Research Article

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Cup quality profiles of Robusta coffee wilt disease resistant varieties grown in three agro-ecologies in Uganda

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Abstract

BACKGROUND: The recently developed Robusta coffee wilt disease resistant (CWD-r) varieties in Uganda outperform the local landraces, both in yield and resilience. However, their uptake has been slow due to limited information on their cup worth. This study profiled the cup worth of the five most commonly grown CWD-r across the Lake Victoria Crescent, Western Mid-altitude farmland and Central Wooded Savannah agro-ecologies.

RESULTS: Significant correlations ($P \leq 0.05$) were observed between soil nutrients and coffee bean size but this was not the case for biochemical and cup quality. The proportion of coffee beans retained on screen 15; minimum acceptable size through coffee commercial markets, ranged from 58.09% in Mukono to 92.49% in Mityana. Interestingly, the bean size of variety KR4 was hardly influenced by environmental variations, with portions of beans retained on screen 15 being relatively the same (80.30% Ibanda, 89.50% Mukono, 98.20% Mityana). Coffee cup quality for most of the varieties was scored as premium (70–79%) across three agro-ecologies, with the exception of KR4, which was scored specialty grade (≥80%). Coffee blends generated were used to make coffee products with specialty score (82.25%) and a distinctive aroma complex.

CONCLUSION: In this study, blends of CWD-r resulted in superior cup scores (76–82%). These findings show that CWD-r varieties have a high cup worth with potential for wide adaptation in Uganda's Robusta coffee growing agro-ecologies. Most importantly, variety KR4 has resilience across three agro-ecologies with a consistent high bean size and superior cup quality, making it a candidate variety for the market and breeding.

Keywords: biochemical analyses; soil nutrients; physical quality; Robusta coffeeagro-ecological zones of Uganda

INTRODUCTION

The coffee industry in Uganda accrues revenues from Robusta and Arabica coffee, with Robusta contributing over 80% of the total production.[1] Robusta is grown in the low altitude areas [1200–1500 m above sea level (a.s.l.)] of Lake Victoria Crescent, Central Wooded Savanah, Western Mid-altitude farmland, South East, Southern dry lands and Lake Albert Crescent Region where it is plagued with coffee wilt disease (CWD).[2] In the early 1990s, CWD wiped out approximately 60% of Robusta coffee trees, causing an estimated loss worth US$ 259 million.[2] This prompted the National Agricultural Research Organization (NARO) to develop CWD resistant (CWD-r) varieties; an effort that resulted in the release of seven varieties (seven CWD-r).[3] The CWD-r varieties were developed by screening naturally infected Robusta coffee fields and inoculating selected plants in the screen house. The disease resistant plants were then evaluated in multi-locational trials for growth and yield performance, disease and pest resistance, prior to their commercial release.[4] Currently, the CWD-r varieties far out perform the existent local landraces, yielding 3.2 tons of green beans per hectare compared to 1.8 tons per hectare of landraces.[3] The CWD-r varieties also have other desirable qualities but with limited information on the worth of cup quality across agro-ecological zones. This has resulted in the low uptake both by farmers and product end-users.

Cup quality is influenced by genetic and environmental factors (altitude, shade, soil fertility, rainfall, water retention and soil acidity and types).[5,6] The diversity of coffee quality due to the genetics and environment interaction, results in a variation of the physical quality and biochemical components accumulating within the coffee bean during development.[7] Subsequently, the biochemical compounds are modified during roasting which influences the final cup quality.[5,8] The current market trends depict a drive in

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the demand for speciality coffees, which command premium prices, according to the International Coffee Organization (ICO),[9] a premium of 11 to 15% is paid on every ton of specialty coffee. Speciality coffees are determined by cup worth.

Differentiating the CWD-r varieties cup quality for the three agro-ecological zones, can enable them to be marketed as speciality coffee both locally and internationally. Therefore this study aimed at profiling five of the seven CWD-r varieties which are currently grown in three major agro-ecological zones in Uganda and producing coffee products suited to consumers' demands.

