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Full Length Research paper

Evaluation of beverage quality and green bean physical characteristics of selected Arabica coffee genotypes in Kenya

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Physical characteristics of green coffee bean have been reported to affect beverage quality to some extent. The objective of this study was to assess the beverage quality and green bean physical characteristics of forty two arabica coffee genotypes and to determine the relationship between the two attributes. Green bean physical characteristics were assesed through actual measurements, grading and weighing while beverage quality was determined by a panel of seven judges using the prescribed sensory evaluation procedures. Sensory data was used to calculate diversity in beverage quality among genotypes and to construct a dendrogram using the unweighted pair-group method with arithmetic average. Data were also subjected to analysis of variance and differences declared significant at 5% level based on Duncan's Multiple Range Test. Linear correlation was done to compare the relationship between variables. Cluster analysis results demonstrated 0 - 47% diversity in beverage quality among genotypes. There was close similarity among coffee tasters in ranking various beverage quality characteristics of the cultivars indicating that the panel was reliable in assessment of beverage quality. All sensory variables evaluated were positively and significantly correlated. However, correlations between the sensory variables and green bean physical characteristics were non-significant.

Key words: Sensory variables, cuppers, Ruiru.

INTRODUCTION

The coffee bean is obtained from the fruit of the coffee plant, a small evergreen shrub belonging to the genus *Coffea,* family Rubiaceae. Although the genus *Coffea* is diverse and reported to comprise about 103 species (Davis et al., 2006), only two species namely arabica (*Coffea arabica* L.) and robusta (*Coffea canephora* Pierre) are under commercial cultivation (Lashermes et al., 1999; Anthony et al., 2002; Pearl et al., 2004). The centre of origin of the genus *Coffea* is geographically isolated from the centre of origin of other species. It is confined to the plateau of southwestern Ethiopia and on the Boma plateau of Sudan (Wellman, 1961; Lashermes et al., 1999; Anthony et al., 2002; Steiger et al., 2002). Populations of *C. arabica* have also been reported in Mt. Imatong (Sudan) and Mt Marsabit (Kenya) (Berthaud and Charrier, 1988). On the other hand, the centre of origin of other coffee species overlaps elsewhere in the central and western parts of Africa (FAO, 1968). *C. arabica* therefore follows the typical distribution features of polyploids, that is, peripheral expansion outside the range of distribution of the other diploid species of the genus (FAO, 1968).

Today, coffee is one of the most important non-alcoholic beverage crops grown in over 80 countries in the tropical and subtropical regions of the world, exported in different forms to more than 165 nations, and provides a livelihood for some 25 million coffee-farming families around the world. It is the second most important commodity in the global trade, rated after petroleum products (Dessalegn et al., 2008). Beverage quality, often referred to as drinking quality or liquor quality, is an important attribute of coffee (Muschler, 2001; Agwanda et al., 2003) and acts as yardstick for price determination (Walyaro, 1983;

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Roche, 1995; Agwanda et al., 2003). Coffee beverage quality is based on the characterization of a large number of factors including taste and aroma. These factors are related to the biochemical content of roasted beans. A thousand of compounds, appearing during roasting, are involved in coffee beverage quality. These compounds rise from a smaller number of biochemical compounds present in green beans. Their presence could have a favorable effect on the coffee beverage quality, as for trigonelline and sugars, or an unfavorable one, as for chlorogenic acids and caffeine (Clifford, 1985; Macrae, 1985).

