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Screening for Drought Tolerance among *Coffea arabica* Cultivars in Kenya

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Abstract **– Drought is an environmental factor that produces water deficit or water stress in plants. Internal water deficit is initiated when low water potential develops and cell turgor begins to fall below its maximum value. The aim of this study was to identify genotypes from the seedling stage that could withstand moisture stress. The seedlings were raised from seed and at 10 months after transplanting they were arranged in a three replicate randomized complete block design (RCBD) under controlled conditions in a green house. Response measurements were made (i) 30 days after moisture stress period, and (ii) at the end of 15 days recovery period. The measurements were made by uprooting three seedlings in the morning then separating the plants into leaves, stems and roots respectively to obtain the Dry Matter, Leaf Mass Ratio, Root Mass Ratio and Shoot Mass Ratio. Other parameters measured included Plant height and girth. The data was be subjected to Analysis of Variance (ANOVA) using COSTAT statistical software and effects declared significant at 5% significance level. Least Significance Difference was used to separate means. Significant changes on Dry Matter partitioning, Leaf Mass Ratio, Plant height and girth was recorded during both water stress and during recovery period. Batian 1, Batian 2, Batian 3, DR 2, Rume Sudan, Code 135 and Code 2 performed better under moisture stress varieties and should be evaluated further in the field for drought tolerance to be able to select the best performing genotype.**

Keywords **–** ***Coffea arabica*****, Drought, Dry Matter, Genotypes.**

I. INTRODUCTION

The genus coffea has about 90 species of which *C. arabica* L. (Arabica coffee) and *C. canephora* Pierre (Robusta coffee) dominate the world coffee trade and contribute about 99% of world bean production [1]. Arabica coffee accounts for more than 62% of the world coffee [2] and commands about 90% of the world coffee market [3]. The remaining 10% of the market segment is Robusta. Unlike Arabica, Robusta coffee generally appears to be more vigorous, productive and robust, but the quality of the beverage derived from its beans is considerably inferior to that from Arabica [4], [1].

Drought is an environmental factor that produces water deficit or water stress in plants. Internal water deficit is initiated when low water potential develops and cell turgor begins to fall below its maximum value [5]. Drought stress results when water loss from the plant exceeds the ability of the plant's roots to absorb water and when the plant's water content is reduced enough to interfere with normal plant processes. A plant responds to lack of water by halting growth and reducing photosynthesis and other plant processes in order to reduce water use. As water loss progresses, leaves of some species may appear to change color—usually to blue-green. In severe cases, foliage begins to wilt and, if the plant is not irrigated, leaves will fall off and the plant will eventually die. There has not been a great deal of attention given to separating productivity under drought, which is important for cultivated plants, from survival mechanisms, particularly for woody species. Species or cultivars more tolerant to drought generally differ morphologically and/or physiologically, with mechanisms allowing greater production under limited water supply [6].

The ability of coffee varieties to survive and maintain productivity in moisture deficit areas also varies. Some varieties of coffee were found to differ in their morphological responses to water deficit in Uganda [7], Zimbabwe, and Colombia and Brazil [8]. Differences among Arabica coffee genotypes in adaptation mechanisms to drought have been reported by many authors; such as stomatal control, soil water extraction efficiency [1], plant water use, biomass allocation to the stems and leaves [2] and tissue water potential [9]. Tolerant varieties display adaptation mechanisms to drought including stomatal closure, osmotic adjustment, non-radiative energy dissipation and leaf area reduction [10]. Drought-tolerant coffee genotypes maintain higher tissue water potential and plant water use more efficiently than drought-sensitive ones under water-deficit conditions [2], [9]. [11] postulated various strategies for drought tolerance among wild coffee populations growing in different agro-ecologies of Ethiopia. They observed coffee plants with extensive root system but vulnerable to drought due to their hydraulic system and stomatal behavior.