MATERIALS AND METHODS

Description of study area

The study was conducted in Uganda in three agro-ecologies; Lake Victoria Crescent (Mukono district at the National Coffee Research Institute), Western Mid-altitude farmland (Ibanda district at the Ankole Coffee Processors), and Central Wooded Savannah (Mityana district at CWD-r farmer's field) (Fig. 1). Mukono district is geographically located between latitude 0.480567 and longitude of 32.770567, at an altitude between 800–1160 m a.s.l. The district receives an average annual rainfall of 1390 mm with an average temperature of 21.5 °C. Ibanda district is geographically located between latitude 0.1167 and longitude of 30.4991, at an altitude between 1000–1800 m a.s.l. and consists of undulating highlands. Ibanda district receives an average rainfall of 1200 mm distributed over two rainy seasons with annual average temperatures of 23.5 °C. Mityana district is located between latitude of 0.4016 and longitude of 32.0440, at an altitude of about 1209 m a.s.l. and receives an average annual rainfall of 1206 mm with an average temperature of 21.2 °C.

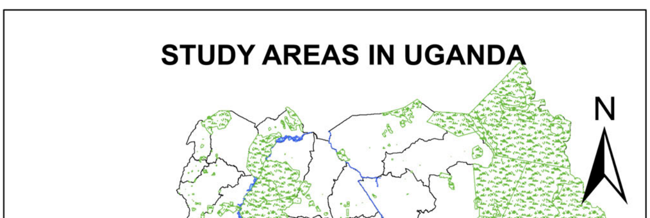


Figure 1. Map of Uganda showing the study areas agro-ecologies; Lake Victoria Crescent (Mukono), Central Wooded Savanah (Mityana) and Western mid-altitude farmland (Ibanda).

Experimental materials and design

Only five of the seven CWD-r varieties were found to be grown in the selected agro-ecological zones. These include Kituza Robusta (KR); KR3, KR4, KR5, KR6 and KR7. The varieties were located in fields which were established in 2007 in Ibanda, Mukono and Mityana districts as demonstration and trial fields. These fields were laid out in a randomized complete block design (RCBD) with three replicates at a spacing of 10 ft × 10 ft. All the fields were managed under uniform good agronomic practices (GAPs) of weeding, pruning, and fertilizer application as recommended in the Robusta Coffee Handbook.[10]

Soil sampling and determination of physio-chemical properties

Soil sampling was done using the bucket soil auger (Bayonet, 2¾″, Eijkelkamp, Morrisville, NC, USA). Each field was divided in to three rectangles from which nine soil samples were picked at a depth of 15 cm and mixed thoroughly. A composite sample of 0.5 kg was taken from each mixture, packed in a paper bag, labeled and transported to Makerere University Plant and Soil Analytical Laboratories for physical and chemical analyses. The soil samples were then air dried under shade for 48 h and later pounded, sieved through 2 mm to remove any debris and thereafter subjected to physio-chemical analysis following standard methods described by Okalebo *et al.*[11]

Cherry harvesting and processing

Red coffee cherries were picked in 2017 during the peak harvesting period of May to August in Ibanda, September to November in Mukono and Mityana, and weighed. Coffee cherries were then sun dried as described by Uganda Coffee Development Authority (UCDA)[2] and hulled to obtain fair average quality (FAQ) green beans. The resultant FAQ beans were packed and labeled for further analyses.

Coffee bean physical analysis

FAQ beans were weighed to calculate the outturn percentage, wherein outturn describes the quantity of clean coffee obtained from a known quantity of coffee cherries (UCDA).[2] Packed and labeled samples were delivered to UCDA quality laboratory for analysis. Before analysis, the moisture content of the samples was checked using an electronic rapid moisture meter (Agrotronix coffee tester) to ensure that the analyzed samples were in the range of 11.5 to 13% for consistency of results.[1] The samples were analyzed for beans size and weight following a method described by the Coffee Quality Institute (CQI).[12] Bean size was determined by conventional screen analysis using coffee standard screen sieves in which a total weight fraction of 350 g of green coffee beans retention of screen 15 and above was recorded and the percentage calculated. A minimum retention on screen 15 was considered because it is the minimum acceptable size in the commercial coffee trade channels according to the ICO.[9] One hundred sound beans were randomly selected from 350 g of each sample and their weight measured in grams using a two-digit electrical sensitive balance.[12]

Extraction and determination of coffee biochemical compounds

Briefly, 50 g of dry coffee bean samples were dried in an oven at 45 °C for 48 h to eliminate moisture before grinding the samples for further analysis.[13] The samples were ground and sieved to obtain a particle size below 0.5 mm. Next, 6 g of each of these samples were then packed in air-tight glass bottles and relabeled for further analyses of oil, sucrose, caffeine, trigonelline and chlorogenic acid content.