Beverage quality assessment is done organoleptically by trained coffee tasters (Van der Vossen, 1985; Agwanda, 1999). Walyaro (1983) recommended this method as a sufficiently reliable for use as a basis of selection in quality improvement programs. Traditionally experts have been engaged to do the analysis and establish an impressive catalogue of information as to the ultimate quality of coffee and thus become the judge of standards of excellence. Formal sensory evaluation can be used successfully for screening breeding selections, and may provide more reliable data than the opinions of only one or two people (Hampson et al., 2000). In the modern scenario, markets are multinational, more competitive and certainly more complex than they were 20 - 30 years ago. A modern trend of the international coffee market is the increasing demand for products of unique characteristics or of high beverage quality. Consumers are more discriminating about differences between groups of coffee, including distinctions based on product origin, taste characteristics, such as smoothness, aroma and acidity, organic characteristics, and other factors (Commission for Environmental Cooperation, 1999). Each day, this interest in quality is translated into bottom-line purchasing decisions.

Arabica coffee accounts for about 70% of the world coffee production and known for the preparation of high quality beverage (Anthony et al., 2002). It is the only tetraploid (2n = 4 x = 44) and self-fertile (over 95%) species in the genus *Coffea* (Silvarolla et al., 2004) as well as the most widely cultivated and the longest known coffee species (Coste, 1992; Moncada and McCouch, 2004). Its two genomes originated from two different diploid wild ancestors, *C. canephora* Pierre and *C. eugenioides* Moore (Lashermes et al., 1999). The species is characterized by low genetic diversity (Lashermes et al. 1996), which is attributable to its reproductive biology and evolution (Bertrand et al., 2003).

The longevity of coffee seed is insufficient to use in the preservation of genetic resources of coffee. Conse-quently, coffee germplasms are conserved in field genebanks (Van der Vossen, 1985). The coffee germ-plasm bank maintained at Coffee Research Station (CRS) Ruiru has many *C. arabica* accessions from Ethiopia, Sudan, Angola, India, Reunion, Portugal, Brazil, South and Central America and some in Kenya. This study was conducted in order to; determine the beverage quality of different arabica coffee genotypes maintained at field gene bank conservation site at CRS alongside two commercial coffee genotypes, K7 and SL34. The study was also aimed at identifying and classifying genotypes on the basis of quality parameters and estimating the type and magnitude of correlations between different sensory variables and green bean physical characteristics.

MATERIALS AND METHODS

Study site

The study was carried out at Coffee Research Station (CRS), Ruiru, Kenya. The site lies at within the upper Midland 2 agro-ecological zone (UM 2) at latitude 1° 06'S and longitude 36° 45'E and is approximately 1620 m above the sea level (Kimemia et al., 2001). The area receives a bimodal mean annual rainfall of 1063mm and the mean annual temperature is 19°C (minimum 12.8°C and maximum 25.2°C). The soils are classified as a complex of humic nitisols and plinthic ferrasols. They are welldrained, deep reddish brown, slightly friable clays with murram sections occassionally interrupting. The soil pH ranges between 5 and 6 (Jaetzold and Schimidt (1983).

Test materials

A total of forty two *C. arabica* genotypes obtained from CRS germplasm conservation site were used in this study (Appendix 1). Many of them are elite genotypes that have been used in breeding programs with two existing commercial varieties (K7 and SL34) which served as reference in quality evaluation. Each of the genotypes was represented by ten trees selected randomly from three blocks superimposed in the site to form a Randomized Complete Block Design. The design was mainly important in the assessment of green bean characteristics but was ignored during beverage quality assessments where test samples were mixed. Cherry samples were collected during the peak harvesting period of October - December, 2008. Ripe healthy berries were harvested in bulk by hand from each of the genotypes and processed using wet processing procedures. The cherry samples were pulped, fermented, washed and the wet parchment dried. The parchment was then hulled and graded to seven grades. Green bean physical characteristics were assesed using the method of Dessalegn et al., 2008 as follows; bean shape: 1 (round), 2 (long); bean size (screen size): small or 1 (<14 mm), medium or 2 (14 - 16 mm), bold or 3 (>17 mm); bean uniformity: 1 (mixed), 2 (uniform); 100 bean weight (g).

