{-3}	7.09×10^{-3}	3.12×10^{-1}
19.	Nonane	2.87×10^{-6}	2.48×10^{-6}	2.90×10^{-6}	2.04×10^{-6}	1.30×10^{-4}
20.	Styrene	1.35×10^{-3}	1.48×10^{-3}	7.07×10^{-3}	7.35×10^{-3}	1.19×10^{-1}
21.	2-heptanal	1.29×10^{-2}	1.32×10^{-2}	2.44×10^{-2}	2.11×10^{-2}	5.23×10^{-1}
22.	Benzaldehyde	6.94×10^{-1}	7.55×10^{-1}	1.15784	1.03	1.54
23.	Decane	7.69×10^{-2}	8.45×10^{-2}	1.70×10^{-2}	1.52×10^{-2}	3.22×10^{-1}
24.	Octanal	2.33×10^{-2}	2.63×10^{-2}	2.93×10^{-3}	2.64×10^{-3}	1.47×10^{-1}
25.	Benzenemethanol	7.11×10^{-2}	7.78×10^{-2}	1.10×10^{-1}	1.15×10^{-1}	1.09×10^{-1}
26.	Benzeneacetaldehyde	1.29×10^{-2}	1.11×10^{-2}	4.54×10^{-3}	5.00×10^{-3}	7.91×10^{-2}
27.	Nonanal	1.93×10^{-2}	1.70×10^{-2}	5.80×10^{-3}	7.61×10^{-3}	6.31×10^{-2}
28.	Naphthalene	2.83×10^{-2}	2.12×10^{-2}	3.27×10^{-2}	4.24×10^{-2}	3.51×10^{-1}
29	2-methyl-naphthalene	6.74×10^{-7}	5.78×10^{-7}	3.53×10^{-6}	3.48×10^{-6}	4.47×10^{-5}

Eight (8) aldehydes were found in both raw and roasted cashew nuts, and the concentrations of several aldehydes increased significantly upon roasting. Four alcohols were identified in raw and roasted cashew nuts, among those 3-methyl-butanol was the most abundant in roasted cashew nuts. Heptanal (fatty), nonanal (green/floral), and decenal (fried) were found in both the control and the roasted cashew nuts. Four alcohols were identified in raw and roasted cashew nuts, among those 3-methyl-butanol was the most abundant in roasted cashew nuts. Two aromatic hydrocarbons were detected in both raw and roasted cashew nuts: toluene and styrene were found in significantly higher amounts in roasted than in the raw nuts.

Flavour is a key factor in choice and applications, and can be simply thought of as the combination of sense of taste, odour, and mouth feel. Cashew kernel flavour is mainly developed during roasting and it is usually the result of the presence of many volatile and non-volatile components possessing diverse chemical and physicochemical properties within complex matrices. These chemical compounds (volatile and non-volatile) are responsible for the aroma and the bitter taste sensation of sourness, bitterness, and astringency. Factors such as variety harvesting, maturity, curing, and storage conditions have been shown to influence the roasted cashew kernel flavour (Sanders et al., 1989). Non-volatile compounds contribute mainly to the taste, while volatile compounds contribute to or influence both the taste and the aroma. Some of these compounds include alcohol, aldehyde, and esters. Twenty-nine (29) volatile organic compounds present in the cashew kernel were identified using a gas chromatograph with a flame ionization detector belonging to the chemical classes of aldehydes, ketones, alcohols, organic acids, and aromatic hydrocarbons. Raw cashews have a lower concentration of volatiles than roasted cashews, with the concentrations of most volatiles increasing with the increased roasting time. Volatile compounds identified from roasted cashew nuts were primarily derived from the Maillard reaction, lipid oxidation, sugar degradation, and/or their interactions. During cashew kernel roasting, reducing sugar and amino acids react and a cascade reaction takes place, resulting in a browning reaction and the formation of a large number of flavour substances (Weeren and DeRooij, 1998).