Oil content was determined by the Soxhlet method as defined by the Association of Official Agricultural Chemists (AOAC) methods.[13] Briefly, 5 g of powdered sample was refluxed with petroleum ether for 8 h. The extracts were evaporated by a rotary evaporated in an oven at 60 °C until all the petroleum ether was evaporated. The flasks containing the oil were dried in an oven until a constant weight was achieved.

Sucrose was extracted and its absorbance read using spectrophotometry at 630 nm wavelength as detailed by Gimase *et al*.[6]

The caffeine concentration was determined using flame ionization detector (FID) gas chromatography-mass spectrometry.[13]

Trigonelline and chlorogenic acid content were analyzed by high-performance liquid chromatography (HPLC) with a photodiode array detector and C18 column. The mobile phase consisted of deionized water, methanol (HPLC grade) and acetic acid in the ratio of 85:15:1 at 1 mL min^{-1} flow rate. The wavelength used were 266 nm for trigonelline and 254 nm for chlorogenic acid. Standard solution for each compound was employed for the peak identification and quantification as defined by Gimase *et al*.[6]

Cup quality evaluation

Briefly, 50 g of green dry beans underwent a medium roast (220 °C for 25 min) using a probat laboratory roaster (PROBAT-Werke, Germany, model 4GN10K, Emmerich Machine Factory, Emmerich, Germany) to ensure uniform roasting. The samples were kept for 8 h to allow for degassing and then ground using a laboratory grinder (ML-INX, serial no.401, USA). A rinsing quantity of every sample was run through the grinder before grinding the test sample. Each ground sample was then deposited into six coffee tasting cups while ensuring whole and consistent quantities in each cup. The ground samples were then infused in hot water using a predetermined ratio of 8.25 g per 150 mL of water prior to cupping. A sensory evaluation procedure described by Lingle[14] was followed; ten sensory variables were assessed by a panel of six certified coffee cuppers aged between 26 to 32 year. The coffee cup quality was rated on a ten-point scale. Total scores were tallied and coffees graded based on the Specialty Coffee Association (SCA) scoring system; ≤70% = commercial grade, 70–79% = premium grade and ≥80% = specialty grade.[15]

Processing value added products from coffee wilt disease resistant (CWD-r) varieties

Blends of coffee from the three locations were made in the ratio of 1:1 (Mityana KR3– MukonoKR3); 1:1:1 (MityanaKR5–IbandaKR7–MukonoKR3) and 2:1 (MityanaKR5–MukonoKR3). The ratios were informed by the coffee cup taste scores obtained for the individual varieties from the three locations considering the varieties with highest scores. The cup quality evaluation of the three blends was done in duplicate. The blend with highest cup score was used to produce coffee powder and cold brew following roasting processes as described by Lingle,[14] with a few modifications. The cold brew was produced by extracting the ground coffee liquor using a percolating system with a micron sieve to remove the solid particles. The liquor was dissolved in water at a ratio of 1:5 (liquor–water) and heated to pasteurization at a temperature of 85 °C for 5 min with permitted preservatives at a ratio of 0.05%.

Data analysis

Data on soil factors, physical quality, cup quality and chemical quality of coffee were tabulated and subjected to analysis of variance using GenStat (version 16). The means were separated using least significant difference (LSD) values at 5% error margin to ascertain significance of differences. Principal component analysis (PCA) was performed to show the relationship between coffee varieties, soil nutrients, biochemical and cup profiles using XLSTAT statistical software, version 2012.

RESULTS

Soil physio-chemical properties and their effect on coffee bean physical quality

The results show that all three study districts have varying soil textures (Table 1). All fields exhibited low composition of critical soil nutrients with the exception of calcium ion (Ca^{2+}, 0.25 cmol kg^{-1}). There was no significant difference ($P \geq 0.5$) in the composition of all soil nutrients across the three districts with the exception of organic matter (OM). Mityana and Mukono (3.74% and 3.27% respectively) had significantly higher OM percentage than Ibanda (2.35%). The results also show that Mityana had better ratio over Mukono and Ibanda since its NPK (nitrogen, phosphorus and potassium) values were within the soil nutrient critical values. Results also reflect that the pH value for Mityana was within the recommended range of 5.5 to 6.8 unlike Ibanda and Mukono, which had more acidic soils.