Sensory evaluation

Roasting was done to attain a medium roast using a Probate laboratory roaster within 24 h of evaluation and allowed to rest for at least 8 h. The samples were weighed before and after roasting to determine the degree of roasting. The samples were ground immediately prior to cupping, no more than 15 min before infusion with water. Samples were weighed out to the predetermined ratio of 8.25 g per 150 ml of water. Each sample was ground after running a rinsing quantity of the sample through the grinder, and then grinding each cup's batch individually into the cupping glasses, ensuring that the whole and consistent quantity of sample gets deposited into each cup (five cups per sample). Sensory evaluation was conducted by a panel of seven judges using the procedures described by Lingle (2001). Seven sensory descriptors were assessed by a trained panel of seven judges and rated on a 10-point scale (appendix 2). The descriptors included fragrance/aroma,

Appendix 1. List of *C. arabica* genotypes evaluated for sensory characteristics (Millot, 1969).

No.	Genotypes	Status	Source
1	63	Museum accession	Kitale, Kenya
2	Dalle	Museum accession	Ethiopia
3	Dilla Alghe	Museum accession	Ethiopia
4	1225VI	Museum accession	Ethiopia
5	Angustifola	Museum accession	NAL, Kenya
6	Arousi	Museum accession	Ethiopia
7	Barbuk Sudan	Museum accession	NAL, Kenya
8	Blue Mountain	Museum accession	Guatemala
9	Dilla	Museum accession	Ethiopia
10	Draught Resistant 1 (DR1)	Museum accession	French Mission Selection
11	Draught Resistant II (DRII)	Museum accession	French Mission Selection
12	Ennareta	Museum accession	Ethiopia
13	Erecta	Museum accession	NAL, Kenya
14	Eritrean Moca	Museum accession	Ethiopia
15	F53	Museum accession	Kitale, Kenya
16	G53	Museum accession	Kitale, Kenya
17	G 5B	Museum accession	Kitale, Kenya
18	Geisha 11	Museum accession	Kitale, Kenya
19	Geisha 12	Museum accession	Kitale, Kenya
20	Gimma Galla	Museum accession	Ethiopia
21	Gimma Galla Sidamo	Museum accession	Ethiopia
22	Gimma Mbuni	Museum accession	Ethiopia
23	H1	Museum accession	Lyamungu, Tanzania
24	Hibrido De Timor	Museum accession	Timor
25	Moca	Museum accession	Aden
26	Mocha (Series D)	Museum accession	NAL, Kenya
27	Mokka Cramers	Museum accession	NAL, Kenya
28	Murta	Museum accession	Guatemala
29	Padang	Museum accession	Puerto Rico
30	Plateau Bronze	Museum accession	NAL, Kenya
31	Polysperma	Museum accession	Lyamungu, Tanzania
32	Pretoria	Museum accession	Guatemala
33	Purpurascens	Museum accession	NAL, Kenya
34	SeriesC	Museum accession	NAL, Kenya
35	SeriesL	Museum accession	NAL, Kenya
36	SL4	Museum accession	NAL, Kenya
37	Tanganyika Draught Resistant (TDR)	Museum accession	Tanzania
38	Wollamo	Museum accession	Ethiopia
39	Y Amarello	Museum accession	Brazil
40	Zeghie Ltana	Museum accession	Ethiopia
41	K7	Commercial variety	Kenya
42	SL34	Commercial variety	Kenya

NB: NAL = National Agricultural Laboratories.

flavour, aftertaste, acidity, body, balance and preference.

Data analysis

The data were organized into a matrix and subjected to cluster analysis using R Statistical Software according to Venables et al. (2006). All variables were entered as numerical factors and clustered using DAISY (dissimilarity matrix calculation) function and unweighted pair-group method with arithmetic average [UPGMA] (Venables et al., 2006). The statistical uncertainty of resulting hierarchical cluster groups was determined by calculating approximately unbiased p-values through multi-scale bootstrap resampling using the R package pvclust (Venables et al., 2006). Statistical

Appendix 2. Descriptors used by the sensory panel to describe the sensory properties of the coffee samples.