Table 2. Mean concentration (mg/100 g) of the volatile content of cashew nuts roasted from 100 °C to 160 °C for 40 min

Peak No.	Name of Compound	Amount (mg/100g)				
		Control	100 °C	120 °C	140 °C	160 °C
1.	Acetaldehyde	4.70×10^{-2}	4.92×10^{-2}	2.21×10^{-1}	1.39×10^{-1}	2.18×10^{-1}
2.	Methanethiol	9.35×10^{-2}	1.03×10^{-1}	2.16×10^{-1}	3.50×10^{-1}	2.09×10^{-1}
3.	Acetone	8.91×10^{-1}	9.03×10^{-1}	8.96×10^{-1}	1.31	1.37
4.	Pentane	2.36×10^{-1}	2.56×10^{-1}	7.36×10^{-3}	6.40×10^{-1}	8.40×10^{-3}
5.	2-methyl-pentane	3.66×10^{-2}	3.32×10^{-2}	1.34×10^{-1}	1.18×10^{-1}	1.41×10^{-1}
6.	Ethanoic acid	8.57×10^{-2}	1.04×10^{-1}	1.36×10^{-1}	2.15×10^{-1}	1.31×10^{-1}
7.	2-butanone	5.03×10^{-2}	4.48×10^{-2}	9.89×10^{-1}	4.17×10^{-1}	9.98×10^{-1}
8.	Hexane	2.24×10^{-1}	2.90×10^{-1}	2.55×10^{-1}	3.99×10^{-1}	2.69×10^{-1}
9.	3-methylbutanol	1.01×10^{-4}	1.261×10^{-4}	1.09×10^{-3}	1.37×10^{-4}	1.21×10^{-3}
10.	1-heptane	1.39×10^{-1}	1.33×10^{-1}	2.12×10^{-1}	2.15×10^{-1}	2.27×10^{-1}
11.	Heptane	1.44×10^{-1}	2.03×10^{-1}	5.10×10^{-1}	3.89×10^{-1}	5.45×10^{-1}
12.	1-pentanol	1.96×10^{-1}	2.09×10^{-1}	1.50×10^{-1}	3.24×10^{-1}	1.70×10^{-1}
13.	Toluene	1.38×10^{-1}	1.40×10^{-1}	3.46×10^{-1}	1.28×10^{-1}	$3.11 \backslash \times 10^{-1}$
14.	3-hexanone	4.65×10^{-2}	4.75×10^{-2}	2.39×10^{-1}	5.71×10^{-2}	2.70×10^{-1}
15.	2-hexanone	1.27×10^{-2}	1.04×10^{-2}	1.31×10^{-1}	4.89×10^{-2}	1.76×10^{-1}
16.	1-octene	1.28×10^{-2}	1.16×10^{-2}	6.83×10^{-2}	3.27×10^{-2}	4.96×10^{-2}
17.	Hexanal	7.46×10^{-1}	7.55×10^{-1}	9.26×10^{-1}	1.25	1.37
18.	Hexanol	3.76×10^{-3}	3.80×10^{-3}	3.22×10^{-1}	7.81×10^{-3}	3.44×10^{-1}
19.	Nonane	2.86×10^{-6}	3.12×10^{-6}	1.33×10^{-4}	2.80×10^{-6}	1.40×10^{-4}
20.	Styrene	1.35×10^{-3}	1.40×10^{-6}	1.06×10^{-1}	9.93×10^{-3}	1.05×10^{-1}
21.	2-heptanal	1.30×10^{-2}	1.30×10^{-2}	4.58×10^{-1}	2.35×10^{-2}	5.19×10^{-1}
22.	Benzaldehyde	6.94×10^{-1}	7.48×10^{-1}	1.18	1.75	1.77
23.	Decane	7.68×10^{-2}	7.20×10^{-2}	3.64×10^{-1}	1.76×10^{-2}	3.47×10^{-1}
24.	Octanal	2.33×10^{-2}	3.02×10^{-2}	1.27×10^{-1}	3.04×10^{-3}	9.87×10^{-2}
25.	Benzenemethanol	7.11×10^{-2}	6.80×10^{-2}	8.10×10^{-2}	1.13×10^{-1}	9.01×10^{-2}
26.	Benzeneacetaldehyde	1.29×10^{-2}	1.11×10^{-2}	6.07×10^{-2}	4.71×10^{-3}	5.94×10^{-2}
27.	Nonanal	1.93×10^{-2}	2.07×10^{-2}	4.34×10^{-1}	5.84×10^{-3}	3.12×10^{-1}
28.	Naphthalene	2.83×10^{-2}	2.66×10^{-2}	3.79×10^{-5}	3.09×10^{-2}	3.35×10^{-5}
29	2-methyl-naphthalene	6.73×10^{-7}	6.72×10^{-7}	3.22×10^{-6}	3.57×10^{-6}	3.62×10^{-6}