Table 2 shows the variations in the bean size (percentage retention on ≥ screen 15) and weight of 100 sound beans. Percentage of beans retained on screen 15 and above ranged from 58.09% to 98.67% except for KR5 from Mukono which had a significantly ($P \leq 0.05$) low retention percentage of 26.23%. Bean weights ranged from 8.52 g for KR6 in Mukono to 23.67 g for KR7 in Mityana. There was a significant ($P \leq 0.05$) difference in the fraction of green beans retained on screen 15 and the bean weight of the same varieties grown in the Ibanda, Mukono and Mityana. Mityana district is noted to have the biggest coffee bean sizes and weights for all five varieties. Mukono district distinctly has the lowest bean size and weight with the exception of varieties KR4 and KR7. There was also a strong positive association ($r^2 = 81.71\%$, $P < 0.05$) between bean size and weight for all five varieties in all three locations. This could imply that bean size for the five CWD-r varieties increases with bean weight.

The results in Table 3 show the relationship between the soil properties and the coffee bean physical properties. There was statistically significant correlation between the coffee bean weight and soil properties such as cation exchange capacity (CEC), the OM, K and P. Bean size, however, is positively correlated to CEC, OM and soil pH. Only N had no effect on the coffee physical bean qualities.

Biochemical and sensory cup profiles

Table 4 shows the biochemical profiles of the CWD-r Robusta varieties at the three locations as defined by content of oil, sucrose, caffeine, trigonelline and chlorogenic acid. The biochemical profiles varied for each variety in each location, albeit with no statistical significance ($P \geq 0.05$). Oil content ranged from 33.20

Table 1. The soil nutrient and texture properties of the study areas and their comparison with the soil nutrient critical values

Soil property	District			LSD (5%)	CV%	Soil-nutrient critical values
	Ibanda	Mityana	Mukono			
pH*	4.80[a]	5.533[a]	4.967[a]	0.499	1.0	5.5–6.8
OM (%)*	2.35[a]	3.74[b]	3.27[b]	0.687	12.2	>3%
P (pmm)*	15.20[a]	21.90[a]	18.80[a]	15.94	12.7	20
K^+ (cmol kg^{-1})*	0.67[a]	0.52[a]	0.65[a]	0.374	24.6	0.4
N (%)**	0.202[a]	0.220[a]	0.218[a]	0.109	12.6	0.25
Ca^{2+} (cmol kg^{-1})*	3.97[a]	4.93[a]	3.97[a]	2.616	7.6	0.25
Mg^{2+} (cmol kg^{-1})*	1.93[a]	1.70[a]	1.35[a]	1.197	1.9	0.25
CEC (cmol kg^{-1})*	6.57[a]	8.13[a]	5.97[a]	3.004	3.4	16
Soil texture	Sandy-clay-loam soils	Sandy-loam soils	Loam soils			

Mean values within the same superscript (letter) are not significantly different at $P \leq 0.05$.
*Significant at 5%.
**Significance at 1%.
OM, organic matter; P, phosphorus; K^+, potassium; N, nitrogen; Ca^{2+}, calcium ion; Mg2$^+$, magnesium ion; CEC, cation exchange capacity; LSD, least significant difference; CV, coefficient of variation.

mg g^{-1} for KR5 in Mukono to 76.20 mg g^{-1} for KR7 in Mityana. Sucrose levels in Ibanda ranged between 34.60 and 56.40 mg g^{-1}, in Mityana between 29.90 and 50.90 mg g^{-1} and in Mukono, between 26.70 and 41.30 mg g^{-1}. Caffeine content ranged from 11.10 to 25.80 mg g^{-1} in Mukono, followed by Ibanda (12.60–25.10 mg g^{-1}) and Mityana (11.20–24.10 mg g^{-1}). Varieties in Mityana had higher chlorogenic acid between 57. 50 and 76.20 mg g^{-1} followed by varieties in Ibanda with values between 54.30 and 77.60 mg g^{-1} and lastly varieties in Mukono with values ranging from 56.70 to 75.30 mg g^{-1}.

Figure 2 shows the cup profiles of CWD-r varieties from three agro-ecologies, with scores spread over the specialty scale. The results showed that all of the varieties regardless of the location passed as premium coffees (score 70–79%), with the exception of varieties KR4, KR5 and KR6 which scored as specialty grade (≥80%) for the case of Mityana.