Scale	Attribute	Word anchor
1 - 10	Fragrance/Aroma	Very poor – Outstanding
1 - 10	Flavour	Very poor – Outstanding
1 - 10	Aftertaste	Very poor – Outstanding
1 - 10	Balance	Very poor – Outstanding
1 - 10	Preference	Very poor – Outstanding
1 - 10	Acidity	Very flat – Very bright
1 - 10	Body	Very thin – Very heavy

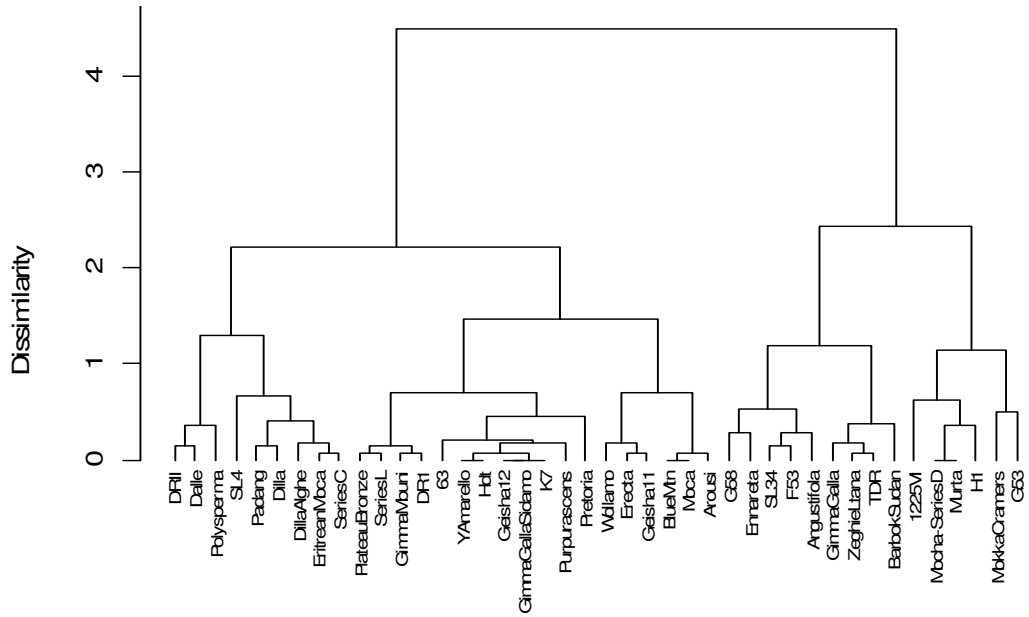

Figure 1. Cluster dendrogram illustrating beverage quality diversity among forty two *C. arabica* genotypes characterized using seven sensory variables. The faint line shows the point at which the dendrogram was truncated by Kelley-Gardener-Sutcliff (KGS) penalty function to define supported sub-clusters.

analyses were also carried out by employing SAS procedures using SAS version 9.1 (SAS Institute, 2005). First, the green bean characteristics and the seven sensory variables were subjected to analysis of variance (ANOVA) and effects declared significant at 5% level. Duncan's Multiple Range Test ($DMRT_{5\%}$) was used to separate the means. Linear correlation was done to compare the relationship between variables. Descriptive statistics were generated using univariate procedure.

RESULTS

Diversity among genotypes

Cluster dendrogram constructed using sensory data from the forty two genotypes was used to estimate beverage quality diversity among the forty two *C. arabica* genotypes thus indicating how closely related different genotypes were. Results of the cluster analysis are illustrated in Figure 1. Interpretation of the cluster dendrogram was based on execution of the Kelley-Gardener-Sutcliffe penalty function which reduced the dendrograms to 4 clusters at dissimilarity level of about 18% as shown by the faint line in Figure 1. The genotypes first separated into two broad clusters which recorded beverage quality diversity of 47%. The first cluster contained 27 genotypes while the second cluster had 15 genotypes as determined by the degree of diversity/similarity in beverage quality. Both clusters were further subdivided into two sub clusters each giving four supported sub-clusters which separated at 22 - 24% level of dissimilarity as shown in Figure 2. Sub-clustering, however, continued with closely related genotypes grouping together down the dendrogram to eight sub-clusters separating at 12-15% dissimilarity which further sub-clustered to smaller groups of closer similarity. The most similar genotypes which recorded

