Chapter

Organoleptic, Sensory and Biochemical Traits of Arabica Coffee and Their Arabusta Hybrids

Kahiu Ngugi, Jane Jerono Cheserek and Chrispine Ogutu Omondi

Abstract

Coffee as a cash crop, reduces food insecurity by providing regular incomes and is a major foreign exchange earner in more than fifty tropical countries where it is grown either as Arabica (*Coffea arabica*) or Robust (*Coffea canepora*). In Kenya which grow some Robusta but mostly Arabica coffee, the production has been declining, mainly because world coffee prices have plummeted to about 5 USD for a 650Kg of un-hulled beans per acre. The only way world prices are likely to increase and benefit the small-scale farmers, is by improving the cup quality and enabling these countries to sell their coffee in specialty markets. This review, underscores the importance of analyzing and estimating organoleptic, sensory and biochemical compounds diversity in Arabica coffee, since these are the factors that determine cup quality. In an attempt to do so, the chapter presents experimental data that analyzed various sensory and organoleptic traits of Arabica coffee and their Arabusta hybrids that proves that tremendous genetic diversity exists in coffee genotypes grown in Kenya and it is possible to utilize this genetic variation to improve cup quality.

Keywords: Arabica coffee, Arabusta hybrids, biochemical traits, cup quality, genetic diversity

1. Introduction

1.1 Arabica coffee production in Kenya

Coffee is an export oriented crop that contributes significantly to the economic growth of 80 developing countries of the world. Approximately, 125 million people in 50 developing countries of Africa, Latin America and Asia produce and sell coffee as their main source of income [1]. *Coffea canephora* Pierre ex A. Froehner or Robusta coffee, makes 30% of the world's commercial coffee and 80% of the production in Africa, with Uganda being among one of the top most producers [2]. Globally, coffee fetches more than $ 79 billion US dollars in the world markets [3] and in Ethiopia, when the genetic value of resistance to diseases, pests, high yield and low caffeine is considered, that value rises to between US $420 - $1.45 billion [2]. Arabica coffee constitutes 70% whereas Robusta, contributes 30% of the total world product and export [2].

Arabica coffee or *Coffea arabica*, earns Kenya, US$230 million, and is the most important export commodity after horticulture, tourism and tea. Kenya has some

of the best quality Arabica coffees globally, but the production has declined from 130,000 metric tons in 1988 to about 45 metric tons, at present [4].

Being a tropical crop, *Coffea* requires specific environmental conditions for commercial cultivation. The quality of developing bean from flowering to ripening is influenced by altitude, latitude, temperature, rainfall, soil, sunlight, wind and humidity [5–7]. Arabica coffee grows at altitude ranges of 1200–1800 meters above sea level (masl) rainfall amounts range between 400 and 600 mm per season though it is also cultivated at 400 m above sea level as long as there is no frost. Robusta coffee cultivation on the other hand is mostly grown at lower altitudes, between sea-level till to an altitude that limits its vegetative growth.

Compared to Arabica, Robusta coffee has smaller bean sizes, poor flavour and high bitterness content but is tolerant to coffee leaf rust disease, has resistance to white stem borer but is susceptible to drought stress [8, 9]. Due its poorer quality characteristics, Robusta coffee global market value is lower than that of *C. Arabica*.

1.2 Coffee origin and diversity

The genus *Coffea* L has over 105 species, prevalently found in Africa and Madagascar [9, 10]. *Coff*ea belongs to the genus of the Rubiaceae family, is indigenous to Africa and is widely distributed in the tropics [11]. The centres of origin of Arabica coffee are the mountainous rain forests of Ethiopia, the western and eastern slopes of the Great Rift Valley and the Boma plateau of the Sudan. Wild species of *C. canephor* are found in Guinea, Uganda, Sudan, Northern Cameroon Southern Angola and in the Congo forests [11–13]. *Coffea liberica* Bull. Ex. Hiern, known for its resistance to diseases, insect pests, adaption to low elevation, is native to the tropical forests of Liberia and Cote de Ivoire [14] whereas *Coffea mascara* characterized by low levels absence of caffeine is found in the forests of Madagascar Mauritius and Reunion [11–13].

The diverse existence of the genus *Coffea* in Uganda, with species such as *C. eugenioides* S. Moore, *C. excelsa* Chev and *C. spathicalyx* K. Schum., suggests that the country is the centre of origin [11, 13]. Whereas three of the genus *Coffea* species are economically important, coffee production and its industry depend on two species only; Arabica and Robusta coffee [15, 16]. The third important species of coffee, *Coffea liberica* is produced mainly in Liberia, Java, Malaysia and the Philippines but because of its low yield and poorer quality, it is used only for local consumption. With advanced breeding techniques, commercial interspecific hybrids such as Arabusta (*C. arabica* x *C. canephora*) have been developed. Blending coffees from the two species at varying ratios probably produces the preferred consumer flavours at lower costs [17]. With the exception of *C. arabica* that is tetraploid and self-fertile (2n = 4x = 44), all the other species in the genus *Coffea* are diploid (2n = 2x = 22), with gametophytic self incompatibility and therefore there exists gene flow between them and the cultivated *C. canephora* [18]. Given its allopolyploidy and self-pollinating nature, *C. arabica* is characterized by low genetic diversity leading to a narrow genetic base [1].

1.3 Objectives in coffee improvement programs

Since the quality of coffee is the key determinant of prices in the world markets, genetic improvement of Robusta coffee organoleptic cup characteristics, yield and caffeine is being undertaken by many researchers throughout the world in an attempt to match Arabica coffee characteristics in order to stabilize and sustain development in the coffee growing areas [17]. Promoting coffee liquor quality would add value, enhance income and increase the competitiveness of the world coffee prices. To sustain value, most coffee improvement programs are aiming to select and breed for cultivars with genetically superior organoleptic cup quality and

are using modern, molecular marker tools such as SSRs, SNPS in combination with, physiological and biochemical green bean tools [17]. In the same manner, the influence of environmental factors such as soil texture, nutrient element composition, altitude, rainfall, temperature that directly or indirectly contribute to coffee quality is given priority and is determined alongside genetic traits [19, 20].

2. Factors that influence coffee quality

Coffee quality is influenced by factors such as the genetics, handling procedures, ecological conditions and agricultural practices. According to the International Organization for Standardization (ISO) quality is "the ability of a set of inherent characteristics of a product, system or process to fulfill requirement of customers and other interested parties" [21]. Depending on the actors in the value chain coffee quality could refer to, the variety, price of coffee, the consuming culture, tonnage or on bean physical characters and biochemical compounds in the green bean. It is the effect of cup quality that determine commercial coffee grade and not the bean size.