After roasting, numerous ketones, aldehydes, alcohols, hydrocarbons, and the acetic acid were found, increasing in concentration, especially at the higher temperature of roasting. Furthermore, the concentration of most carbonyl compounds initially present in cashew nuts increased as a result of the enhanced oxidation due to roasting. The results of this study are in good agreement with Mexis and Kontominas (2009) who opined that the volatile compounds found in cashew kernels increased as the concentration of the irradiation dose increased. Also, Diehl (1995) reported that different irradiation doses produced different kinds and different amounts of compounds during cashew kernel irradiation.

Volatile compounds generated from Maillard reactions are a good indicator of the effectiveness of roasting, as they play an important role in determining the overall flavour, while the by-products of lipid degradation are the indicators for shelf life determination of cashew nuts. All the compounds were produced by the heating process (roasting), which catalyses the reaction between the amino acid and sugar via the Maillard reaction, which is responsible for the development of colour and volatile heterocyclic compounds (Morini and Maga, 1995). Some of the identified compounds include a compound adding the stale attribute (acetaldehyde), compound with a sweet odour (toluene and styrene), and two lipid oxidation compounds (nonanal and octanal). Many of these compounds have been previously reported in peanuts (Johnson et al., 1971; Vercellotti et al., 1992a). Eight (8) aldehydes were found in both raw and roasted cashew nuts and concentrations of several aldehydes increased significantly upon roasting. Many aliphatic aldehydes, such as hexanal and nonanal, and aliphatic hydrocarbons such as nonane are formed from the decomposition of linoleic and oleic acid, and they increased in concentration during roasting. Hexanal and nonane are responsible for green and herbaceous odours in cashew nuts, while nonanal is responsible for a fatty aroma. Hexanal should be present only at low concentrations to improve the aroma and avoid a rancid flavour (Mexis and Kontominas, 2009). Benzene acetaldehyde and ethylbutanoate are responsible for a sweet-fruity and cashew-like aroma (Franco and Janzantti, 2005). The increase in acetaldehyde, benzaldehyde, and benzenacetaldehyde could be directly correlated to the Strecker aldehyde formation pathway during the Maillard reaction (Maarse, 1991).

Table 3. Mean concentration (mg/100 g) of the volatile content of cashew nuts roasted from 100 °C to 160 °C for 60 min