Drought tolerance has become of major importance in the production of various crops due to decrease in available moisture for plants. This has caused waters stress to plants and thus the need to breed for plants that can withstand drought for longer periods and still produce high yields. Severe drought periods can lead to plant death, moderate drought periods are also very damaging to coffee growers by affecting flowering, bean development and, consequently decline in coffee production and quality. In addition, large variations in rainfall and temperature also increase bean defects, modify bean biochemical composition and the final quality of the beverage [8], [12]. As a result of global climate change, periods of drought may become more pronounced, and the sustainability of total production, productivity and coffee quality may become more difficult to maintain. In Kenya not much work under drought tolerance has been done on the various C*offea arabica* genotypes available. The aim of this study was to identify genotypes from the seedling stage that could withstand moisture stress. The drought tolerant genotypes must also have good combining abilities for yield, diseases and quality. Under low-input conditions typical of many farming systems of drought-prone regions, cultivars with better yield stability under drought stress, or better adapted to survive drought episodes, may be of greater value than cultivars with high potential yield selected for improved environments.

II. MATERIALS AND METHODS

2.1 Study site

The study was conducted at Coffee Research Institute (CRI) Ruiru, about 33Km North of Nairobi. CRI lies within the Upper Midland (UM2) at a latitudem1^{o} 06’S and longitude 36o 45’E and is approximately 1620 m above sea level. The area receives a bimodal rainfall of 1063 mm annually with mean temperature of 16ºC annually (Min 12.8ºC, max 25.2ºC). The soils are classified as complex humic nitisols and plinthic ferrasol. They are well drained, reddish brown, slightly friable clays with murram sections occasionally interrupting. The soil P.H ranges from 5 to 6 [13].

2.2 Test materials

The test materials used in the experiment were 13 coffee genotypes which included commercial varieties Batian (1, 2 and 3), K7, SL 28 and SL34. Batian varieties were developed by CRI and are true breeding with tall stature while Ruiru 11 is a hybrid with compact growth and both are resistance to Coffee Leaf Rust (CLR) and Coffee Berry Disease (CBD). Ruiru 11 variety is a population of genetically distinct genotypes but phenotypically similar. Three of the genotypes namely Code 2, Code 135 and Code 180 were used for this study. SL28, SL34 and K7 varieties are high yielding with good quality but are susceptible to both CBD and CLR. Non-commercial genotypes were Rume Sudan which is resistant to both CBD and CLR, Marsabit which is a collection from Marsabit hills in Kenya and finally DRI and DR 11 which are drought tolerant selections from Tanzania.

2.3 Experimental design

The seedlings were raised from seed and at 10 months after transplanting they were arranged in a three replicate randomized complete block design (RCBD) under a controlled condition in a green house. Each experimental plot had 15 seedlings totaling to 45 plants per genotype per treatment. Two treatments were applied whereby one treatment was watered normally while the other treatment was stressed by withholding water for 30 days and irrigating it again for 15 days to observe recovery rate.

2.4 Data collection

Response measurements were made (i) 30 days after moisture stress period, and (ii) at the end of 15 days recovery period. The measurements were made by uprooting three seedlings in the morning then separating the plants into leaves, stems and roots respectively. The roots were carefully excavated and cleaned with tap water. The fresh and oven-dry weight (70°C for 24 h) of leaves, shoots, roots and total dry matter measured. The data of leaf mass ratio (LMR = leaf dry weight/total dry matter), shoot mass ratio (SMR = shoot dry weight/ total dry matter), root mass ratio (RMR = root dry weight/total dry matter) and root to shoot ratio (RSR = root dry weight/shoot dry weight) was used to assess the effect of drought on dry matter partitioning (Worku and Astatkie 2010). The shoot length was measured to determine the height of the plant (cm) and this was done by measuring the plant from the point where the first root was formed to the last node of the plant.

2.5. Statistical Analysis

The data was be subjected to Analysis of Variance (ANOVA) using COSTAT statistical software and effects declared significant at 5% significance level. Least Significance Difference was used to separate means.

