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Evaluation of Coffee Genotypes for Drought Tolerance in South Ethiopia

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Abstract

Drought is a major environmental constraint affecting the growth and production of coffee. Selection of drought tolerant Arabica coffee genotypes an important way to mitigate climate change impacts on coffee production. A Study was conducted at Awada research sub-center in Sidama zone of south Ethiopia(6045' N, 380 38'E and 1740 m.a.s.l) with the objective to screen drought tolerant Sidamo coffee genotypes. The experiment was conducted during 2011/12 and 2013 under a controlled condition in a rain shelter; it was laid down in a RCBD with three replications. Fourteen Sidamo coffee genotypes were subjected to two watering regimes, water stressed and well watered for 28 days. The genotypes were also evaluated under field condition during 2014 season at Korkie sub-station which is located 20 km south of Awada (6034 N, 38039'E and 1800masl). Results of the experiment indicated that there was high significant difference among the genotypes for extent of wilting, total dry matter, relative leaf water content and leaf retention capacity. C85238 shows high drought stress resistance with 1.58 scale value while c9744 indicated as sensitive to drought stress with 2.99 scale value.c9722 obtained the highest value 11.76 gram in total dry matter, c85237 obtained the highest leaf retention capacity 51.28% and c85257 obtained the maximum relative leaf water content. Significant difference was also observed in root to shoot ratio and stomatal conductance with highest values obtained by c974 and c75227 respectively The field evaluation indicated that plant height, canopy diameter, coffee yield and number of primary branch were significantly influenced at P<0.01 and number of bearing branches and leaf turgid weight were influenced by the genotypes at P<0.05 with c9722 scored maximum value 288.9 cm plant height, 76 NBB, 163.43 cm CD and 11.76 qt/ha coffee yield. There was strong correlation observed between extent of wilting scored at seedling stage and grain yield at field condition of genotypes (r = -0.80). Therefore from all the three year evaluations c979, c974, c85238 c9722, c75277 and c1377 performed better in resisting drought under both field and controlled conditions.

Keywords: Genotypes • Coffee • Drought • Resistant

Introduction

Coffee (Coffea arabica) is produced in many developing countries significantly contributing to poverty alleviation and national economic development. In Ethiopia, coffee production is increasingly constrained by changes in local weather and global climate, which brought about erratic distribution of the seasonal rain fall and recurrent droughts [1]. Ethiopia is the largest Africa's coffee producer with about 400,000 tons per annum, and about 1.2 million smallholder farmers are engaged in coffee production. Drought is an environmental factor that induces water deficit or water stress in plants. Internal water deficit is initiated when low water potential develops and cell turgidity begins to fall below its maximum value [2]. Coffee is the main source of income for many smallholder farmers in Ethiopia and in recent years coffee production faces high risk of drought, as coffee is a perennial crop and it stays in the field throughout the year. Drought and unfavorable temperatures are the major climatic limitations for coffee production in Ethiopia. These limitations are expected to be increasingly difficult challenges in several coffee growing areas and are the main factors responsible for the fluctuations in coffee yield. Because of population pressure for arable lands in most of coffee growing areas in Ethiopia, coffee cultivation has spread towards marginal areas where water shortage and high temperature constitute significant reduction in coffee yield. Also, in most cases, there is shortage of water resources for irrigation during prolonged dry spells, which affects the growth and development of plants under different forms during the phonological phases of the coffee crop [3]. Agronomic measures against drought control, such as shading, irrigation, high density planting and use of tolerant genotypes that are adapted to climatic fluctuations are alternative solutions against drought in coffee cultivation. Therefore this study was conducted from 2011 to 2015 to screen drought tolerant Sidamo coffee genotypes under both rain-shelter and field conditions.

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Materials and Methods

Description of the experimental area

The experiment was carried out from April, 2011 to December, 2014on Sidamo coffee genotypes in a rain shelter at Awada Agricultural Research Sub-Center of the Ethiopian Agricultural Research institution (EIAR). The research Sub-center is located at $6^0$45' N latitude, $38^0$38' E longitude, and at an altitude of 1740masl. The center receives an average annual rainfall of about 1216 mm with monthly mean maximum and minimum temperatures of 26.49^{0}C and 10.97^{0}C, respectively, and an average relative humidity of 47.2%. Similar screening experiment was also conducted under field condition during 2014 season at Korkie ($6^0$34'N $38^0$39'E and 1800 m.a.s.l) which is 20 km south of Awada.