2.1 Organoleptic cup quality

Coffee bean physical appearance is an integral indicator of cup quality, but it is the assessment by consumers through their human sensory organs and consumption habits that determine the final quality [17]. The most important attributes are; fragrance, aroma, flavour, bitterness, sweetness, saltness, acidity, mouth feel, aftertaste and cup balance. Fragrance originates from the smell of roasted or ground beans whereas aroma emanates during brewing with boiled water. Aroma helps evaluate flavour and coffee liquor brightness [22]. Flavour is described as an individual person feeling of appreciation during the tasting of the coffee brew taste, which does also include aroma. Fat stabilizes flavour compounds formed during roasting [18, 22, 23]. The undesirable coffee bitter taste in the mouth is positively correlated with the total dissolved coffee solids. High levels of saltiness and undesirable aroma are associated with high levels of potassium in Robusta coffee. Coffee brew taste is less preferred by consumers when potassium and caffeine are at lower levels [24]. Coffee medium roast has less soluble solids, a higher acid content, and more stringent aroma compared to the dark roast [25]. Roasted beans that are less bitter but have a high sweet taste is rated high by many consumers.

Acidity is regarded as the sharp and pleasing sweet to fruity/citrus taste close to the dry taste experienced on the back sides of the tongue while drinking red wine. Perceived acidity in coffee does not necessarily correlate with coffee pH, but is a result of the acids such as aliphatic, chlorogenic, alicyclic carboxylic and phenolic acids that are developed during medium and dark roasted stages. Cup acidity is influenced by high concentrations of citric acid, malic acid, and acetic acid and low concentrations of phosphorus and potassium. Acidity is thought to be influenced by phosphoric acid levels,though it may not directly correlate with perceived acidity [26]. Mouth-feel or liquor body is determined by micro fine fiber and fat content. Liquor weight is caused by micro fine fiber particles whereas texture is derived from oils extracted from ground coffee suspended in the brew. Brew colloids are formed when oils coagulate around fibers suspended in the brew. Coffee weight and texture (slipperiness) in the tongue is compared to pure water and is determined by the micro fine fiber and fat content [27]. Viscosity is caused by proteins and fibers in the brew and is normally denser in medium roasted and dark coffees than in lighter roasted beans (http://www.coffeeresearch.org/science/news.htm) [24].

Taste is normally perceived as the feeling in the mouth after sipping the beverage whereas aftertaste is perceived as the lingering remnant sensation experienced at the back of the throat after swallowing but often changes over time [24]. In a balanced cup, a complementary synergistic combination of flavor, aftertaste, mouth feel and bitter/sweet aspect ratio occurs when the four attributes are in equal intensities [24].

Soft, pleasing and delicate taste derived from acidity and sweet coffee is obtained from fruit acids, high sugars levels and chlorogenic acids (http://www.ico.org/vocab.asp) [28].

There are four major reactions that determine to a great extent of the aroma of roasted beans. Firstly is the Maillard reaction that occurs between nitrogen containing substances such as amino acids, proteins, trigonelline and serotonine with carbohydrates such as sugars. Degradation of individual amino acids, particularly sulphur amino acids, hydroxy-amino acids and praline is the second reaction. Thirdly, sucrose degrades to aliphatic acids compounds and caramel- like substances that contribute to flavour either as volatile aroma compounds, or non-volatile taste compounds [29–31]. The fourth reaction is the degradation of phenolic acids especially the quinic acid moiety.

Roast bean fat has been shown to be positively significantly correlated with aroma, body, acidity, flavor, aromatic intensity and quality, overall judgment and preference [18, 19, 23, 32, 33]. Higher bean yields produced under favourable environmental conditions have reduced acidity. Caffeine content has been found to be negatively, significantly correlated with cup quality attributes although, [34, 35] reported positive correlation coefficients between preference and acidity and aroma in Robusta coffee hybrids and in commercial clones.

Specialty coffee markets demand distinctive cup attributes such as homogeneity, regularity and reliability. Organoleptic cup attributes have to be stable, for the roaster and the consumer [17]. Evaluation of organoleptic cup attributes and other quality parameters using various scientific methods reveal varietal differences and similarities in genetic traits. Genotypic as well as environmental effects influence cup quality that is determined further by the way cherries and beans are picked, shipped and roasted [36]. Varying cup differences that result from genotypic differences contribute greatly to market value, as is the case for Central America consumers who prefer traditional cultivars (Bourbon, Caturra, Catuai, Pacamara) to newer cultivars derived from the 'Hybrid of Timor' hybridization. In Uganda, where *C. canephora* has evolved over years and traditionally cultivated as a culture, farmers and buyers have been less inclined to consume products of Arabusta hybrids selected on quality and other desirable agronomic traits even when they have resistance to the coffee wilt disease. Genotypes show different cup qualities under different environments. For instance, Blue Mountain genotype, has superior liquor quality when grown under Latin American farmer conditions than when grown by East African farmers [17]. Coffee from Africa tend to have high acidity, low body, sweet fruits, floral and dry wine taste [37].

Coffee from Asian countries such as India, Java, Sumatra, Sulawesi and Papua New Guinea is perceived to have low acidity, high body and smoothness, earthy and spice flavor characteristics [38] whereas Latin America countries such as Brazil, Columbia, Costa Rica, Guatemala, Nicaragua, Mexico, El Salvador, Peru, Panama and Honduras produce coffee with medium acidity and body, intense aroma but has a full spectrum of tastes.

2.2 Biochemical compounds of coffee

The interaction of caffeine, oil, sucrose, chlorogenic acids, and trigonelline is what determines the final cup quality of coffee [39]. Organoleptic factors such as

aroma and taste within the coffee to the biochemical composition of the bean that affects the final cup quality. These biochemical compounds act as aroma precursors and the interaction between then is key to the coffee quality of specific cultivars.

2.2.1 Caffeine

Caffeine (1, 3, 7-trimethyl xanthine), is the main alkaloid found in its natural form in leaves, seeds or fruits in 63 different plant species [40]. This chemical occurs in natural form in leaves, seeds, or fruits of 63 different plant species [40]. The biological role of caffeine in plants has not been clear, although it has been suggested that caffeine protects the plant from pests and that t has an allelopathic effect on seeds affecting their germination [41]. Caffeine is an odorless, white powder with a molecular weight of 194.19 g, melting point of 236°C, sublimation point of 178°C with pH values ranging from 6 to 9 [40].