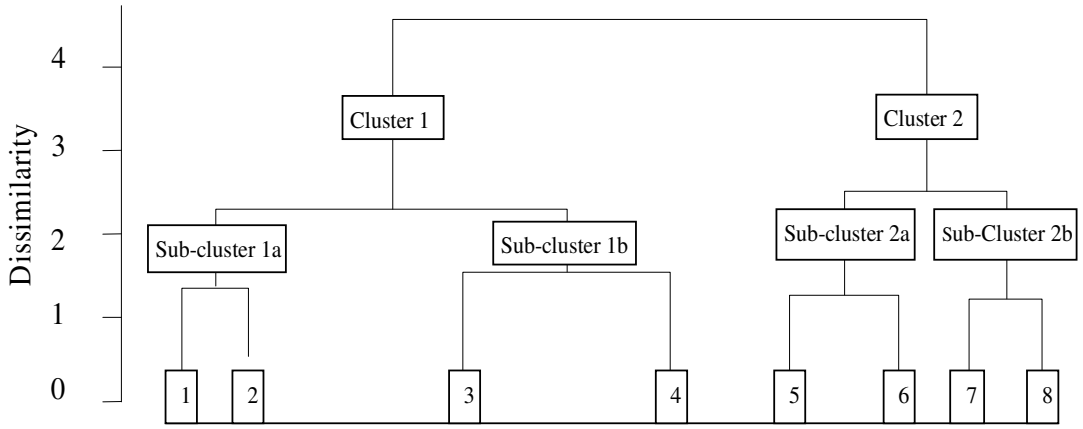

Figure 2. Pruned cluster dendrogram illustrating four supported sub-clusters into which the genotypes of similar beverage quality were grouped as determined by seven sensory variables assessed by seven cuppers.

Table 1. Diversity among cuppers in their perception of the sensory characteristics.

Cupper's	Fragrance	Flavour	Aftertaste	Acidity	Body	Balance	Preference
KE-C01	7.52ab	7.35b	7.29cd	7.43b	7.40b	7.63a	7.51b
KE-C02	7.38bc	7.48b	7.48b	7.55ab	7.57ab	7.62a	7.65ab
KE-C03	7.44ab	7.38b	7.24d	7.40b	7.45ab	7.31c	7.24c
KE-C04	7.48ab	7.48b	7.37bcd	7.61a	7.46ab	7.38bc	7.51b
KE-C05	7.20c	7.45b	7.25d	7.52ab	7.49ab	7.37bc	7.57ab
KE-C06	7.39b	7.35b	7.44bc	7.57ab	7.43ab	7.48abc	7.49b
KE-C07	7.62a	7.65a	7.67a	7.69a	7.60a	7.56ab	7.73a
Min CR (5%)	0.1788	0.1536	0.1487	0.1489	0.1634	0.1941	0.1686
CV%	5.88	5.74	5.71	5.58	5.38	6.56	6.33
SD	0.4370	0.4274	0.4219	0.4205	0.4024	0.4909	0.4764

0% dissimilarity were Yellow Amarello and HDT in one cluster, Geisha 12, Gimma Galla Sindamo and K7 in a separate cluster, Blue Mountain and Moca in another cluster, as well as Mocha Series D and Murta in their own cluster (Figure 1).