Experimental design

The experiment was conducted in a RCBD in a factorial combination with three replications that involved 14 Sidamo coffee cultivars c (c85259, c85238,c85237,c85294,c85257, c971,c974, c979, c9718, c9722, c9744, c1377, c75227 and c744) and two watering regimes(well-watered and water-stressed).Each experimental block consisted of28 plots (14 cultivars x 2 watering regimes);the seedlings were germinated in pots filled with 10 liter volume of soil for well water treatments each cultivar received full irrigation at four days intervals, whereas for stressed plots water was withheld until desirable stress observed for 28 days. Each plot consisted of 6 pots of seedlings. The performance of these cultivars was also evaluated under field condition with RCBD in 2014 at Korkie.

Planting material

Pure seeds of the fourteen Sidamo coffee genotypes were prepared from promising and released coffee mother trees from verification plots, and they were sown in nursery, managed according to recommended nursery management standards. Vigorous and healthy seedling of 8-month old, after they developed greater than 8-pairs of fully expanded leaves have been chosen, then uniform seedlings were planted to the pots of 10 liter volume and transported to the rain-shelter and then evaluated for some physiological and morphological mechanisms associated with drought tolerance under controlled rain shelter. At the beginning of the trial, young tree of promising and released Sidamo coffee cultivars and those land races in verification plots have been evaluated at stations for their response to moisture stress during the peak dry spell and rate of recovery at the end of the wet season using method of visual scoring both at greenhouse and field condition.

Parameter measurements

The first response measurements were made after four days of moisture stress period and continued for one month at every two days interval for stress, destructive biomass were taken at the end of the stress period and after recovery, it was separated into leaves, stems and roots. Plant height was measured as the distance between the stem base and the apical bud by using ruler with 1m length after stress and recovery rate. Girth was measured with a digital caliper in the stem base region. The total leaf area was determined with the leaf area meter. Number of nodes and leaf number were determined by physical counting from destructed seedling at start, end of stress and recovery periods. Total dry mater yield was determined from stem, leaf and root dry weights**.** The dry root and shoot material (stem and leaf) was obtained from samples that were dried in an oven at 70°C until a constant weight. Relative leaf water content was determined from fresh leaf weight, turgid weight and dry weight. Three well developed leaves were sampled from each plot and placed in a distilled water for 24 hrs in cool and dark place, then turgid leaf weight was measured the samples more dried in an oven at 70°c until constant weight attained. Relative leaf water content was then calculated as follows [4]

$$RLWC\ \% = \frac{(FLW - LDW)}{(LTW - LSW)} \times 100 \quad (1)$$

Whereas: - FW= Fresh leaf weight (gram)

LDW- leaf dry weight (gram)

LTW- leaf turgid weight (gram)

Leaf thickness (LT) was calculated from leaf dry weight (LDW) and leaf area (LA). (Tesfaye S.G et al, 2013)

$$LT = \frac{LDW}{LA} \quad (2)$$

Whereas: - LT=leaf thickness (mm)

LTW= leaf dry weight (gram)

LA= leaf area (cm^2)

Stress scoring was measured visually every day, in the morning at 8.00am and at noon at 1:00 pm. Score alues were given in 1 to 5 scales, where 1 given for when all leaves green and turgid, 2 when most leaves still turgid, but younger leaves show leaf folding, 3 when all leaves wilt or fold, 4 when leaves are turning pale green and showing severe wilting and 5 when leaves are turning brown and dry, mostly drooping) Furthermore, the degree of leaf folding, rolling, cupping, rate of leaf fall and branch death, rate of recovery (production of new flushes) were recorded based on visual observation and counting.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) and tested for significance using least significance difference (LSD) by SAS software.