Robusta coffee has a higher content of caffeine than that of Arabica, with an average value of 2.2%, whereas Arabica has about 1.2% with a range of 0.6 to 1.9% [42, 43]. Liberica has the lowest caffeine content of 1.35% of caffeine whereas Arabusta hybrids follow closely at about 1.72% [44]. Genetic and environmental factors are the major causes of variations of caffeine content in the coffee beans. Different levels of caffeine content in the coffee bean cause various physiological and psychological effects in humans [45–47]. About 80% of administered caffeine (1,3,7-trimethylxanthine) is metabolized by demethylation to paraxanthine (1,7- dimethylxanthine) via liver *cytochrome* P-450 1A2, and about 16% is converted to theobromine and theophylline, (3,7- and 1,3-dimethylxanthine, respectively) [47]. Higher levels of caffeine consumption have been associated with improved performance in human reaction time, verbal memory, and visuospatial reasoning but may also cause heart disease, kidney malfunction, and asthma among other disorders [48].

2.2.2 Carbohydrates

Arabica coffee is more preferred by most consumers than Robusta because it is less bitterness and has good flavour [49, 50]. These characteristics are contributed by the carbohydrates that account for more than 50% of the coffee bean dry weight [8]. During roasting, sucrose is degraded to form the anhydro-sugars and glyypxal that determine flavour and aroma [29]. These compounds react with amino acids through the Maillard reaction to form aliphatic acids, hydroxymethylfurfural, pyrazine and other furans. Furan derivatives are the principal products of decomposition of monosaccharides and higher sugars [51]. The composite roasting is regarded as essential in contributing to the final coffee flavour either being volatile or non-volatile [52]. Sucrose levels in Arabica coffee range from 5.1% to 9.4% in the dry matter of coffee beans which is higher than that of Robusta that range between 4–7% [53, 54].

2.2.3 Trigonelline

Trigonelline, a nitrogenous compound is derived from the methylation of the nitrogen atom of nicotinic acid (niacin) and an alkaloid that has a chemical formula, of $C_7H_7NO_2$ and molecular weight of 137.138 g/mol [55]. Trigonelline is a major source in discriminating between Arabica and Robusta coffees during roasting [56]. Arabica has trigonelline levels ranging from 0.88% to 1.77% dmb whereas *C. canephora* species levels range from 0.75% to 1.24% dmb [53]. Trigonelline is a vitamin B6 derivative with 100% solubility in water and contributes to bitterness

in coffee [54]. Degradation of trigonelline during roasting results in niacin, nicotinamide and a wide range of aroma volatiles, that include pyridines and pyrroles which in turn influence flavour [6, 53].

2.2.4 Chlorogenic acids

Chlorogenic acids (CGA) are the highest occurring polyphenols in coffee and form a significant part of coffee antioxidants [57, 58]. CGA belongs to hydroxycinnamic acids classes that comprise caffeic acid (3,4-hydroxycinnamic acid), ferulic acid (3-methoxy-4-hydroxycinnamic acid), p-coumaric (4-hydroxycinnamic acid), and sinapic acid (3,5-dimethoxy-4-hydroxycinnamic acid) [59]. CGA varies from 4% to 8.4% in Arabica coffee and between 7% to 14.4% in Robusta coffee whereas Arabusta hybrids have intermediate levels [60]. Maillard and Strecker's reaction cause chlorogenic acids to form pigments that affect taste and flavour [61].

2.2.5 Lipids/oils

Oil which is produced during roasting process, is the key determining factor of flavour and its quantity in the green bean is cultivar specific. The most important lipids in Arabica beans are the fatty acids that include the triacylglycerols, sterols, and tocopherols which are also found in vegetables [62]. Arabica coffee contains about 15% lipids compared to 10% in, Robusta coffee. Most lipids in the green coffee bean are located in the endosperm whereas the rest is found on the outer layer of the beans [63].

3. Organoleptic attributes of arabusta hybrids from experimental data

3.1 Materials and methods

3.1.1 Experimental materials and site

Field trials were conducted in Siaya and Busia counties of Kenya, in 2018/2019. Nineteen genotypes including seven Arabusta hybrids, six different backcross derivatives of Arabica to Arabusta hybrids, Congusta, Congensis, Arabusta cultivar, Robusta, *C arabica* (Batian) and *C arabica* (Ruiru 11) were evaluated. The Uganda tetraploids used in generating the interspecific hybrids were sourced from Uganda while the Robusta and Arabica genotypes are all from Coffee Research Institute-Ruiru, Kenya.

The trials were established at Siaya ATC (Siaya County) and KALRO Alupe (Busia County) both of which sites are located near the Lake Victoria basin in the low altitude zones suitable for planting Robusta coffee. Siaya lies between 0° 30 N′ and 0° 45′ E with an altitude that varies from 1,135 m to 1,500 m above sea level receiving a mean annual rainfall of 1,500 mm whereas Busia county lies between 0° 30 N′ and 34° 30' SE with an altitude that varies from 1241 m to 1343 m above sea level with mean annual rainfall of 1400 mm.

3.2 Sensory evaluation of coffee

The evaluation of the sensory attributes was conducted by five trained judging panel using the procedures described by [64, 65]. A probate laboratory roaster was used in the roasting process and the roasted beans were left to rest for at least 8 hours before cupping. Green coffee beans were weighed before and after roasting

to be able to determine the roasting degree. After the 8 hours', the roasted beans were ground into individual cups ensuring that the whole sample was deposited into each cup. Each sample representing a specific genotype was placed into five cups. Samples were weighed to get 8.25 g and 150 ml of hot water was added per cup. The evaluation of the sensory attributes was conducted by five trained judges forming a panel using the procedures described by [65]. The descriptors measured included acidity, body, balance, fragrance/aroma, flavour, aftertaste, and preference as described by SCA.

The attribute scores of clean cup, sweetness, and uniformity were each scored and a maximum of two points per cup was awarded getting a maximum score 10. These scores were added to the scores obtained from the other seven sensory attributes to constitute the total score. This would then reflect the total performance of genotypes regarding cup quality. The average score of a cupper was considered as a replication.

3.3 Biochemical compounds analyses

3.3.1 Extraction and quantification of crude oil

Two (2) grams of the dried green coffee powder from the green coffee bean was weighed and dried for 1 h at 105°C ± 2°C. Extraction was carried out after adding 100 mm of hexane to the coffee powder which was then in the soxhlet extraction apparatus [66]. Rota vapor was used to dry the extract and placing it an oven at105 ± 2°C to complete drying process. The extract was cooled and then weighed to get the final weight after evaporation. The drying process continued for another two hours weighing being undertaken at a 30-minute interval until there was no more than one milligram loss between successive weighing. Crude oil content was then calculated by as the increase in weight of the extraction flasks [67].