Diversity among the sensory panel

Significant variation among sensory panel was observed in all the descriptive sensory variables except body as indicated in Table 1. However, in every variable, most of them recorded close similarity in their sensory ranking thus resulting in a coefficient of variation of less than 7% (Table 1). The cupper coded KE-C07 tended to give consistently high scores in most cases and was significantly ($p = 0.05$) different from other cuppers for the variables flavour and aftertaste.

Relationship among variables

Any one sensory variable had a significant positive correlation with all other variables. However, there was no significant correlation between beverage quality characteristics and green bean physical characteristics as evident in Table 2.

DISCUSSION

The results indicated significant variation among genotypes in both beverage quality and bean physical characteristics. This was in agreement with previous findings reported by Dessalegn et al. (2008) on forty-two Ethiopian collections of arabica coffee genotypes. The relationship of genotypes based on beverage quality was analyzed using the UPGMA method of cluster analysis which grouped coffee genotypes into two major groups. The first group comprised 27 coffee genotypes, most of which are characterized by low beverage quality. The second cluster comprised the remaining 15 coffee genotypes, most of which were relatively better in beverage quality. Both clusters further bifurcated into two subclusters. The first two subclusters comprised 9 and 18 coffee genotypes while the other two sub-clusters com-

Table 2. Correlation coefficients between sensory variables and green bean physical characteristics.

	Flavour	Aftertaste	Acidity	Body	Balance	Preference	Weight of 100 beans	Bean Shape	Bean Size	Bean Uniformity
Fragrance	0.398***	0.426***	0.418***	0.470***	0.375***	0.374***	0.141^{ns}	0.102^{ns}	0.068^{ns}	-0.030^{ns}
Flavour		0.788***	0.680***	0.586***	0.526***	0.673***	-0.054^{ns}	-0.204^{ns}	0.038^{ns}	-0.083^{ns}
Aftertaste			0.727***	0.599***	0.602***	0.687***	-0.053^{ns}	-0.097^{ns}	0.035^{ns}	-0.072^{ns}
Acidity				0.684***	0.542***	0.680***	-0.033^{ns}	-0.034^{ns}	0.060^{ns}	0.044^{ns}
Body					0.491***	0.594***	-0.064^{ns}	-0.069^{ns}	0.081^{ns}	0.009^{ns}
Balance						0.616***	-0.331^{ns}	0.178^{ns}	-0.133^{ns}	0.260^{ns}
Preference							-0.219^{ns}	0.093^{ns}	-0.101^{ns}	0.099^{ns}
Bean Weight								-0.612***	0.730***	-0.606***
Bean Shape									-0.691***	0.905***
Bean Size										-0.690***

*** = Highly Significant; ns = Not Significant

prised 9 and 6 coffee genotypes. This indicates the presence of coffee genetic resource diversity in beverage quality in CRF museum.

In some past studies, some of the museum genotypes maintained at CRF have been evaluated for disease resistance, yield, and quality (Walyaro, 1983). However the consumer preferences are continually changing. Specialty buyers are looking for unique and differentiated products (Hide, 2009). Within the United States, the specialty coffee segment is the major growth area with a 20% annual growth rate and total sales in 2006 of $12.27 billion (Mintel, 2007 as reported by Condliffe et al., 2008). In 2007 some specialty coffee from Kenya was sold at $954 per 50 kg bag and this was part of some Ethiopian collection genotypes grown by an estate in Kenya (Anonymous, 2007). Therefore the diversity observed in the conserved genotypes can be exploited for improvement of beverage quality in arabica coffee.

These genetic resources should therefore be properly conserved in order to utilize them for genetic improvement of sensory coffee quality in the future.

Sensory analysis using described procedures makes it possible to study organoleptic properties of coffee using human judgement (Lingle, 2001). A reliable sensory panel is a prerequisite to quality data. In this study most of the cuppers tended to agree in most beverage quality characteristics although the cupper coded KE-C07 consistently recorded relatively higher scores. The seven therefore formed a reliable sensory panel. Owuor (1988) observed close similarity among coffee tasters in ranking various beverage quality characteristics of the cultivars, indicating that any one panel could be relied on for selection of beverage quality. However, the results of this study emphasize the importance of using a panel of many tasters with higher degrees of freedom that can allow one to discard any outlier thus ensuring more reliable results.