Results and Discussions

Results indicated that scoring has been highly significantly influenced P<0.001 by the genotypes tested for drought tolerance. c75227 scored 1.58 in maintaining its greenness despite the drought it was subjected to, and c9744 scored 2.99 wilt score in indicated it was drought sensitive cultivar. Scoring measurement was recorded in August - September 2011/12 main rain season in the study area and the duration may have its own effect on the extent of greenness of the cultivars and in 2013 wilt scoring measurement was taken during November 2013 – January 2013 (Table 1). Scoring was also measured at field condition screening in 2013 and it is statistically significantly influenced (P<0.05) by the genotype tested. Both c85238 and c1377 scored the best value 1. As shown from the green house and the field condition evaluations c85238, c1377, c979, c9722, and c974 performed better than the rest genotypes. Total dry matter was also significantly influenced (P<0.001) by the genotypes. C9722 scored the maximum value 11.76 gram of total dry matter whilst c85237 scored minimum value 5.75grams from the over years evaluationc 979, c9722, c974, c1377 and c85238 have shown consistent higher total dry yield matter. Root to shoot ratio is significantly influenced (P<0.01) in both experimental years. c974

Table 1. Evaluation of Sidama Coffee Genotypes for Drought Tolerance at Awada rain sheltered.

Genotype	STC***	SCO***	PH***	PG^{ns}	LT^{ns}	LRC***	RLWC***	RSR***	TDM***
85259	8.53^{efg}	2.70^{cd}	50.25^{bc}	0.65^{ab}	15.68^{ab}	40.44^{bcd}	58.66^{ab}	0.63^{f}	7.47^{fg}
85238	8.86^{efg}	1.58^{i}	43.35^{g}	0.70^{a}	17.58^{a}	36.35^{efg}	51.59^{cd}	0.91^{ab}	11.17^{ab}
85237	9.36^{de}	2.97^{a}	55.66^{a}	0.66^{ab}	13.11^{b}	51.28^{a}	51.36^{cd}	0.73^{de}	5.75^{h}
85294	7.66^{g}	2.72^{cd}	45.55^{def}	0.58^{ab}	17.72^{a}	37.80^{def}	59.31^{ab}	0.84^{bc}	8.56^{ef}
971	10.67^{b}	2.86^{ab}	48.10^{cd}	0.65^{ab}	13.56^{ab}	22.41^{i}	54.91^{bcd}	0.83^{bc}	9.05^{cde}
974	10.30^{bc}	1.77^{ih}	51.76^{b}	0.65^{ab}	13.40^{ab}	50.59^{a}	57.30^{abc}	0.94^{a}	10.18^{bc}
9722	8.09^{fg}	1.98^{h}	48.04^{cd}	0.67^{ab}	17.40^{ab}	35.29^{fg}	54.66^{bcd}	0.79^{cd}	11.76^{a}
9718	9.54^{cd}	2.80^{bc}	47.87^{cde}	0.63^{ab}	15.65^{ab}	38.88^{cde}	50.53^{d}	0.76^{cd}	725^{g}
75227	12.89^{a}	2.17^{g}	50.99^{b}	0.54^{b}	14.48^{ab}	42.28^{b}	54.11^{bcd}	0.65^{f}	7.21^{g}
744	12.18^{a}	2.53^{e}	44.42^{fg}	0.62^{ab}	12.98^{b}	33.28^{gh}	50.25^{d}	0.83^{bc}	6.70^{gh}
9744	8.93^{def}	2.99^{a}	38.78^{h}	0.68^{ab}	15.08^{ab}	42.12^{cb}	59.54^{ab}	0.66^{ef}	8.71^{de}
979	10.93^{b}	2.02^{gh}	51.15^{b}	0.60^{ab}	14.79^{ab}	41.49^{cb}	59.51^{ab}	0.91^{ab}	9.77^{cd}
1377	9.24^{de}	2.38^{f}	56.03^{a}	0.61^{ab}	14.93^{ab}	30.99^{h}	53.90^{bcd}	0.90^{ab}	9.73^{cd}
85257	8.80^{efg}	2.61^{de}	46.78^{def}	0.58^{ab}	13.86^{ab}	39.66^{bcde}	63.46^{a}	0.77^{cd}	5.76^{h}
LSD	0.93	0.14	2.48	0.143	4.5	3.38	6.56	0.08	1.15
CV%	5.7	2.94	3.06	13.49	17.79	5.21	7.05	5.79	8.05

