Ex-situ Performance Evaluation of Coffee (*Coffea arabica*) Seedlings under Different Management Conditions: I. Relationship between Hydraulic Resistances and Growth Characters

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Abstract

The study was conducted with the aim of determining the variations in growth and hydraulic resistances and identifying the relationship between these traits in seedlings of Arabica coffee populations. Coffee accessions collected from four wild coffee forests in Ethiopia (Harenna, Bonga, Berhane-Kontir and Yayu) were ex situ evaluated under controlled nursery conditions at the Jimma Agricultural Research Center, southwest Ethiopia. One-year-old coffee seedlings were used to record growth and hydraulic characteristics. The results revealed highly significant differences among coffee populations for most morphological and destructive growth characteristics. The Harenna and Yayu coffee populations had maximum growth values as opposed to the lowest response from the Berhane-Kontir population. Coffee populations also exhibited significant variations in the hydraulic resistance of main stem-cut and its contribution to whole-shoot resistances. The hydraulic resistance contributions across seedling root and shoot components followed the order of root>leaf>whole-shoot>branch>petioles. Seedling growth characters and root hydraulic resistance were correlated strongly and indirect in optimum nursery conditions. Main stem diameter had highly significant inverse relationships with hydraulic resistance components in stem-cut, whole-shoot, leaf and root growth parts. Stem and leaf growths are the most useful traits to describe the extent of variability among Arabica coffee genetic resources in hydraulic resistances. As a whole, coffee population of varying geographical origins in Ethiopia, seedling growth habits and segments are important in determining hydraulic resistance patterns and hence can be used as selection and characterization criteria in the local coffee variety development program of the country.

Key words: Arabica coffee, drought tolerance, genetic diversity, water relations

Introduction

In Ethiopia, the fragmented friendly forest coffee habitats with wild Arabica coffee populations, coffee landraces and traditional coffee production culture are shrinking from time to time, largely due to increasing population, deforestation and land degradation. Thus, coffee genetic resources are either replaced by other crops or their cultivation is expanding into marginal and vulnerable areas to drought stress problems (Paulos and Demel, 2000). Taye (2010) reported that these threats coupled with climate change could be seriously damaging friendly environments and maximum biodiversity and thus demands for urgent global collaborative reactions for sustainable conservation, management and use of the untapped coffee genetic resources in the country.

The water status of plants has received much attention in recent years to provide baseline information for evaluating plant needs for water or how well it is adapted to its environment, especially where water is a limiting factor (Larcher, 2003). The physiology of plant responses to drought stress is complex, showing different modifications following soil drying. Furthermore, particularly in the tropics, drought episodes are aggravated by both high solar radiation and temperature, so drought should be accounted for as a multidimensional stress (DaMatta, 2004). The degree of drought stress tolerated profoundly influences virtually all physiological and metabolic functions that are responsible for determining plant adaptation, growth and distribution (Sobrado, 1993). The distribution of leaf-specific conductivity within a tree influences patterns of water potential throughout the crown and can impose constraints on such physiological processes as transpiration and photosynthesis (Yang and Tyree, 1993). Many authors (Dias *et al.*, 2007) reported differences among Arabica coffee genotypes in adaptation mechanisms to drought stress conditions, though this remains for in-depth studies in Ethiopia.

The recurrent drought stress and limited availability of soil moisture, particularly at critical growth stages of coffee trees are among the major constraints observed at most coffee producing areas in Ethiopia (Taye, 2010). Yacob *et al.* (1996) reported that the released coffee selections and landraces can be broadly grouped into three canopy classes of open, medium and compact crown nature. They also differ in growth and adaptations under varying field conditions (Taye *et al.*, 2004). Greenwood *et al.* (2010) found there are opportunities for improving irrigation efficiency with quantitative models, soil water sensors and wireless technology. Patil *et al.* (2010) reported on the possibility of predicting hydraulic properties of seasonally impounded soils.

In view of the threats largely due to anthropogenic factors coupled with the challenges of climate change and variability there is an urgent need to generate scientific information and technologies for the benefits of the coffee sector. According to Taye and Burkhardt (2011), the wild Arabica coffee populations showed variations in agronomic parameters and hydraulic resistances in coffee trees, largely due to genetic and site factors. Nonetheless, baseline information on relationship between growth architecture and hydraulic properties is lacking under a more homogenous environment for sustainable use and management of coffee genetic diversity and wide coffee growing zones of Ethiopia. Hence, it is crucial to assess the underlying mechanisms and identifying drought tolerant coffee cultivars and improved agronomic practices including practical pruning and training options. The study therefore aims to determine the variations among wild Arabica coffee populations in seedling growth characteristics and hydraulic resistances and to assess the relationships between these traits under controlled nursery conditions at the Jimma Agricultural Research Center in southwest Ethiopia.