There were significant positive correlations between different sensory characteristics indicating that any one characteristic is an important component of beverage quality. However, aftertaste, acidity and flavor in that order showed the highest correlation with preference. Agwanda (1999) also reported high correlation between flavour and preference and recommended flavour as the best selection criterion for genetic improvement of cup quality in arabica coffee. Although, beans with low 100-bean weight had relatively better beverage quality than heavy beans, there was no significant correlations in beverage quality with bean physical characteristics. Simultaneous selection both for beverage quality and desirable green bean physical characteristics is therefore difficult. These findings contradicts Dessalegn et al., 2008 who reported the possibility of simultaneous selection for beverage quality and green bean physical characteristics

Conclusion

Overall, the study confirmed the presence of diversity in coffee beverage quality and bean physical characteristics among the forty two *C. arabica* genotypes and this could be exploited in genetic improvement through hybridization and selection. The beverage preference which is the main measure of quality showed positive and significant associations withall other sensory variables. Therefore, genetic improvement for better

beverage quality is possible. There was no significant correlation between beverage quality and bean physical characteristics. Therefore, it is difficult to use green bean physical characteristics in selection of better beverage quality in arabica coffee.

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REFERENCES

Agwanda CO (1999). Flavour: an ideal selection criterion for the genetic improvement of liquor quality in arabica coffee. In the proceedings of 18th International Scientific Colloquium on Coffee Helsinki, Finland pp. 383-389.

Agwanda CO, Baradat P, Eskes AB, Cilas C, Charrier A (2003). Selection for bean and liquor qualities within related hybrids of arabica coffee in multi-local field trials. Euphytica 131: 1-14.

Anonymous (2007). Auction; Special Coffee Fetches Top Price. Business News. Daily Nation Newspaper; 21st March. pp. 30.

Anthony F, Combes MC, Astorga C, Bertrand B, Graziosi G, Lashermes P (2002). The origin of cultivated *Coffea arabica* L. varieties revealed by AFLP and SSR markers. Theor. Appl. Genet. 104: 894-900.

Berthaud J, Charrier A (1988). Genetic resources of Coffea L. In Coffee: Agronomy, R J Clarke and R Macrae (Eds). Elsevier Appl. Sci. London. 4: 1-42.

Bertrand B, Guyot B, Anthony F, Lashermes P (2003). Impact of the *Coffea canephora* genome introgression on beverage quality of *C. arabica*. Theor. Appl. Genet. 107: 387-384.

Clifford MN (1985). Chlorogenic acids. In : R.J. Clarke and R. Macrae (eds), Coffee, Elsevier Appl. Sci. London. 1: 153-202.

Commission for Environmental Cooperation (1999). Measuring Consumer Interest in Mexican Shade-grown Coffee: An Assessment of the Canadian, Mexican and US Markets, Published by the Communications and Public Outreach Department of the CEC Secretariat p. 37

Condliffe K, Kebuchi W, Love C, Ruparell R (2008). Kenya Coffee: A Cluster Analysis. In: Professor Michael Porter, Microeconomics of Competitiveness. Harvard Business School, May 2. p. 2

Coste R (1992). Characteristics and composition of green coffee. *In* Coffee: the plant and the product. The Macmillan Press Ltd. London and Basingstoke p.328.

Davis AP, Govaerts R, Bridson DM, Stoffelen P (2006). An annotated taxonomic conspectus of the genus *Coffea* (*Rubiaceae*). Bot. J. Linnean Soc. 152: 465-512.

Dessalegn Y, Labuschagne MT, 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.) Society of Chemical Chemistry. J. Sci. Food Agric 88: 1726-1730.