When the data was subjected to discriminant analysis, the two discriminant factors explained 100% (89.95, 10.05) of the total variation. The negative side of the graph was characterized by oil, sucrose, caffeine, trigonelline and chlorogenic acid, while the positive side was characterized by cup score (specialty score). Varieties grown in all three agro-ecologies were placed both in the positive and negative side of the graph (Fig. 3).

A correlation analysis was run to assess which biochemical compounds contribute to the total cup scores attained and which of the ten sensory variables are vital in grading coffee (Table 5). The correlation results depicted that biochemical compounds chlorogenic acid, oil, sucrose, trigonelline and caffeine have a

Table 2. The green bean quality of coffee wilt disease resistant (CWD-r) Robusta varieties grown in Mityana, Ibanda and Mukono districts of Uganda

Location	Variety	Parameters	
		Bean size (percentage retention on screen 15 and above)	Weight (g) of 100 sound beans
Ibanda	KR3	85.27[b]	16.12[b]
Mukono	KR3	65.33[a]	12.74[a]
Mityana	KR3	91.87[b]	16.40[b]
Ibanda	KR4	80.30[a]	15.59[ab]
Mukono	KR4	89.50[ab]	14.14[a]
Mityana	KR4	98.20[b]	17.19[b]
Ibanda	KR5	59.73[b]	12.12[b]
Mukono	KR5	26.23[a]	9.50[a]
Mityana	KR5	84.67[c]	16.33[c]
Ibanda	KR6	67.33[b]	13.66[b]
Mukono	KR6	26.70[a]	8.51[a]
Mityana	KR6	89.03[c]	14.50[b]
Ibanda	KR7	72.40[a]	13.04[a]
Mukono	KR7	82.70[abc]	14.42[ab]
Mityana	KR7	98.67[c]	23.67[c]
LSD (5%)		9.127	0.892
CV%		0.4	0.3

Mean values followed by the same superscript (letter) within the same column are not significantly different at $P \leq 0.05$.
LSD, least significant difference; CV, coefficient of variation.

Table 3. Correlation between soil properties and physical quality parameters (bean size and weight) of coffee wilt disease resistant (CWD-r) from districts of Uganda

Soil nutrient parameters	Physical quality parameters	
	Weight (g) of beans	Percent of beans ≥ 15
K (cmol kg^{-1})	0.6882*	0.2476
% N	0.126	0.1342
P (pmm)	0.5076*	0.2573
CEC (cmol kg^{-1})	0.321*	0.38*
% OM	0.5741*	0.7156*
pH	0.1988	0.4291*

*Values have a significant relationship at $P \leq 0.05$.
K, potassium; N, nitrogen; P, phosphorus; CEC, cation exchange capacity; OM, organic matter.

Table 4. Biochemical composition of coffee wilt disease resistant (CWD-r) varieties grown in the three agro-locations dry matter basis

	Oil (mg g^{-1})			Sucrose (mg g^{-1})			Caffeine (mg g^{-1})			Trigonelline (mg g^{-1})			Chlorogenic acid (mg g^{-1})		
Variety	Ibanda	Mityana	Mukono	Ibanda	Mityana	Mukono	Ibanda	Mityana	Mukono	Ibanda	Mityana	Mukono	Ibanda	Mityana	Mukono
KR3	41.60[a]	60.00[a]	54.10[a]	37.70[a]	47.90[a]	34.40[a]	22.50[a]	12.70[a]	23.70[a]	4.70[a]	6.70[a]	5.52[a]	66.10[a]	63.80[a]	66.30[a]
KR4	68.70[a]	41.10[a]	46.80[a]	56.30[a]	29.90[a]	38.90[a]	12.80[a]	23.20[a]	25.80[a]	7.80[a]	5.60[a]	8.62[a]	65.80[a]	57.50[a]	75.30[a]
KR5	43.20[a]	43.20[a]	33.20[a]	36.40[a]	37.30[a]	26.70[a]	23.60[a]	24.10[a]	21.00[a]	6.20[a]	7.40[a]	6.42[a]	54.30[a]	63.30[a]	58.60[a]
KR6	62.50[a]	43.10[a]	48.80[a]	55.40[a]	33.20[a]	41.30[a]	12.90[a]	22.60[a]	11.10[a]	6.50[a]	7.50[a]	5.10[a]	66.00[a]	72.10[a]	56.70[a]
KR7	54.90[a]	76.20[a]	43.00[a]	34.60[a]	50.90[a]	28.70[a]	25.10[a]	11.20[a]	22.70[a]	8.10[a]	7.10[a]	5.12[a]	77.60[a]	76.20[a]	65.40[a]
LSD	4.077			3.679			2.216			0.612			2.807		
CV%	6.8			19.8			49.7			17.6			4.3		

Mean values followed by the same superscript (letter) within the column are not significantly different at $P \leq 0.05$.
LSD, least significant difference; CV, coefficient of variation.

statistically positive correlation with cup scores ($P \leq 0.05$). Of the sensory variables, only aroma is statistically positively correlated with the cup scores ($P \leq 0.05$). The results further show that aroma has a positive statistical correlation to chlorogenic acid, sucrose, caffeine, acidity, mouthful and bitter-sweet.