Peak No.	Name of Compound	Amount (mg/100g)				
		Control	100 °C	120 °C	140 °C	160 °C
1.	Acetaldehyde	4.70×10^{-2}	2.732×10^{-1}	2.22×10^{-1}	2.90×10^{-1}	5.35×10^{-1}
2.	Methanethiol	9.35×10^{-2}	2.87×10^{-1}	3.49×10^{-1}	3.05×10^{-1}	1.78×10^{-1}
3.	Acetone	8.91×10^{-1}	1.46	1.53	1.79	1.94
4.	Pentane	2.36×10^{-1}	1.16×10^{-2}	2.17×10^{-1}	6.41×10^{-2}	4.82×10^{-2}
5.	2-methyl-pentane	3.66×10^{-2}	2.94×10^{-1}	2.77×10^{-1}	1.74×10^{-1}	3.03×10^{-1}
6.	Ethanoic acid	8.57×10^{-2}	1.38×10^{-1}	2.77×10^{-1}	1.52×10^{-1}	2.72×10^{-1}
7.	2-butanone	5.03×10^{-2}	4.6×10^{-1}	1.01	1.01	1.20
8.	Hexane	2.24×10^{-1}	2.57×10^{-1}	3.41×10^{-1}	3.56×10^{-1}	3.81×10^{-1}
9.	3-methylbutanol	1.01×10^{-4}	9.52×10^{-4}	1.24×10^{-3}	1.55×10^{-3}	1.65×10^{-3}
10.	1-heptane	1.40×10^{-1}	2.91×10^{-1}	1.14×10^{-1}	2.45×10^{-1}	1.96×10^{-1}
11.	Heptane	1.44×10^{-1}	5.11×10^{-1}	7.83×10^{-1}	5.95×10^{-1}	6.92×10^{-1}
12.	1-pentanol	1.96×10^{-1}	1.49×10^{-1}	1.97×10^{-1}	2.40×10^{-1}	2.99×10^{-1}
13.	Toluene	1.38×10^{-1}	3.53×10^{-1}	4.89×10^{-1}	3.78×10^{-1}	2.93×10^{-1}
14.	3-hexanone	4.65×10^{-2}	2.21×10^{-1}	2.24×10^{-1}	2.15×10^{-1}	1.65×10^{-1}
15.	2-hexanone	1.27×10^{-2}	1.24×10^{-1}	1.11×10^{-1}	1.59×10^{-1}	7.0×10^{-2}
16.	1-octene	1.28×10^{-2}	6.17×10^{-2}	8.98×10^{-2}	1.58	1.69
17.	Hexanal	7.46×10^{-1}	1.55	1.62×10^{-1}	1.85	3.96×10^{-1}
18.	Hexanol	3.76×10^{-3}	3.26×10^{-1}	3.84×10^{-5}	4.40×10^{-1}	1.39×10^{-4}
19.	Nonane	2.86×10^{-6}	1.40×10^{-4}	2.20×10^{-1}	2.12×10^{-4}	1.56×10^{-1}
20.	Styrene	1.35×10^{-3}	1.11×10^{-1}	4.11×10^{-1}	1.06×10^{-1}	4.34×10^{-1}
21.	2-heptanal	1.29×10^{-2}	3.93×10^{-1}	4.57×10^{-1}	2.06	2.47
22.	Benzaldehyde	6.94×10^{-1}	3.64×10^{-1}	4.81×10^{-1}	2.16	2.24
23.	Decane	7.68×10^{-2}	3.25×10^{-1}	1.45×10^{-1}	3.40×10^{-1}	2.09×10^{-1}
24.	Octanal	2.33×10^{-2}	1.44×10^{-1}	1.11×10^{-1}	1.37×10^{-1}	1.68×10^{-1}
25.	Benzenemethanol	7.11×10^{-2}	1.22×10^{-1}	1.50×10^{-1}	1.65×10^{-1}	1.03×10^{-1}
26.	Benzeneacetaldehyde	1.29×10^{-2}	6.74×10^{-2}	7.66×10^{-2}	8.14×10^{-2}	7.48×10^{-2}
27.	Nonanal	1.93×10^{-2}	5.97×10^{-2}	6.54×10^{-1}	6.44×10^{-2}	6.35×10^{-1}
28.	Naphthalene	2.83×10^{-2}	5.10×10^{-1}	6.89×10^{-5}	4.79×10^{-1}	4.78×10^{-5}
29	2-methyl-naphthalene	6.74×10^{-7}	5.24×10^{-5}	4.95×10^{-5}	4.46×10^{-5}	4.46×10^{-5}

These aldehydes are formed from free amino acids such as isoleucine and leucine or valine (Agila and Barninger, 2011). They are responsible for the pleasing odour of many roasted foods (Coleman et al., 1994). Also, acetaldehyde is formed from the reaction of alanine with reducing sugar and is responsible for a pungent aroma in cashew nuts (Maxis and Kontominans, 2009). Acetaldehyde and acetic acid are responsible for the pungent "green" odour and the herbaceous odour impressions can be correlated to hexanal, 1-hexanol, nonane, styrene, and 2-heptenal (Krist et al., 2004). Nonanal and octanal produce a fatty odour, while the unpleasant ethereal odour is derived from 2-butanone and 2-hexanon (Kalua et al., 2007; Krist et al., 2004). By measuring the important volatile compounds in cashew nuts, one can establish how variable roasting parameters affect roasted cashew flavour. Cashew nut roasting could be optimized for roasted cashew nut flavour by measuring the volatile compounds present in finished products. Cashew nuts are mainly composed of lipids, proteins, and sugars. These chemical elements can participate in chemical reactions to form new compounds. Cashew nuts have high contents of oleic and linoleic acids, which