III. RESULTS

There was a significant (P<0.05) difference in Dry Matter (DM) partitioning. After water stress period, K7 and SL 28 recorded significantly (P<0.05) higher DM partitioning and Rume Sudan recorded a significantly lower DM partitioning. There was no difference in DM partitioning amongst the other varieties. After the recovery period, SL 28 recorded a significantly (P<0.05) while Rume Sudan recorded a significantly (P<0.05) lower DM partitioning when compared to SL28 (Table 1).

Table 1: Variation in, Dry Matter, Root Mass Ratio, Leaf Mass Ratio and Shoot Mass Ratio after 30 days of water stress and 15 days of recovery respectively amongst various coffee genotypes.

	Day 30 (Stress period)				**Day 45 (Recovery period)**			
Variety	**DM**	**RMR**	**LMR**	**SMR**	**DM**	**RMR**	**LMR**	**SMR**
Batian 1	13.39ab	0.2a	0.5ab	0.79a	45.74ab	0.19a	0.49abc	0.81a
Batian 2	13.96ab	0.17a	0.53ab	0.81a	50.24ab	0.16a	0.54abc	0.84a
Batian 3	14.39ab	0.19a	0.5ab	0.8a	52.6ab	0.19a	0.48abc	0.81a
K7	16.73a	0.15a	0.53ab	0.84a	48.13ab	0.16a	0.52abc	0.083a
SL 34	16.51ab	0.17a	0.5ab	0.82a	59.68ab	0.21a	0.46bc	0.79a
SL28	18.24a	0.17a	0.5ab	0.82a	62.11a	0.17a	0.47abc	0.83a
Code 2	12.18ab	0.17a	0.58a	0.82a	40.25ab	0.18a	0.51abc	0.81a
Code 135	13.9ab	0.18a	0.56ab	0.81a	51.24ab	0.15a	0.58a	0.84a
Code180	15.33ab	0.17a	0.55ab	0.82a	48.15ab	0.18a	0.55abc	0.82a
Marsabit	12.89ab	0.22a	0.46b	0.78a	48.41ab	0.16a	0.54abc	0.84a
Rume Sudan	9.83b	0.18a	0.52ab	0.81a	38.71b	0.16a	0.54abc	0.84a

DR 1	14.9ab	0.17a	0.52ab	0.83a	48.48ab	0.16a	0.51abc	0.83a
DR2	12.9ab	0.19a	0.48ab	0.81a	44.33ab	0.21a	0.42c	0.078a
LSD (0.05)	**3.99**	**0.054**	**0.066**	**0.054**	**13.3**	**20.97**	**12.63**	**4.46**
CV (%)	**23.9**	**23.9**	**11.01**	**5.68**	**4.23**	**0.426**	**0.075**	**0.065**

Significant ($P<0.05$) difference in Leaf Mass Ratio (LMR) was observed amongst the coffee genotypes during water stress period. Code 2 recorded a significantly ($P<0.05$) higher LMR when compared to other genotypes being followed by Code 135, and Code 180 respectively. During the same period, Marsabit recorded a significantly ($P<0.05$) lower LMR when compared to Code 2. During the recovery period Code 135 recorded a significantly ($P<0.05$) higher LMR, followed by Code 180 while DR 2 and SL 34 recorded a significantly ($P<0.05$) lower LMR. There was no significant ($P<0.05$) difference in Shoot Mass Ratio (SMR) and Root Mass Ratio (RMR) for all the genotypes during water stress period and even after the recovery period.

There was no significant ($P<0.05$) difference in plant girth during the water stress period. However during the recovery period, SL 28 recorded significantly wider girth followed by SL34, Rume Sudan and Batian 1 (Table 2). Code 2 recorded a significantly ($P<0.05$) narrow girth. There was a significant ($P<0.05$) difference in plant height within the genotypes. Batian 1, K7, SL 34, SL 28 and DR 2 recorded significantly ($P<0.05$) taller plants followed by Batian 2 during the water stress period. During the recovery period K7, SL34, and SL28 recorded significantly ($P<0.05$) taller plants followed by DR 2, Batian 3, and Batian 2 respectively.