3.3.2 Extraction of caffeine, trigonelline and total chlorogenic acids (CGA)

Caffeine, trigonelline and chlorogenic acids levels were determined using the protocols as provided by [68, 69] with slight modifications as described below.

3.3.3 Analysis of caffeine, trigonelline and total chlorogenic acids

HPLC system (Knaeur) equipped with a Super Co Discovery C-18 column was used to analyse caffeine and trigonelline and BDS HYPERSIL C-18 column used to analyse chlorogenic acids. Diode Array Detector was used to detect the three wavelengths, at 278 nm for caffeine, 266 nm for trigonelline and 324 nm for CGA. HPLC grade methanol (PANREAC) 35% was used as the mobile phase, distilled water 65%, acetic acid (PROLABO) 0.1%, at a flow rate of 1 ml/min under ambient temperature. The retention times of the trigonelline standard (Sigma Aldrich), CGA standard (Acros organics) and caffeine standard (99%) (Fischer Scientific) were used to calculate trigonelline, CGA and Caffeine quantities respectively. Calibration equations were used to calculate using the peak area of the slope [67].

3.3.4 Extraction and analysis of sucrose

The extraction and analysis of sucrose was done according to the method of [70] used by [67]. 0.2 g of the green coffee powder was added to 100mls of 96% ethanol under reflux. The extract was evaporated to dryness after filtering it using the Whatman filter paper number 42. Recovery of sucrose was done using 10mls

deionized water and 2mls of the extract mixed with 2mls Diethyl ether (AR) and the top layer was discarded after settling. The process was repeated three times and 1 ml of acetonitrile was added to 1 ml of the extract. Filtering was conducted using the 0.45 μm micro filter. HPLC system (Knaeur) equipped with a Eurospher 100–5 NH2 column and a refractive index detector was used to analyse sucrose. Acetonitrile HPLC grade (SCHARLAU) 75%, and distilled water 25% was used as the mobile phase at a flow rate 1 ml/min. The sucrose standard (Fischer Scientific) was used in quantifying the sucrose level through comparison of the retention peak of standards and sample peak the sucrose level calculated using the calibration equation.

3.4 Data analysis

The bean grades, sensory data and biochemical data were subjected to Analysis of Variance (ANOVA) using GENSTAT statistical software version 18 and effects declared significant at 5%. The General Linear Model (GLM) was used.

$$Y\hat{} = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + E_i. \quad (1)$$

Where,

For each observation i = 1, ..., n. where n is the observations of one dependent variable.

$Y\hat{}$ = j^{th} observation of the dependent variable.

j = 1,2, ..., k.

X = is the observation of the j^{th} independent variable.

β = parameters to be estimated.

Ei = Distributed normal error.

Least Significance Difference was used to separate means [71]. Separate as well as combined analysis of variance was performed on data from the two sites. GENSTAT statistical software was used to compute correlation and to show relationship between sensory traits using the Pearson Correlation Coefficient.

3.5 Sensory performance

Sensory traits significantly varied among the coffee genotypes tested across the two locations with Arabica genotype SL28 recording the highest Fragrance value and Robusta genotypes the lowest. Again as for Flavour, Arabica genotype, SL28 recorded the highest value whereas CV1 recorded the lowest (**Table 1**). Again, genotype SL28 recorded significantl higher values for Aftertaste in both sites. As for Acidity, Robusta genotypes had the lowest values but Arabica genotype SL 28 recorded the highest. Body value was high in both Arabusta hybrids and Arabica genotypes. For all the traits scored, Arabica genotype, SL28 recorded significantly higher values than all the rest, across the two locations (**Table 2**).

The genotypic effect varied significant for all the sensory traits with the exception of the environmental variations were significant for all the sensory trait whereas the G x E interaction was not significant for all the sensory traits measured (**Table 2**). Preference scored the highest maximum score, whereas acidity scored the lowest. (**Table 3**). The highest rated sensory attribute was Body, followed closely by Aroma whereas Flavour and Aftertaste had the lowest mean. Acidity and preference indicated that they had wider phenotypic variance than all the other sensory traits (**Table 3**).

Genotypes	Fragrance		Flavor		Aftertaste		Acidity		Body		Balance		Preference		Total score	
	Bu	Si	Bu	Si	Bu	Si	Bu	Si	Bu	Si	Bu	Si	Bu	Si	Bu	Si
ARH1	7.5	7.0	7.4	7.0	7.6	7.1	7.4	7.2	7.7	7.5	7.4	7.2	7.4	7.1	82.4	80.1
ARH4	7.4	7.5	7.2	7.0	7.4	6.9	7.2	7.0	7.6	7.4	7.3	7.0	7.4	7.0	81.5	79.8
ARH5	7.8	7.3	7.5	7.2	7.7	7.1	7.5	7.1	7.8	7.5	7.6	7.1	7.6	7.2	83.5	80.5
ARH6	7.5	7.4	7.3	7.3	7.4	7.3	7.4	7.4	7.5	7.6	7.6	7.4	7.5	7.4	82.2	81.8
ARH7	7.6	7.6	7.5	7.4	7.7	7.2	7.6	7.4	7.7	7.7	7.7	7.3	7.7	7.4	83.5	82.0
BC01	7.4	7.4	7.2	6.9	7.3	6.8	7.3	6.9	7.6	7.4	7.4	7.0	7.4	6.9	81.6	79.3
BC02	7.5	7.5	7.3	7.2	7.3	7.1	7.3	7.0	7.5	7.5	7.2	7.2	7.3	7.1	81.4	80.6
BC03	7.8	7.7	7.1	7.3	7.3	7.3	7.3	7.5	7.5	7.5	7.2	7.4	7.4	7.4	81.6	82.3
BC04	7.6	7.5	7.4	7.2	7.5	7.2	7.5	7.4	7.5	7.5	7.4	7.1	7.4	7.2	82.3	81.2
BC05	7.7	7.4	7.6	7.3	7.6	7.1	7.6	7.4	7.7	7.5	7.8	7.4	7.7	7.4	83.7	81.6
BC06	7.6	7.4	7.4	7.0	7.4	6.8	7.5	6.8	7.6	7.5	7.4	7.0	7.4	6.9	82.3	79.0
CV1	7.6	7.1	7.2	6.7	7.4	6.6	7.2	6.7	7.6	7.5	7.4	7.3	7.3	6.6	81.7	78.2
CV2	7.4	7.2	7.2	6.8	7.4	6.9	7.2	6.9	7.5	7.5	7.4	7.0	7.3	6.7	81.4	78.7
ARV	7.4	7.6	7.4	7.3	7.5	7.3	7.4	7.4	7.7	7.5	7.4	7.4	7.4	7.4	82.2	82.0
Robusta	6.8	6.9	7.2	7.0	7.1	7.1	7.0	6.9	7.2	7.5	7.0	7.0	7.1	7.0	79.5	79.1
Ruiru 11	7.7	7.2	7.3	7.0	7.3	7.0	7.5	7.2	7.5	7.5	7.3	7.4	7.4	7.3	82.0	80.6
Batian	7.6	7.9	7.5	7.9	7.3	7.9	7.4	8.1	7.6	7.5	7.2	7.2	7.2	7.2	81.8	83.8
SL28	8.1	8.2	7.9	8.2	8.0	8.1	7.8	8.2	7.9	7.5	7.9	7.9	8.3	7.9	85.9	86.2
LSD	0.3	0.4	0.3	0.5	0.3	0.4	0.3	0.4	0.4	7.5	0.3	0.6	0.3	0.4	1.5	2.4
%CV	0.7	3.6	1.8	2.3	2.5	2.4	2.0	2.7	1.6	7.5	1.1	3.1	1.5	1.9	0.7	0.9
Ftest	S	S	S	S	S	S	S	S	NS	7.5	S	S	S	S	S	S