oxidize and decompose into hexanal or octanal (Shahidi, 2001), which is supported by the results. Lipid oxidation compounds, such as heptanal (fatty), nonanal (green/floral), and decenal (fried), were found in both, the control and the roasted cashew nuts. Products such as nonanal and decanal are formed from monohydroperpxide precursors during linoleate oxidation (Min and Smouse, 1989). While some of these compounds, such as heptanal, are associated with cardboard or rancid off-flavour (Warner et al., 1996), other lipid oxidation compounds, such as hexanal, were the major volatile compounds formed in almonds, Brazil nuts, pecans, pine nuts, macadamia nuts, and pistachio nuts by lipid oxidation, while propanal was the highest in walnuts, and 2,4-decadienal has been documented in good quality peanuts (Vercellotti et al., 1992b). These findings agree with the results of others, including Pino et al., (2009) and Alasalvar et al., (2003). Morini and Maga (1995) studied volatile compounds in roasted and boiled Chinese chestnuts and also concluded that heating processes induce Maillard reactions based on amino acids and sugars as substrates. This process is accompanied by colour development. Many of these compounds have been

previously reported in peanuts (Vercellotti et al., 1992a). Four alcohols were identified in raw and roasted cashew nuts and among those 3-methylbutanol was the most abundant in roasted cashew nuts. This compound was previously reported in roasted hazelnuts (Alasalvar et al., 2003) and may impart a dark chocolate and sweet odour (Hansen et al., 2000; Back and Cadwallader, 1997; Alasalvar et al., 2003). The majority of the other alcohols detected may be formed by the decomposition of hydroperoxides of fatty acids, or by the reduction of aldehydes (Tarichotikul and Hsieh, 1991). Two aromatic hydrocarbons were detected in both raw and roasted cashew nuts: toluene and styrene were found in significantly higher amounts in roasted than in raw and roasted hazelnuts by previous researchers (Wickland et al., 2001; Alasalvar et al., 2003). Watanabe and Sato (1971) reported the formation of various alkyl-benzenes, including 1,2,4-trimethyl-benzene and 1,2,3-trimethyl-benzene, from beef fat during heating. These two compounds contributed a naphthalene-like note in roasted beef fat. In raw cashew nuts, acetone was the highest in concentration among the organic volatiles. Ethanoic acid contributes to a pungent aroma (Mexis and Kontominans, 2009) and its concentration was lower. Also, acids strongly contribute to the pungent aroma in cashew apples to which the cashew nut is attached (Maarse, 1991). Alcohol does not contribute to the aroma; however, it contributes to the formation of esters that usually have a fruity odour (Vitova et al., 2007). Only a few volatiles significantly decreased; 3-methylbutanol and toluene decreased significantly during roasting as the roasting time increased. This study is in agreement with the study by Agila and Barringer (2011), who also stated that toluene decreased during the roasting of cashew nuts of different geographical origin. 1-heptene is responsible for a fatty aroma in many lipid foods (Brewer, 2009) and toluene is responsible for a green fatty and laval odour (Clark and Nursten, 1976), while ethanol does contribute significantly to the aroma (Vitova et al., 2007). Acetone has the highest concentration, which is as the result of the reaction of D-xylose with valine; other acids were formed in the early stages of the Maillard reaction between glycine and D-xylose (Davidek et al., 2008). Also, the acids could be formed from the decomposition of oleic acid, and ketones are formed from the decomposition of linoleic acid (Mexis and Kontominans, 2009). Most Maillard reaction volatiles were at higher concentrations than the lipid decomposition and sugar degradation volatiles. Based on the level and the types of characterized volatiles, the Maillard reaction contributed the most of the volatile formations in the studied cashew kernels. Similarly, an increase in the concentration of alkanes could be explained by the oxidation and decomposition of both oleic and linoleic acid (Frankel, 1982). Methanethiol was also found after roasting, cashew nuts contain 1.3% of methionine (Bhattacharjee et al., 2003b) which oxidizes during roasting to produce Methanothiol (Finkelstein and Benevenga, 1986). Methanothiol is responsible for the off-flavour of cabbage and broccoli (Chin and Lindsay, 1993).