Product development

Figure 4 shows results of the cup superiority of the blends against specialty grading (≤70% = commercial grade, 70–79% = premium quality and ≥80% = specialty coffee). The results showed that blend ratios of 1:1 (Mityana KR3–Mukono KR3) and 2:1 (Mityana KR5– Mukono KR3) had a cup taste which qualified as specialty but ratio 1:1:1 (Mityana KR5–Ibanda KR7–Mukono KR3) scored as a premium coffee. The coffee blend of Mityana KR5–Mukono KR3 at a ratio of 2:1 had the highest specialty score of 82.25% with a characteristic aroma/flavor complex of strawberries, caramel, chocolate, roasted hazelnuts, coffee blossom, molasses, butter, smooth creamy mouth feel, and malic (apple) acidity as was perceived by the cuppers.

DISCUSSION

Soil physio-chemical properties and their effect on coffee bean physical quality

Bean size variation across agro-ecologies for varieties KR3, KR5, KR6 and KR7 were observed, which was not the case for KR4. This implies that variety KR4 is a robust genotype that can attain a high bean size across Uganda's Robusta growing areas. Bean size is influenced by agro-ecological conditions like temperatures, light intensity, soil moisture stress and soil nutrients.[6] The growth factors favor the development of the coffee bean, its expansion and size uniformity.[16,17] In Mukono, KR5 recorded six poor physical qualities (Table 2) despite having conducive environmental conditions. This may indicate that the varieties are not well-suited to Mukono, or perhaps the agronomic practices on the farms in Mukono fall short of the recommended GAPs.[18]

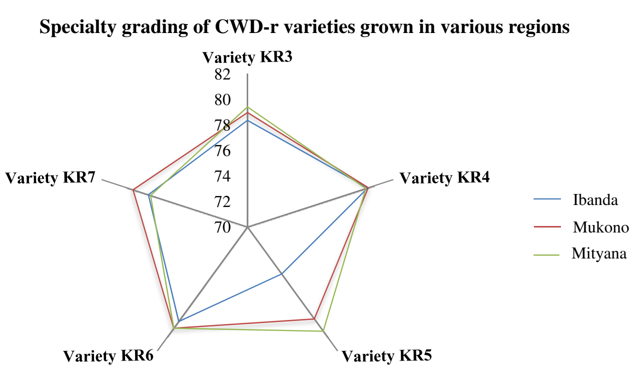
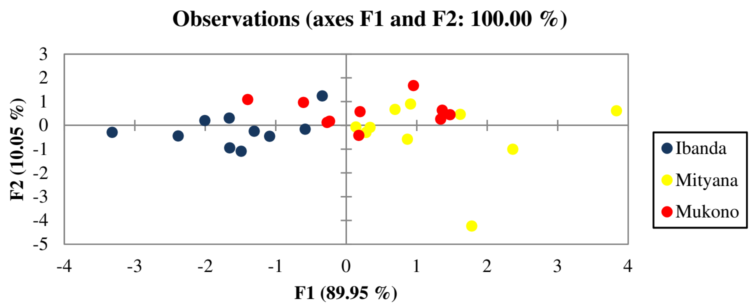


Figure 2. Performance of the CWD-r Robusta varieties per agro-ecology against the specialty scale.

The Robusta coffee growing regiment recommends growing the varieties in a composite. Despite the observed bean size variations amongst KR3, KR5, KR6 and KR7; the overall retention of beans on screen 15 was above 60% across the agro-ecologies which is the minimum acceptable size through the market channels.[19] This implies that the coffee rejects (remaining 40% or less) can be channeled to alternative valuable commercial products such as instant coffee and beauty products[20] thus diversifying farmer incomes.