Key: Bu- Busia Si- Siaya; Reproduced from PhD thesis, University of Nairobi.

Table 1.
Sensory traits for coffee genotypes at KALRO-Alupe and Siaya ATC.

Source	Rep	Gen (G)	Envt (E)	G x E	Error
Df	4	17	1	17	140
Fragrance	0.598	0.3514***	0.73472**	0.12296NS	0.096
Flavour	0.152	0.6629***	2.6889***	0.0793NS	0.102
Aftertaste	0.151	0.4416***	7.4014***	0.0911NS	0.106
Acidity	0.213	0.7609***	2.6281***	0.1524NS	0.113
Body	0.536	0.1769***	0.6183***	0.0926NS	0.102
Balance	0.202	0.3225NS	2.4019***	0.1402NS	0.159
Preference	1.218	21.18***	134.421***	4.525NS	2.882

*Key: *, **, *** and NS represent significant at (P < 0.005), (P < 0.001), (P < 0.0001) and non-significant respectively. Reproduced from PhD thesis, University of Nairobi.*

Table 2.
Mean squares for sensory traits of 17 coffee genotypes evaluated at Siaya ATC and KALRO-Alupe (Busia).

Attributes	Minimum	Maximum	Mean	Variance range	Standard Error
Aroma	7.23	8.00	7.48	0.78	0.09
Flavor	6.93	8.00	7.28	1.08	0.10
Aftertaste	6.98	7.88	7.28	0.90	0.10
Acidity	6.90	8.08	7.31	1.18	0.10
Body	7.30	7.83	7.53	0.53	0.10
Balance	7.15	7.85	7.34	0.70	0.13
Preference	6.93	8.10	7.32	1.18	0.09

Reproduced from PhD thesis, University of Nairobi.

Table 3.
Variability of the sensory attributes for the 20 coffee genotypes.

The biochemical attributes scored here, varied significantly among the genotypes with genotypes ARH2 and ARH3 scoring the highest levels of chlorogenic acids, caffeine, sucrose and Trigonelline contents (**Figure 1**). Arabica genotypes, Ruiru 11, Batian and SL28 gave the highest oil content values, whereas Robusta recorded the highest caffeine contents (**Figure 1**). In the two locations over the two seasons, there was variation in the biochemical composition of the Arabusta hybrids, backcrosses, Robusta and Arabica coffee genotypes evaluated here. Arabica coffee genotypes had the highest composition of sucrose, trigonelline and oils, whereas the Arabusta hybrids scored intermediate values between Arabica and Robusta. Robusta genotypes scored the highest caffeine and cholorogenic acid contents whereas Arabica scored the lowest (**Figure 2**).

The Arabusta hybrids had higher values of oil, sucrose and trigonelline contents than Robusta genotypes which contributed to a better cup quality. As noted elsewhere in this chapter, chlorogenic acids are involved in aroma formation and pigmentation of coffee whereas caffeine influences the mildness in the cup [72]. But higher levels of caffeine and chlorogenic acids lower the quality by infusing bitterness and the astringency taste in the coffee brew [64, 73]. The results reported here showed that, Arabica and Arabusta genotypes had higher levels of sucrose, oil and trigonelline contents than Robusta genotypes, that contributed to a better cup quality due to the aroma and flavor that these biochemical compounds produce. All the interspecific

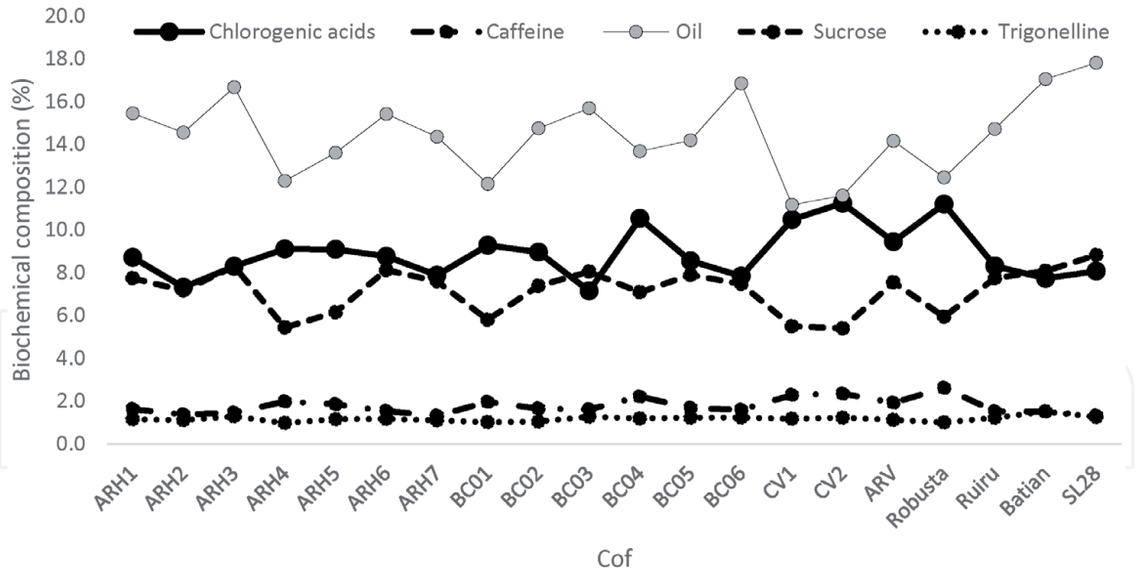

Figure 1.
Biochemical contents of twenty coffee genotypes in Busia and Siaya. Reproduced from PhD thesis, University of Nairobi.