Consumer acceptance test of roasted cashew nuts

The mean hedonic scores of the sensory properties of roasted cashew kernels are summarized in Table 4. The mean scores for colour ranged from 1.62 to 8.466, flavour attributes had a mean score ranging from 1.11 to 8.36, while texture, taste, and acceptability were between 1.26 to 8.68, 1.02 to 8.80 and 1.02 to 8.83, respectively. Acceptability had the highest rating among the sensory attributes examined. Analysis of the results using ANOVA indicated that there was a significant difference at $p \leq 0.05$ between samples in terms of colour, flavour, texture, and overall acceptability. Cashew kernels roasted at 120 °C for 20, 40, and 60 min, and samples roasted at 160 °C for 60 min obtained significantly lower colour, flavour, texture, and overall acceptability than others, indicating a dislike of texture. Texture of the samples roasted at 140 °C for 60 min was among the highest scores, which indicated a very liked texture. But the texture of samples roasted at 120 °C for 20 min was among the lowest scores.

Therefore, the consumers preferred samples roasted at 140 °C for 60 min and the commercial sample during the overall evaluation. While consumers preferred samples roasted at 160 °C for 20 min, 140 °C for 60 min, 140 °C for 40 min; and 140 °C for 20 min during texture evaluation. Samples roasted at 160 °C for 60 min (excluding flavour and taste); at 160 °C for 40 min (excluding flavour and texture); and 160 °C for 20 min (excluding taste, and texture) were in the category of neither liked nor disliked, having a mean score of 5.98 to 8.43. Colour, flavour, texture and overall acceptability scores of samples roasted at 120 °C for 20, 40, and 60 min were below 5, which indicates a dislike for the category. Sensory evaluation is the expression of an individual's like or dislike of a product, as a result of biological variations in people, and what people perceive as appropriate sensory properties (Pautus, 1988). Consumer evaluation involves testing certain products using untrained people who are or will become the ultimate users of the product. Consumer testing is necessary throughout the various stages of the product cycle, including the development of the product itself, product maintenance, product improvement and optimization, and assessment of market potential (Resurreccion, 1998).

Table 4. Mean sensory scores for roasted cashew kernels

Samples	COLOUR	FLAVOUR	TASTE	TEXTURE	ACCEPTABILITY
Control	7.92±0.52[e]	7.78±0.55[de]	8.6±1.02[e]	8.68±0.33[f]	8.81±0.25[g]
160 °C 60min	6.62±0.67[cd]	6.60±0.76[d]	5.98±0.14[c]	6.66±0.78[cd]	6.40±0.93[cd]
160 °C 40min	6.95±0.41[cd]	6.93±0.35[d]	6.93±0.35[cd]	7.72±0.63[e]	6.94±0.28[de]
160°C 20min	8.07±0.53[ef]	7.62±0.79[de]	8.04±0.17[e]	7.76±0.51[e]	8.43±0.65[fg]
140 °C 60min	8.46±0.54[f]	8.36±0.48[e]	8.80±0.40[e]	8.68±0.49[f]	8.83±0.38[g]
140 °C 40min	6.70±1.41[cd]	6.30±0.10[d]	7.66±0.75[cd]	7.23±0.97[e]	7.64±0.52[ef]
140 °C 20min	5.66±0.61[c]	5.41±0.83[c]	5.46±1.08[c]	5.41±0.69[c]	5.40±0.10[c]
120 °C 60min	2.96±0.34[b]	3.20±0.47[b]	3.03±0.88[b]	3.32±0.85[b]	3.48±0.54[b]
120 °C 40min	2.41±0.68[b]	3.04±0.56[b]	2.85±0.70[b]	2.91±1.14[b]	3.09±0.85[b]
120 °C 20min	1.62±0.49[a]	1.11±0.31[a]	1.02±0.14[a]	1.26±0.44[a]	1.02±0.14[a]