*SCO Extent of wilting (scale value), TDM = total dry matter (gram), FPG= plant girth at field (cm), PB = Number of primary branch at field, CD= canopy diameter (cm), YLD = grain yield (quintal/ha), PHF = plant height at field (cm) scored highest ratio with 0.94 and minimum ratio was scored 0.63 by c85259. From both years evaluation c85238, c979, c1377 and c974 are selected as best performing with respect to RSR parameter. Leaf thickness was not significantly influenced but maximum leaf thickness 17.72x10^{-3} mm has been obtained by c85294 and 12.98x10^{-3} mm minimum leaf thickness was obtained from c744. In Therefore from both years evaluations c85238, c744 and c9722 are selected as better genotypes Stomatal conductance has been significantly influenced (P<0.01) by the cultivars tested. c75227 scores the highest magnitude 12.89 mmohm^{-2}s^{-1} and cultivars c85294 scored the minimum value 7.66 mmohm^{-2}s^{-1}. Relative leaf water content is significantly influenced (p<0.01) by the genotypes subjected to drought stress. c85257 scored the highest relative leaf water content 63.46% whilst c744 obtained the least relative water content 50.53%. And from both years evaluation c85259, c974, c1377, c85257, c85294 and c979 have shown the highest relative leaf water content. Leaf retention capacity is also significantly influenced (P<0.001) by the cultivars. c85237 retained 51.28% of its leafs during the stressed time and c974 also scored the second highest value next to best cultivar and c971 scored the minimum value 22.41% (Figures 1-4).

On field evaluation

Plant height was significantly (p<0.01) influenced by coffee genotypes at field condition. Maximum plant height 288.87 cm was obtained by c9722. Number of primary and number of bearing branch were significantly (p<0.01) influenced by coffee genotypes and c85238 scored highest number of primary branch 96.80 and maximum number of bearing branch was scored by c85294 which scored 76. Plant girth was not significantly influenced by coffee variety but c85294 scored higher mean value of 6.93 cm (Table 2). Canopy diameter was significantly (p<0.001) influenced by variety with highest 174.35 cm canopy diameter by c1377 and Coffee yield was also influenced significantly (p<0.01) by coffee genotypes on field condition at Korkie, and maximum coffee yield 12.53qt/ha obtained byc85238followed by c971 genotype with yield of 11.90 qt/ha. Moreover, on leaf elongation rate coffee genotypes of c979 and c85238 scored maximum 2.37 mm/day and minimum 0.81mm/day respectively. There was a strong positive relationship between a variety total dry matter at seedling stage and canopy diameter at field condition (r=0.52), grain yield (r=0.70), number of primary branch

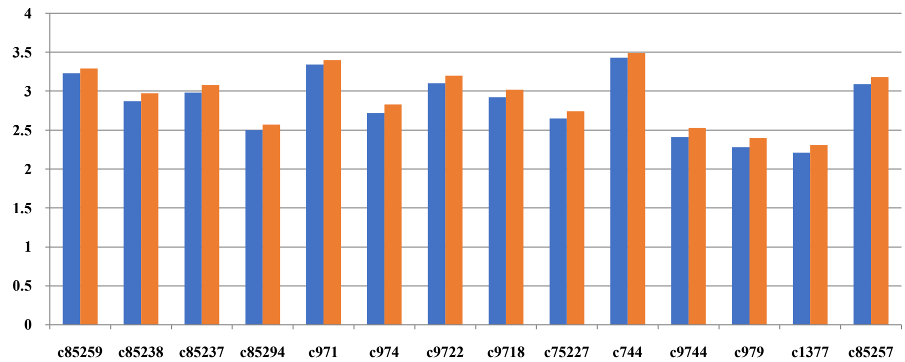

Figure 1. Wilting score at Morning and Afternoon.

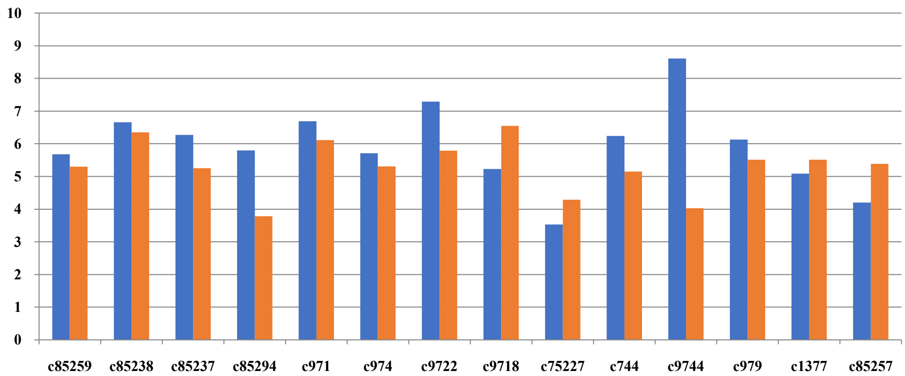

Figure 2. Total dry yield (TDY).