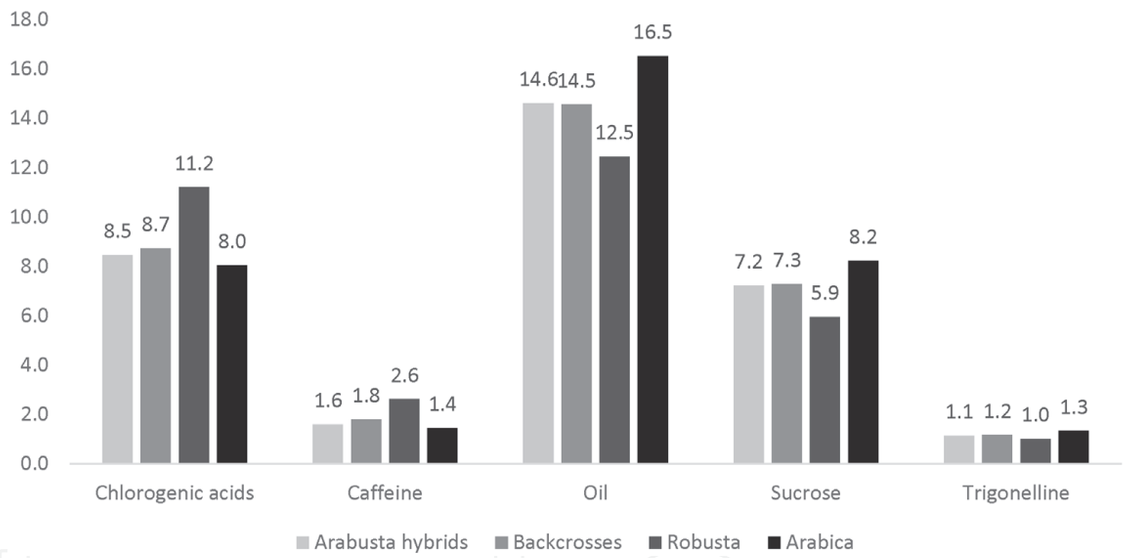

Figure 2.
Biochemical composition for the Arabusta coffee hybrids, Backcrosses, Arabica and Robusta coffee. Reproduced from PhD thesis, University of Nairobi.

hybrids with the exception of ARH4 genotype recorded a 80% quality performance compared to Robusta genotypes.

4. Conclusions

Arabica and Arabusta genotypes evaluated in these experiments, confirmed that there is genetic variation for organoleptic, sensory and biochemical traits in coffee.

Interspecific hybridization between *C. Arabica* and *C. canephora*, produced hybrids with improved sensory and organoleptic traits that were intermediate between the two species. Cup quality in coffee can be improved through selection and hybridization in coffee improvement programs.

Author details

Kahiu Ngugi[1*], Jane Jerono Cheserek[2] and Chrispine Ogutu Omondi[3]

1 Department of Plant Science and Crop Protection, Faculty of Agriculture, College of Agriculture and Veterinary Sciences, University of Nairobi, Nairobi, Kenya

2 Coffee Research Institute, Kenya Agricultural and Livestock Research Organization (KALRO), Ruiru, Kenya

3 Sugar Research Institute, Kenya Agricultural and Livestock Research Organization (KALRO), Kisumu, Kenya

*Address all correspondence to: kahiukahiu@gmail.com

References

[1] Aga, E., Bryngelsson, T., Bekele, E., & Bjorn, S. (2003). Genetic diversity of forest Arabica coffee (*coffea arabica* L.) in Ethiopia as revealed by random amplified polymorphic DNA (RAPD) analysis. Hereditas 138, 36-46.

[2] Orozco-Castillo, C., Chalmers, K.J., Waugh, R., & Powell W. (1994). Detection of genetic diversity and selective gene introgression in coffee using RAPD markers. Theoretical Applied Genetics, 87, 934-940.

[3] Osario, N. (2008). Evolution of the world coffee market 2002 to 2008. www.ico.org.

[4] International Coffee Organization (ICO). (1991). Sensory evaluation of coffee: Technical Unit Quality Series. *ICO* No 9, 209-243.

[5] Cannell, M G R. (1985). Physiology of the coffee crop. In N.M. Clifford & K.C. Willson (Eds), *Coffee: Botany, Biochemistry and Production of Beans and Beverage* (pp 108-134), London, Croom Helm.

[6] Clifford, M.N., & Wilson K.C. (1985). Chemical and physical aspects of green coffee and coffee products. In M.N. Clifford & K.C. Wilson (Eds), *Coffee: Botany, Biochemistry and Productions of Beans and Beverage* (pp 305-374), London, Croom Helm.

[7] Vaast, P., Bertrand, B., Perriot, J.J., Guyot, B., & Génard, M. (2006). Fruit thinning and shade influence on bean characteristics and beverage quality of *C. arabica* in optimal conditions. Journal of Science Food Agriculture, 86, 197-204.

[8] Wrigley, G. (1988). Coffee (p 639), New York, Longman.

[9] Prakash, N.S., Combes, M.C, Dussert, S., Naveen, S., & Lashermes, P. (2005). Analysis of genetic diversity in Indian robusta coffee genepool (*Coffea canephora*) in comparison with a representative core collection using SSRs and AFLPs. Genetic Resources and Crop Evolution 52, 333-342 .

[10] Medina-Filho, H.P., Maluf, M.P., Bordignon, R., Guerreiro-Filho, O., & Fazuoli L.C. (2007). Traditional breeding and modern genetics: a summary of tools and developments to exploit biodiversity for the benefit of the coffee agro-industrial chain. Acta Hort, 745, 351-368.

[11] Thomas, A.S. (1940). Robusta coffee. In J.D. Tothill (Ed), Agriculture in Uganda (pp 289-313), London, Oxford Univ. Press.

[12] Berthaud, J. (1986). Genetic differentiation between *coffea liberica* var. liberica and *C. liberica* var. Dewevrei and comparison with canephora. Plant systematics and Evolution, 253, 1-4.

[13] Leakey, C.L.A. (1970). The improvement of Robusta coffee in East Africa. In C.L.A Leakey. (Ed), Crop improvement in East Africa (pp 250-277), *Commonwealth Agricultural Bureaux*.