Values in the same column with different lower-case letters (a-g) are significantly different at $p<0.05$

In this study, the consumer test was conducted to detect differences between products. The analysis of the results using ANOVA indicated that there were significant differences at $p<0.05$ between samples in terms of colour, aroma, flavour, texture, taste, and overall acceptability. Among the 10 different treatments, samples roasted at 160 °C, 60 min (very dark roasted) and 120 °C, 60; 120 °C, 40 and 120 °C, 20 min (very light roasted) had the lowest mean ratings for colour, aroma, texture, taste, and overall acceptability, which were lower than either like or dislike. The texture of samples roasted at 140 °C for 60 min had one of the highest scores, indicating a very liked texture. But the texture of samples roasted at 120 °C for 20 min had one of the lowest scores, indicating a disliked texture. The reasons for not liking the samples were attributed to its uncooked, low aroma and hard texture. The reason for not liking the samples roasted at 160 °C for 60 min was stated to be its burnt flavour. Therefore, the consumers preferred samples roasted at 140 °C for 60 min and 140 °C for 40 min during the overall acceptability evaluation. Saklar (1999) also stated that samples roasted at 125 °C for 15 min and samples roasted at 165 °C for 25 min obtained the lowest scores and were in the dislike category. He also opined that samples roasted at 145 °C for 28 min and 165 °C for 25 min obtained the highest scores for roasted hazelnuts. The result showed that very dark and very light roasted samples were found to be unacceptable to consumers, these correspond to 160 °C, 60 min and 120 °C, 60 min, 120 °C, 40 min and 120 °C, 20 min process conditions, respectively. Samples roasted at 140 °C, 60 min and 140 °C, 40 min produced the most acceptable products. The increased roasted cashew nutty aromatic scores coupled with the increased taste scores collectively suggest that the low temperature/long time roasting negatively impacts the overall cashew nut flavour, while the high temperature/short time roasting has the potential to positively impact the cashew nut flavour. The samples that were most associated with bitter and total off-notes were the 160 ºC dark roast, which had roasting times of 40 and 60 min respectively, which were the two longest roasting times of all 13 treatments. Longer roasting times at the same temperature have been associated with the formation of hexanal, which have been associated with negative sensory attributes in high concentrations, including bitter and dark roast (Smyth et al., 1998). Therefore, the longer roasting time of 160 ºC for 60 min (dark roast) was thought to contribute to the negative flavour attributes associated with these samples.

Conclusion

The study also showed that the flavour generation in roasted cashew kernels was significantly ($p<0.05$) influenced by the main effect of the roasting temperature and time, which increased as the roasting temperature and time increased. Furthermore, the Maillard reaction contributed to the formation of most of the volatiles in cashews, which can be used to determine the best roasting time for the cashews. The knowledge about flavour compounds may assist manufacturers in food formulation, flavour and fragrance development, and other potential applications. The findings have further explored the relative balance of many volatile active compounds present in cashews, which have not been documented for Nigerian cashews. The identification of the compounds responsible for the flavour of cashews could enable better quality control and may aid in the adoption of alternative roasting conditions in cashew processing. The use of hot air drying in the process of roasting cashew nuts reduces processing time and leads to a cashew nut product with better flavour and uniform colour. This study clearly demonstrated the significant effect of roasting on the typical volatile flavour formation of cashew nuts. These volatiles profile can be used to determine the best roasting

time for cashews. The results are valuable as scientific guidance for the roasting process that can better satisfy the demand for cashew nuts with better flavour. The study further showed that the sensory quality of the cashew kernel increased with the roasting temperature and time up to 140 °C and up to 60 min respectively. The results of the consumer acceptability test showed that the samples roasted at 140 °C, 60 min and 40 min produced the most acceptable products in terms of all the measured attributes, and also produced acceptable cashew kernels and paste of desirable colour and superior flavour quality with short processing time that will be very useful for direct and commercial consumption.

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