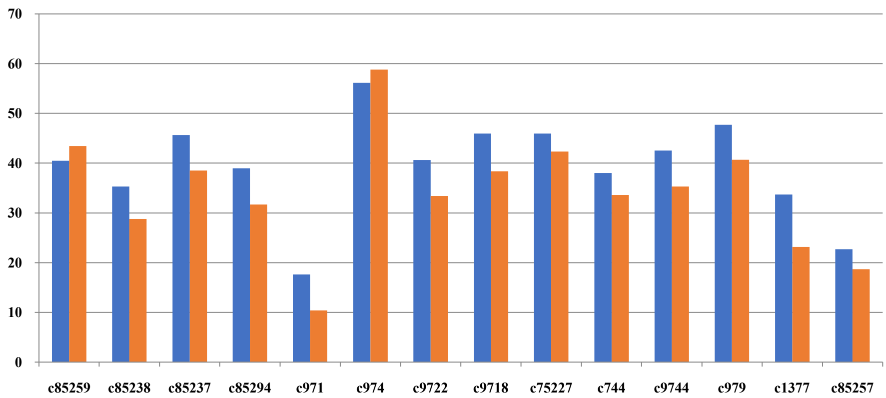

Figure 3. Leaf Retention capacity (%).

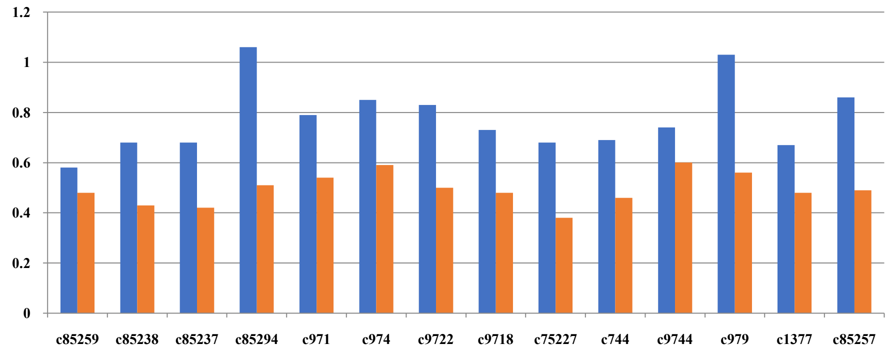

Figure 4. Root to shoot ratio (RSR).

Table 2. Coffee genotypes at field condition at Korkie, Sidama Zone South Ethiopia.

Treatments	PH**	NPB***	NBB*	NBB*	CD**	RR^{ns}	LE^{ns}
c85259	255.53^{de}	80.90^{ef}	56.0^{bc}	70.8^{ab}	150.00^{cd}	69.6	1.51
c85238	268.90^{abcd}	96..80^{a}	70.8^{ab}	63.0^{ab}	152.83^{c}	74.5	0.81
c85237	260.00^{de}	81.69^{def}	59.1^{ab}	59.1^{ab}	146.50^{cde}	77.1	2.34
c85294	267.80^{bcd}	84.80^{cde}	76.0^{a}	59.1^{ab}	150.00^{cd}	72.8	1.67
c971	245.53^{e}	81.30^{ef}	51.7^{bcd}	39.7^{cd}	140.83^{ef}	77.8	1.51
c974	284.43^{ab}	96.23^{a}	59.1^{ab}	54.8^{bcd}	163.63^{b}	80.9	1.76
c9722	288.87^{a}	90.66^{abc}	35.8^{d}	57.8^{abc}	163.43^{b}	82.4	1.82
c9718	266.53^{bcd}	88.76^{bc}	63.0^{ab}	58.4^{abc}	148.57^{cd}	78.5	1.51
c75227	271.10^{abcd}	88.43^{bcd}	70.8^{ab}	35.8^{d}	162.33^{b}	56.4	1.12
c744	244.43^{f}	76.00^{f}	57.8^{abc}	76.0^{a}	137.74^{f}	71.5	1.53
c9744	264.43^{bcde}	81.56^{def}	54.8^{bcd}	56.0^{bc}	145.83^{de}	75.7	1.43
c979	282.20^{abc}	91.80^{ab}	58.4^{abc}	57.1^{abc}	166.16^{b}	80.3	2.37
c1377	274.43^{abcd}	88.27^{cd}	39.7^{cd}	51.7^{bcd}	174.35^{a}	73.7	0.82
c85257	263.33^{cde}	83.76^{cde}	57.1^{abc}	70.8^{ab}	140.00^{ef}	62	1.74
LSD	20.52	6.95	19.4	20	6.98	ns	ns
CV (%)	4.59	4.81	20	19.4	6.3	12.3	35.6