The highest bean weight was found for the beans with large screen size, particularly for the coffee samples from Mityana. The CWD-r Robusta coffee in the study had a weight range of 8.51 to 23.67 g, these weights are in the range of the average bean weight of Uganda's Robusta (12–15 g) as reported by the ICO.[15] Among many factors, the bean weight is influenced by environmental conditions like shade, soil moisture and soil nutrient.[7,21] During the development stage of the coffee cherry, light intensity slows bean maturation which increases and unifies bean fill thus increased bean weight.[7,22] It can therefore be hypothesized that the high altitude in Ibanda and Mityana (1800 and 1209 m a.s.l. respectively) partly influenced light intensity which influenced development thus the high bean weight.

The bean size and weight are reported to be affected by the soil nutrition and quality.[23] In the current study, soil quality (K, P, CEC, OM and pH) had a positive correlation with weight and size implying that the physical quality of the coffee beans improves with good soil quality (fertility and texture). CEC represents the total sum of the exchangeable basic cations on the soil colloids, Mityana soils had relatively higher CEC of 8.13 cmol kg^{-1} compared to Mukono and Ibanda, this could explain why it had coffee beans with higher size and weight. According to findings reported by the FAO (Food and Agriculture Organization of the United Nations),[24] the CEC gives the relative fertility of soil, and this subsequently influences the bean quality (weight and size). OM represents the micro nature of the soils and determines the bioavailability of the nutrients and their uptake which directly



Variable	F1	F2
Fat	-0.3	-0.102
Sucrose	-0.531	0.054
Caffeine	-0.407	-0.2
Trigonelline	-0.097	-0.733
Chlorogenic acid	-0.29	-0.155
Specialty score	0.366	0.508
Eigen value	1.57	0.175
Discrimination (%)	89.951	10.049
Cumulative %	89.951	100

Figure 3. Discriminant analysis of two discriminant factors illustrating a negative relationship for biochemical bean properties and a positive relationship for cup scores amongst CWD-r varieties grown in Ibanda, Mityana and Mukono. Corresponding eigen values show no statistical difference (≥0.05).

Table 5. Correlation coefficients of sensory attributes of coffee cup taste with the biochemical compounds in coffee bean

Variable	Bitter-sweet	Trigonelline (mg g^{-1})	Sucrose (mg g^{-1})	Acidity	Mouth feel	Oil (mg g^{-1})	Aroma	Flavor	Chlorogenic acid (mg g^{-1})
Bitter-sweet									
Trigonelline (mg g^{-1})	−0.612*								
Sucrose (mg g^{-1})	0.333	0							
Acidity	0.018	0.893*	−0.890*						
Mouth feel	0.137	0.764	0.747*	0.0011					
Oil (mg g^{-1})	0.500*	0	0	0.966*	0.943*				
Aroma	0.984*	0.198	0.509*	0.983*	0.983*	0.295			
Flavor	0.117	0.116	0.192	0.431*	0.196	0.121	0.238		
Chlorogenic acid (mg g^{-1})	−0.759*	0	0	0.948*	0.957*	0	0.310*	0.214	
Caffeine (mg g^{-1})	0.202	0	0	0.877*	0.647*	0	0.395*	0.107	0

*Values have a statistically significant association at $P \leq 0.05$.

influences the bean quality.[25] Potassium in coffee pulp is considered a key component for accumulation of bio-compounds such as sugars, chlorogenic acids and oils in the coffee bean which also improves the coffee bean weight.[21,23] This could explain the positive correlation of soil quality and bean weight and size as observed in the current study. The findings in the current study also agree with the findings of Clemente *et al.*[26] who reported that high K enhances accumulation of biocompounds thus increasing the bean weight.[8]

Sensory cup quality of coffee wilt disease resistant (CWD-r) varieties

All the varieties (KR3, KR5, KR6 and KR7) were premium with cup scores ranging from 77% to 79.8% across three agro-ecologies except KR4 which had specialty score average of 80%. The cup quality results obtained for the KR varieties compare with commercial Robusta varieties commonly grown in Uganda (Nganda and erecta-landraces) which have cup scores of 75 to 81% as reported by Aluka *et al.*[27] KR4 variety showed consistency in the cup quality across three agro-ecologies (Fig. 2), this shows its resilience in the Robusta growing areas of Uganda. The complex trait of coffee cup profile trait is influenced by interaction of several factors ranging from genetics, harvesting time and methods, shade management, soil nutrient, elevation, climate and geographic location.[28]