FAO (1968). FAO Coffee Mission to Ethiopia 1964–1965. FAO, Rome.

Hampson CR, Quamme HA, Hall JW, MacDonald RA, King MC, Cliff A (2000). Sensory evaluation as a selection tool in apple breeding Euphytica 111(2): 2000

Hide R (2009). Beyond certifications: Taking sustainable African specialty coffees to the next level, EAFCA, Kigali 12th February.

Jaetzold R, Schimidt H (1983). Farm Management Handbook of Kenya, Vol. II/B:, Natural Conditions and Farm Management Information, Central Kenya. Ministry of Agriculture, Nairobi Kenya p.731.

Kimemia JK, Chweya JA, Nyabundi JO (2001). Green Manure Decomposition and Nitrogen Mineralization. In: Green Manure Application to Coffee Plants After Establishment. Kenya Coffee 66 (772): 3046-3051

Lashermes P, Combes MC, Robert J, Trouslot P, Hont AD, Anthony F , Charrier A (1999). Molecular characterization and origin of the Coffea arabica L. genome. Mol. Genet. 261: 259-266

Lashermes P, Trouslot P, Anthony F, Combes MC, Charrier A (1996). Genetic diversity for RAPD markers between cultivated and wild accessions of Coffea arabica. Euphytica 87: 59–64

Lingle TR (2001). The Cuppers Handbook. Systematic Guide to the Sensory Evaluation of Coffee`s Flavour, Third edition pp 71.

Macrae R (1985). Nitrogenous compounds. In : Clarke RJ, Macrae R (eds), Coffee, Elsevier Appl. Sci. London. 1: 115-152.

Millot F (1969). Inventory of the Coffee Varieties and Selections Imported into and Growing Within East Africa. Record of Previous Selection and Breeding Work. East African Agriculture and Forestry Research Organization, Nairobi, Kenya 193 p.

Moncada P and McCouch S (2004). Simple sequence repeat diversity in diploid and tetraploid *Coffea* species. Genome 47: 501-509.

Muschler RG (2001). Shade improves coffee quality in a sub-optimal coffee zone of Costa Rica. Agrofor. Syst. 51:131-139.

Owuor JBO (1988). An Assessment of the Cup Quality of the New Disease Resistant *Coffea arabica* cultivar Ruiru 11 in Kenya. Acta Hortic. 224: 383-388.

Pearl HM, Nagai C, Moore PH, Steiger DL, Osgood RV, Ming R (2004). Construction of a genetic map for arabica coffee. Theor. Appl. Genet. 108: 829-835.

Roche D (1995). Coffee Genetics and Quality. In the proceedings of the 16th International Scientific Colloquium on Coffee pp. 584-588. Kyoto, Japan.

SAS Institute (2005). SAS Users Guide; SAS/STAT, Version 9.1. Cary (NC, USA): SAS Inst. Inc.

Silvarolla MB, Mazzafera P, Fazuoli LC (2004). A naturally decaffeinated Arabica coffee. Nat. 429: 826

Steiger DL, Nagai C, Moore PH, Morden CW, Osgood RV, Ming R (2002). AFLP analysis of genetic diversity within and among *Coffea arabica* cultivars. Theor. Appl. Genet. 105: 209-215.

Van der Vossen HAM (1985). Coffee Selection and Breeding. In: Clifford MN, Willson KC (Eds.) Coffee Botany, Biochemistry and Production of Beans and Beverage, Croom Helm, London pp. 49-96. Venables WN, Smith DM, R Development Core Team (2006). An introduction to R: A programming environment for data analysis and graphics. Version 2.5.1. Online publication: <http://www.r-project.org>

Walyaro DJA (1983). Considerations in Breeding for Improved Yield and Quality in Arabica Coffee (*Coffea arabica* L.). A PhD thesis, Wageningen Agricultural University.

Wellman FL (1961). Coffee: Botany, Cultivation and Utilization. Leonard Hill Books, London.