Materials and Methods

Study area

The study was carried out under controlled nursery conditions at Jimma Research Center (7^0 46′ N latitude and 36^0 0′ E longitude), southwest Ethiopia. The area is located within the Tepid to cool humid highlands agro-ecological zone and lies at an altitude of 1753 m a.s.l. The area receives an average annual rainfall of 1595 mm per annum distributed into 173 days. The driest season usually lasts between December and January. The average maximum and minimum air temperatures are 25.9 and 11.2 ^{0}C, respectively, the coldest month being December (Paulos and Demel, 2000).

Experimental procedures and design

Fully ripe red cherries were collected from coffee trees at three sub-sites within four wild Arabica coffee populations at Harenna, Bonga, Berhane-Kontir and Yayu. Consequently, a total of twelve Arabica coffee germplasm accessions of varying geographical origins were *ex-situ* established under controlled nursery settings. Each seedling was planted in black plastic plant pots (5.8 litre) filled with the recommended potting medium ingredients of topsoil and decomposed coffee husk compost at the respective ratio of 3:1 v/v (Taye *et al.*, 2002). The plastic pots were perforated at the bottom, firmly filled with the soil medium and arranged on nursery seedbeds. The seedlings were managed under moderate shade conditions for a year period and all the other nursery operations were applied according to the recommendations (IAR, 1996). The wild Arabica coffee accessions were arranged in a randomized complete block design with three replicates of 25 coffee seedlings per plot. The seedlings were uniformly well-irrigated to field capacity of the potting medium at four-day intervals. This was accomplished to each seedling in the late afternoon of the day before the hydraulic measurements.

Data measurements

Microclimate

Microclimatic variables (air temperature, soil temperature and relative humidity) were monitored in potted coffee seedlings in the open sun and moderate shade using the Tinytag-Gemini Data Loggers (GLM version 2.8, UK). The probe of the Tinytag was inserted into the potting soil to about 15 cm depth to record soil temperature. The air and soil data were recorded from the same seedlings arranged in open sun and shade plots. The seedlings received all the conventional nursery practices (IAR, 1996).

Growth characters

One-year-old coffee seedlings were used for the study. Five central coffee seedlings per plot were used to record intact and destructive morphological growth parameters as described by Yacob *et al*. (1996).

Hydraulic resistances

Root and shoot hydraulic resistances were determined for the central coffee seedlings of each accession. The data were measured using a high-pressure flow meter (HPFM, Dynamax Inc, Houston, TX, USA). In this study, the red flow range was determined to be the most suitable and used for the hydraulic measurements as described in Tyree *et al*. (1995) and Tausend *et al*. (2000). First, the HPFM was connected to the base of the debarked main stem cut at about 0.50 cm above the soil surface. The initial pressure was set and increased at 5 kPa/s and flow rates were recorded at 2 seconds intervals.

Root hydraulic resistance was measured by the transient method and hydraulic conductance was calculated from the slope of the change in the amount of water flow and applied pressure as described by other authors (Tyree *et al*., 1983; 1995). Next, the seedling was saturated by immersing and flushing with clean water and the main stem was cut to a height of 0.20 cm again under water, debarked and attached to the HPFM to measure hydraulic resistances in the whole shoot and different shoot parts (leaf, petiole and primary branch). This was measured using a steady state flow meter method of the HPFM. The resistance of the shoot components was determined by the consecutive removal of each growth part. The hydraulic resistance was recorded whenever the steady state flow meter attained a constant flow rate. The initial result with all above-ground shoot parts was recorded as whole-shoot resistance and then, leaves, petioles and primary branches were sequentially removed. The contribution to whole-plant and whole-shoot hydraulic resistance was calculated from the difference in resistance before and after removal of each growth segment. The whole-plant resistance included root and whole-shoot hydraulic resistance. After the hydraulic measurements, each part of the seedling was separated into leaves, main stem, lateral branches and roots. Then, fresh weights of each sample were recorded and oven-dried for 24 h at 105°C and immediately weighed using a Sartorius analytic sensitive balance. The relationship between seedling growth and hydraulic characteristics were assessed under optimal nursery environments.

Data analysis

The analysis of variance (ANOVA) was computed for the growth and hydraulic parameters using the SAS V9 for windows (SAS, 2002). The wild coffee population means were compared with t-tests at P = 0.05, whenever significant differences were declared. Pearson correlation matrix and regressions were run between growth parameters and hydraulic resistances in seedlings of twelve wild Arabica coffee accessions.

Results

Microclimate variables

The results of microclimatic monitoring indicate significant differences between daylight and night in terms of relative humidity and air temperature (Table 1). Significantly lower relative humidity and higher air temperature were recorded during daytime. The difference between day and night soil temperatures as well as their interaction between time and shade were not significant. However, the significant variations in microclimatic variables are enough to evalaute the response of different coffee accessions to varying nursery environmets.