[14] http://www.hear.org/pier/wra/pacific/coffea_liberica- htmlwra.htm,

[15] Coste, R. (1992). Characteristics and composition of green coffee. *In Coffee: The Plant and the Product*, p 328, London and Basingstoke, U.K, The Macmillan Press Ltd.

[16] Thomas, A.S. (1944). The wild coffees of Uganda. Empire Journal Experiment of Agriculture, 12 1-12.

[17] Leroy, T., Ribeyre, F., Bertrand, B., Charmetant, P., Dufour, M., Montagnon, C., Marraccini, P., & Pot,

D. (2006a). Genetics of coffee quality. Braz. J. Plant Physiol., 18 (1), 229-242.

[18] Charrier, A., & Berthaud, J. (1985). Botanical classification of coffee. In M.N. Clifford & K.C. Wilson (Eds), *Coffee: Botany, Biochemistry and Production of Beans and Beverages* (pp 13-47), London, Croom Helm.

[19] Decazy, F., Avelino, J., Guyot, B., Perriot, J.J., Pineda, C., & Cilas, C. (2003). Quality of different Honduran coffees in relation to several environments. Journal of Food Science, 68, 2356-2361.

[20] Geromel, C., Ferreira, L.P., Guerreiro, S.M.C., Cavalari, A.A., Pot, D., Pereira, L.F.P., Leroy, T., Vieira, L.G.E., Mazzafera, P., & Marraccini, P. (2006). Biochemical and genomic analysis of sucrose metabolism during coffee (*Coffea arabica*) fruit development. Journal of Experimental Botany, 57(12) 3243-3258

[21] International Standard, 5492 (ISO). (2008). Sensory analysis – Vocabulary, Second edition, published in Switzerland

[22] Clarke, R.J. (1985). The technology of converting green coffee into the beverage. In M.N. Clifford, & K.C. Wilson (Eds), *Coffee: Botany, Biochemistry and Production of Beans and Beverages* , (pp 375-393), London, Croom Helm

[23] Davrieux, F., Manez, J. C., Durand, N., & Guyot, B. (2005). Determination of the content of six major biochemical compounds of green coffee using near infrared spectroscopy. *11th International Conference on Near Infrared Spectroscopy*, Cordoba, Spain.

[24] http://www.coffeeresearch.org/science/bittermain.htm

[25] Wintgens J N. (2004). Coffee: growing, processing, sustainable production. A guidebook for growers, processors, traders, and researchers (Ed), Wilet-VCG Verlag GmbH & Co.

[26] Maier, H.G. (1987). The acids of coffee. *Proceedings of 12th International Conference on Coffee Science (ASIC)*, (pp 229-237), Paris, France.

[27] http://soluble- coffee.com/coffee_vocabulary.html

[28] ICO (2019). International Coffee Organization, International coffee Council, 124th Session, country coffee profile, Kenya.

[29] De Maria, C.A.B., Trugo, L.C., Aquino, Neto, F.R., Moreira, R.F.A., & Alviano, C.S. (1996). Composition of green coffee water-soluble fractions and identification of volatiles formed during roasting. Food Chemistry, 55, 203-207

[30] Ginz, M., Balzer, H., Bradbury, A., & Maier H. (2000). Formation of aliphatic acids by carbohydrate degradation during roasting of coffee. European Food Research and Technology, 211, 404-410.

[31] Gower, J.C. (1971). A general coefficient of similarity and some of its properties. Biometrics, 27, 857-874.

[32] Barboza, J.A., Araya, J. C., Fonseca, C., Davrieux, F., Guyot, B., & Cilas, C. (2005). Effects of slope exposure, altitude and yield on coffee quality in two altitude *terroirs* of Costa Rica, Orosi and Santa María de Dota. Journal of the Science of Food and Agriculture, 85, 1869-1876. http://dx.doi.org/10.1002/jsfa.2188.

[33] Tessema, A., Alamerew, S., Kufa, T., & Garedew, W. (2011). Variability and Association of Quality and Biochemical Attributes in Some Promising *Coffea arabica* Germplasm Collections in Southwestern Ethiopia. International Journal of Plant Breeding and Genetics, 5, 302-316.

[34] Dessalegn, Y., Labuschagne, M.T., Osthoff, G., & Herselman, L. (2008). Genetic diversity and correlation of bean caffeine content with cup quality and green bean physical characteristics in coffee (*Coffea Arabica* L.*)*. Journal of the Science of Food and Agriculture, 88 (10), 1726-1730

[35] Moschetto, D., Montagnon, C., Guyot, B., Perriot, J.J, Leroy, T., & Eskes, A.B. (1996). Studies on the effect of genotype on cup quality of *Coffea canephora*. Tropical Science, 36 18-31.

[36] Barbosa J., Borem, F., Alves, H., Cirillo, M., Sartori, M., Ducatti, C (2014). Discrimination of Production Environments of Specialty Coffees by Means of Stable Isotopes and Discriminant Model. Journal of Agricultural Science, 6(5):50-55.

[37] http://www.nature.com/nature/journal/v429/n6994/full/429826a.html

[38] http://www.blackcow.com/Beans/Beans.html

[39] Aluka, P., Musoli, P., Curbry, P., Davrieux, F., Ribeyre, F., Guyot, B., De Bellis, F., Pinard, F., Kyetere, D., Ogwang, J., Dufour, M., & Leroy, T. (2006). *Proceedings of the 21st International Conference on Coffee Science*, Montpellier, France, 93.

[40] Mumin, M.A., Akhter, K.F., Abedin, M.Z. and Hossain, M.Z. (2006). Determination and characterization of caffeine in tea coffee and soft drink by solid phase extraction and HPLC, Malaysian Journal of Chemistry., 8(1): 045-051

[41] Hollingsworth, R.G., Armstrong, J.W., Campbell, E. (2002). Caffeine as a repellent for slugs and snails. Nature, 417: 915-916.

[42] Belay, A. (2011). Some biochemical compounds in coffee beans and methods developed for their analysis. International Journal of the Physical Sciences, 6(28), 6373-6378. http://dx.doi.org/10.5897/IJPS11.486.

[43] Franca, A. S., Oliveira, L. S., Mendonca, C. F. and Siva, X. A. (2005). Physical and chemical attributes of defective crude and roasted coffee beans. Food Chemistry, 90, 89-94.

[44] Clarke, R. J. and Macarae, R. (Eds.) (1985). Coffee: volume 1-Chemistry (pp. 1-7). England: Elsevier Applied Science Publishers.

[45] Zhang, Q., Lian, H., Wang, W. and Chen, H. (2005). Separation of caffeine and theophylline in poly (dimethylsiloxane) microchannel electrophoresis with electrochemical detection, Journal of chromatography Analysis, 1098:172-176.