Table 2: Variation in, Plant Height and Plant Girth after 30 days of water stress and 15 days of recovery respectively amongst various coffee genotypes.

	Day 30 (stress period)		**Day 45 (Recovery period)**	
Variety	**Plant Height**	**Plant Girth**	**Plant Height**	**Plant Girth**
Batian 1	43.45ab	0.59a	45.48a	0.64ab
Batian 2	42.61ab	0.55a	42.8ab	0.59ab
Batian 3	43.63ab	0.56a	44.66abc	0.63ab
K7	46.13a	0.57a	46.71a	0.63ab
SL 34	47.01a	0.59a	47.32a	0.65ab
SL 28	47a	0.62a	47.51a	0.69a
Code 2	33.16d	0.51a	33.34e	0.53b
Code 135	33.28d	0.54a	33.7de	0.61ab
Code180	36.03bcd	0.52a	36.10d	0.57ab
Marsabit	41.44abc	0.52a	42.53ab	0.59ab
Rume Sudan	34.25cd	0.53a	36.22cd	0.65ab
DR 1	42.16abc	0.55a	43.04ab	0.61ab
DR2	44.34ab	0.55a	44.5a	0.58ab
LSD (0.05)	**5.6**	**17.39**	**4.62**	**0.075**
CV (%)	**11.87**	**0.113**	**9.8**	**10.6**

IV. DISCUSSION

Seedling survival in drought prone environments may depend upon the species' ability to compensatefor the negative effect of low water potentials in the atmosphere by adjusting root and shoot morphological and physiological patterns. In this context an improved [14], [15] plasticity in promoting a shift in the allocation of assimilates from shoot to root and in adjusting the growth and distribution of the root system in response to soil drying are generally considered important acclimation mechanisms to drought [16], [17], [15].

The significant change in growth characteristics of coffee plants from the water stress period to recovery in the study shows drought effects differs with the varieties. There was a significant increase in dry matter partitioning during the recovery period from the water stress period (Table 1). This illustrates the fact that the coffee plants responds faster to change in moisture. Similar results were reported by [3] who found out that there was a significant interaction effect of the varieties which responded differently to water stress and recovery periods. This was also confirmed by [18] who found that every growth characteristics in coffee seedlings is affected by drought stress. Reduction in the growth of coffee under field and/or greenhouse conditions due to drought stress or deficit irrigation was also observed by various authors [2] [19] [20].

During stress period there was more root biomass allocation in all genotypes except for SL28, Code 135, Marsabit and DR 2 when compared to well watered plants. This result shows that when plants are stressed, they tend to allocate more biomass to the roots. It hasbeen reported that plants growing under drought stress altered photosynthate allocation from leaves and stems to roots to increase root: shoot ratio [21]. However as much as there was more root biomass allocation due to stress, this study and work by [2], [3]did not confirm high root to shootmass ratio.

The Average plant height during the stress period and after stress period was significantly different amongst the genotypes as SL 34, K7, SL28, Batian1, Batian 2 and Batian 3 recorded a higher growth (Table 2) and this confirms the findings by [19]. The tall stature of these plants may suggest their extensive root system. There was no significant change in SMR and RMR both after stress and recovery and this may imply that not all morphological characteristics are affected equally by same level of moisture stress. Reference [3] also found out that some of the morphological traits did not show any significant difference during the stress and recovery period.

V. CONCLUSION AND RECOMMENDATION

The adaptation of coffee to moisture stress is dependent mainly on its allocation of dry matter. After a detailed comparison of the two treatments during both water stress and recovery period, the following genotypes performed better under moisture stress ; Batian 1, Batian 2, Batian 3, DR 2, Rume Sudan, Code 135 and Code 2. These varieties can be evaluated further in the field for drought tolerance to be able to select the best performing genotype. This will assist in identifying the most promising genotype that can be planted in dry regions if it will be a commercial cultivar or used to develop a new drought tolerant coffee variety if the selected genotype will not be a commercial variety.

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