Association between biochemical components and cup quality has been studied by several researchers.[5,29] The biochemical profiles (oil, sucrose, caffeine, trigonelline and chlorogenic acid) of the CWD-r coffee varieties from three agro-ecologies of Mityana, Ibanda and Mukono ranged from 33.20 to 76.20 mg g^{-1}, 34.60 to 56.40 mg g^{-1}, 11.10 to 25.80 mg g^{-1}, 4.70 to 8.60 mg g^{-1} and 54.30 to 77.60 mg g^{-1} respectively. Though variations in values reported was observed (Table 4), they were not significant ($P \geq 0.05$). The observed variation in the biochemical profiles could be due to the environmental factors such as altitude, rainfall patterns and soil nutrient.[30]

In this study a significant correlation between the biochemical compounds and the sensory attributes of the coffee cup was portrayed. Acidity, mouth feel and sweetness of the cup were strongly associated with sucrose, trigonelline and chlorogenic acid (Table 5). For sweetness and bitterness, a positive correlation was noticed with increasing sucrose levels, hence the acidity and bitterness reduced with increase in sucrose and increased with increase in trigonelline and chlorogenic acids. The acidity, sweetness, and mouth-feel have always been recognized as important attributes of coffee sensory quality and specialty grading and they showed strong positive association with the coffee cup aroma. These biochemical compounds therefore contribute to the aroma of the coffee cup.[30] The biochemical compounds contributing to these sensations are formed during the development of the coffee bean while some are developed during the roasting stage.[29] During roasting, trigonelline gives rise to flavor products including furans, pyrazine, alkyl-pyridines and pyrroles. High levels of sucrose and lipids act as flavor binders thus improving the cup quality and contributing to sweetness.[30]

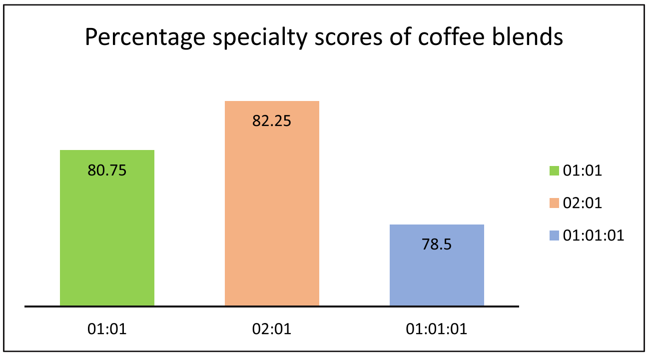


Figure 4. Cup taste scores of the coffee blends. Key: Blend ratios. 1:1, MityanaKR3–MukonoKR3; 2:1, MityanaKR5–MukonoKR3; 1:1:1, MityanaKR5–IbandaKR7–MukonoKR3.

Despite the fact that the varieties scored premium with the exception of KR4 which scored specialty, Uganda's Robusta coffee is usually marketed as a blend for the Arabica consumer.[31] When the CWD-r varieties were blended, one of the blends gave a specialty score of 82%. This makes blending a diversified approach to selling Uganda's Robusta all the while fetching a higher price than it usually would if it is sold as a blend for Arabica coffee. This could therefore increase the price for Uganda's CWD-r Robusta coffee varieties on the world market.[15,32] The results in blends further point out the importance of Robusta coffee blends from different agro-ecologies. These perhaps improve the cup uniformity in terms of cleanliness, sweetness and balance thus superior cup quality. KR4 can be marketed on its own without being blended and possess genetic traits that make it a good candidate for breeding studies.

CONCLUSION AND RECOMMENDATION

The physical quality (beans size and weight) of CWD-r coffee varieties had high correlation with the soil nutrient and quality in all the three studied agro-ecologies. The varieties also exhibited relatively good bean size qualities in all the agro-ecologies, therefore they can be adopted across the Robusta growing agro-ecological zones in Uganda. A good biochemical profile of the varieties was also demonstrated and these influenced the cup quality traits. Blending of varieties grown in different regions resulted into specialty scores, this indicates that blends of the CWD-r from different regions can be made for enhanced cup taste. Variety KR4 was scored as speciality and can be marketed as it is without any need for blending, thus fetching a higher price. It is hoped that the findings of this study can enhance utilization and profitability of the CWD-r varieties, with the robust KR4 being singled out for coffee breeding purposes due its consistency in bean size and cup quality across the three agro-ecologies.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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