[46] Minamisawa, M., Yoshida, S. and Takai, N. (2004). Determination of biologically active substances in roasted coffee using a diode-HPLC system, Analytical science., 20: 325-328.

[47] Benowitz, N.L., Jacob, P. III, Mayan, H. and Denaro, C. (1995). Sympathomimetic effects of paraxanthine

[48] Leroy, T., De Bellis, F., Legnate, H., Kananura, E., Gonzales, G., Luiz Felipe Pereira, L.F., Andrade, A.C., Charmetant, P., Montagnon, C., Cubry P., Marraccini, P., Pot, D., & De Kochko, A. (2011). Improving the quality of African robustas: QTLs for yield and quality related traits in Coffea canephora. Tree Genetics & Genomes, DOI 10.1007/s11295-011- 0374-6.

[49] Geromel, C., Ferreira, L., Davrieux, F., Guyot, B., Ribeyre, F., Santos-Scholz, M.B., ... Marraccini, P. (2008). Effects of shade on the development and sugar metabolism of coffee (Coffea arabica L.) fruits. Plant Physiology and Biochemistry, 46(5-6), 569-579. DOI: 10.1016/j.plaphy.2008.02.006

[50] De Maria, C.A.B., Trugo, L.C., Aquino Neto, F.R., Moreira, R.F.A. and Alviano, C.S. (1995). Composition of green coffee water-soluble fractions and identification of volatiles formed during roasting. Food Chemistry, **55:**203-207.

[51] Flament, I. and Bessière-Thomas, Y. (2002). Coffee Flavour Chemistry. John Wiley and Sons Ltd New York. pp. 410.

[52] Grosch, W. (2001). Chemistry III: Volatile Compounds. In R.J. Clarke and Vitzthum O.G., (Eds.), Coffee Recent Developments, Blackwell Science Ltd cap.3, p.68-90

[53] Ky, C. L., Louarn, J., Dussert, S., Guyot, B., Hamon, S., & Noirot, M. (2001a). Caffeine, trigonelline, chlorogenic acids and sucrose diversity in wild *Coffea arabica L.* and *C. canephora* P. accessions. Food Chemistry, 75, 223-230.

[54] Ky, C.L., Guyot, B., Louarn, J., Hamon, S., & Noirot M. (2001b). Trigonelline inheritance in the interspecific *Coffea pseudozanguebariae* x *C. liberica* var. dewevrei cross. *Theor Appl.* Genet., 102, 630-634.

[55] Nuhu, A.A. (2014). Bioactive Micronutrients in Coffee: Recent Analytical Approaches for Characterization and Quantification. ISRN Nutrition, 2014, 1-13. DOI: 10.1155/2014/384230

[56] Bicho, N. C., Leitao, A. E., Ramalho, J. C. and Lidon, F.C. (2011) Identification of chemical clusters discriminators of the roast degree in Arabica and Robusta coffee beans. European Food Research and Technology, vol. 233, no. 2, pp. 303-311.

[57] Farah, A, Depaulis T, Trugo LC, Martin PR (2005a). Effect of roasting on the formation of chlorogenic acid lactones, Journal of agriculture and food chemistry., 53: 1505-1513

[58] Wen, X., Takenaka, M., Murota, M. and Homma, S. (2004). Antioxidative activity of a zinc chelating substances in coffee. *Journal of BioSciences,* Biotechnology and Biochemistry., 68(11): 2313-2318.

[59] Zhu, H., Shako, H., Zhang, Z., Wang, W. and Yao, S. (2006). Laser flash photolysis study on antioxidant properties of hydroxycinnamic acid derivative, Journal of Radiation Environment Biophysiology, 45: 73-77.

[60] Farah, A. Franca, A. S., Mendonca, J. C. F. and Oliveira, S. D. (2005b). Composition of green and roasted coffee of different cup qualities. Lwt - Food Science and Technology, 38, 709-715.

[61] Variyar, P. S., Ahmad, R., Bhat, R., Niyas, N. and Sharma, A. (2003). Flavoring components of raw munsoned Arabica coffee and their changes during radiation process. Journal of Agriculture and Food Chemistry, 51, 7945-7950.

[62] Cheng, B., Furtado, A., Smyth, H.H., and Henry, R.J. (2016). Influence of genotype and environment on coffee quality. Trends in Food Science & Technology 57 (2016) 20-30.

[63] Upadhyay, R., & Mohan Rao, L. J. (2013). An outlook on chlorogenic acids occurrence, chemistry, technology, and biological activities. Critical Reviews in Food Science and Nutrition, 53(9), 968-984.

[64] Ngugi, Kahiu and Aluka, P. (2016). Sensory and Organoleptic Cup Attributes of Robusta Coffee (*Coffea canephora* Pierre ex A. Froehner). *Journal of Agricultural Studies* ISSN 2166-0379 2016, Vol. 4, No. 1(1)

[65] Lingle, T. R. (1996). The Coffee Brewing Handbook, (1996). 1st edition. Long Beach:

[66] Association of Official Analytical Chemists (A0AC). (1995). Official

methods of analysis of AOAC International (16th Ed.) Gaithersburg, MD, USA: AOAC International.

[67] Liu,C., Yang, Q., Linforth,R., Fisk, I.D., and Yang, N. (2019). Modifying Robusta coffee aroma by green bean chemical pre-treatment. *Food chemistry* Volume 272, 30 January 2019, Pages 251-257

[68] CIRAD, Centre de coopération International en Recherche en Agronomique pour le Développement (2003a). Analysis of caffeine in green coffee beans, Ref: CIR/CP:

[69] CIRAD, Centre de coopération International en Recherche en Agronomique pour le Développement (2003b). Determination of trigonelline in green coffee beans, Ref: CIR/CP: 005

[70] Osborne, D.R., and Voogt, P. (1978). Carbohydrates, In the Analysis of Nutrients in Foods, (pp 130-150). Academic Press Inc. London Ltd.

[71] Martin, M.J., Pablos F. and Gonzalez A.G. (1998b) Discrimination between Arabica and Robusta green coffee varieties according to their chemical composition. Talanta 46:1259-1264

[72] Farah, A., Monteiro, M. C., Calado, V., Franca, A. S. and Trugo, L. C. (2006). Correlation between cup quality and chemical attributes of Brazilian coffee. Food Chemistry, 98.373-380

[73] Grosch, W. (2001). Chemistry III: Volatile Compounds. In R.J. Clarke and Vitzthum O.G., (Eds.), Coffee Recent Developments, Blackwell Science Ltd cap.3, p.68-90