NB:PH is plant height (cm), NPB = number of primary branch, NBB number of bearing branch, CD canopy diameter (cm), RR survival rate (%) and LE elongation rate (mm/day).

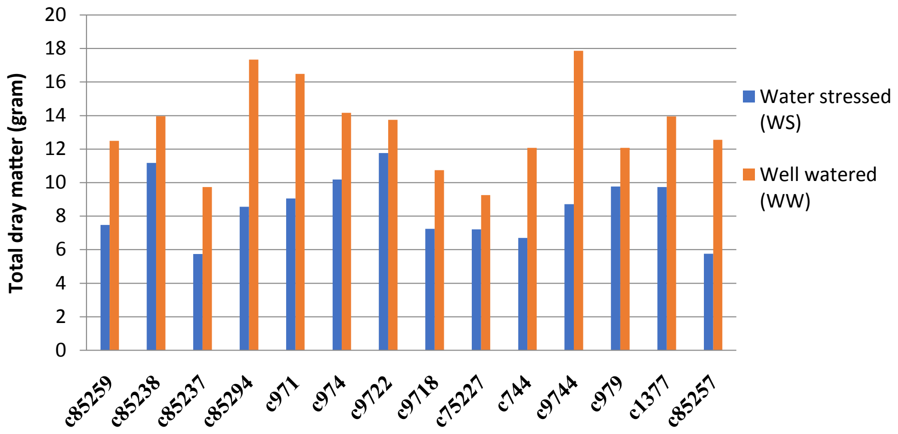

Figure 5. Total dry yield of well watered (WW) and water-stressed (WS) coffee seedlings.

at field condition (r=0.55). There was also strong relationship observed between extent of wilting at seedling stage and total dry matter at seedling stage (r=-0.64), number of primary branch at field condition (r=-0.69), canopy diameter at field condition (r=-0.57) and plant height at field condition (r=-0.51) The strongest relationship was obtained from extent of wilt score at seedling stage and grain yield at field condition (r=-0.80) (Figure 5).

Exposing the genotypes to soil moisture stress for 28 days significantly affected total dry biomass indicating that the growth performance of coffee varieties is significantly affected by soil moisture deficit and stress. This confirms that drought stress has significant effect on morphological and other growth characteristics of coffee plants [5]. For most of the varieties there was a reduction in total dry biomass during period of soil moisture deficit stress. Reduction in total dry biomass could largely be due to the loss of water which considerably contributes to the total dry biomass of the coffee plants. This water is important in maintaining tissue elasticity in plants and its loss is evident in the morphological characteristics of plants such as wilting and leaf folding [6].

Conclusion and Recommendations

Developing drought tolerant coffee genotypes is better option in mitigation climate change impacts on coffee growing areas in Ethiopia. From the promising coffee genotypes in South Ethiopia fourteen cultivars have been tested for their drought tolerance potential. The findings revealed that c979, c974, c85238 c9722, c75277 and c1377 have performed well in terms of extent of wilting scored value, leaf retention capacity, relative leaf water content, dry matter partitioning and root to shoot ratio, This study provides important information into selection of varieties for drought tolerance for use in the coffee sector. However, a holistic approach to variety selection that incorporates drought, disease, pest, and frost tolerance may provide a stronger basis. An understanding of drought tolerance in coffee at a molecular level is also required.

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