Table 1. Microclimate variables in the full sun light and moderate shade conditions

Variable	**RH (%)**	**Temperature (°C)**	
		Air	**Soil**
Time of day	*	**	Ns
Night	80.97	16.56	19.10
Day	70.82	20.47	23.83
Irradiance	Ns	Ns	Ns
Full sun	73.42	18.75	24.03
Shading	78.36	18.28	18.90
Mean	**75.89**	**18.51**	**21.46**
CV (%)	**3.17**	**3.58**	**30.42**
Time x shade	Ns	Ns	Ns

*Ns = Not significant; *P<0.05; **P<0.001 .*

Growth characteristics

Significant differences were observed among coffee populations for the extension shoot growth parameters considered in one-year-old coffee seedlings. The Harenna and Yayu collections had maximum growth values as opposed to the lowest values from the Berhane-Kontir wild coffee population (Table 2). The tallest seedlings with the highest leaf dimensions were found from the Yayu and Harenna coffee population with highly significantly higher numbers of leaves and node growth. This was in contrast to the lowest values for the Berhane Kontir and Bonga coffee germplasm accessions (Table 2).

Table 2. Morphological growth characteristics of seedlings of Arabica coffee populations used for the hydraulic measurements

Variable	Harenna	Bonga	Berhane Kontir	Yayu	Pr>F	Mean	CV (%)
Plant height (cm)	14.89	13.83	12.58	15.32	*	14.15	6.85
Girth (cm)	0.31	0.30	0.27	0.31	*	0.30	4.78
Leaf number	8.46	7.91	7.00	8.06	**	7.86	2.97
Leaf length (cm)	6.86	6.62	6.54	7.15	ns	6.79	4.98
Leaf width (cm)	3.00	2.79	2.72	2.91	ns	2.86	4.06
Total leaf area (cm^2)	116.79	97.66	83.24	112.36	*	102.51	10.94
Mean leaf area (cm^2)	13.73	12.29	11.81	13.87	ns	12.93	8.63
Leaf area index[a]	0.34	0.28	0.24	0.33	*	0.30	10.95
Node number	4.25	3.96	3.50	4.06	***	3.94	2.56
Internode length (cm)	3.49	3.50	3.60	3.76	ns	3.59	4.67

, * = significant at P≤0.01 and P≤0.001 levels, respectively; [a]leaf area index was calculated as total leaf area/crown area, cm^2/cm^2).

With regard to destructive growth, coffee populations significantly differed in total root volume (P<0.001), taproot length (P<0.05) and length of lateral roots (P<0.01). The accessions, however, did not differ in the number of lateral roots, though the respective maximum and minimum counts were obtained from the Harenna and Berhane-Kontir accessions. The longest and shortest lateral roots were obtained from Yayu and Harenna seedlings, respectively. Berhane-Kontir populations had the significantly lowest root volume as opposed to the highest value for the Harenna seedlings (Table 3). Likewise, coffee populations significantly differed (P<0.001) in root dry mass. Consequently, the lowest and highest average values were determined from Berhane-Kontir and Harenna seedlings, respectively. The Harenna seedlings had a highly significantly higher root mass than the others, particularly that of the Berhane-Kontir population (Table 3).

Similarly, coffee populations also significantly (P<0.05) differed in stem dry weight, with average results ranging from 15.10 g to 18.06 g for Berhane-Kontir and Harenna seedlings, respectively (Table 3). Significantly (p<0.05) the lowest and highest respective total biomass were recorded from the Berhane-Kontir and Harenna coffee accessions (Table 3; Figure 2). The ratios of root to shoot dry mass of the seedlings also significantly differed among the accessions. The lowest and highest root to shoot results was determined for the Berhane-Kontir and Harenna accessions (Figure 2).

Table 3. Destructive growth characteristics of seedlings of four wild arabica coffee population

Variable	Harenna	Bonga	Berhane Kontir	Yayu	P>F	Mean	CV (%)
LDW (g)	13.35	12.93	13.08	13.93	Ns	13.32	6.17
SDW (g)	18.06	15.82	15.10	17.17	*	16.54	6.07
RDW (g)	9.89	8.14	6.85	8.76	***	8.41	4.72
RV (g/cm^3)	45.82	35.92	30.9	36.45	***	37.27	5.62
TRL (cm)	34.64	30.41	27.83	30.31	**	30.80	4.95
LRN	40.91	38.51	35.39	38.33	*	38.29	4.01
LRL (cm)	19.42	18.00	17.80	17.58	ns	18.20	4.03
R:S	0.32	0.28	0.25	0.28	***	0.28	3.78
TDM (g)	41.29	36.88	35.03	39.86	*	38.26	5.20

Ns = Not significant; *, ** and *** = significant at P<0.05, P<0.01 and P<0.001, respectively. Abbreviations: LDW = leaf dry weight, LRL = lateral root length, RDW= root dry weight, R:S = root to shoot ratio, RV = root volume, SDW = stem dry weight, TDM = total dry matter, TRL = taproot length.

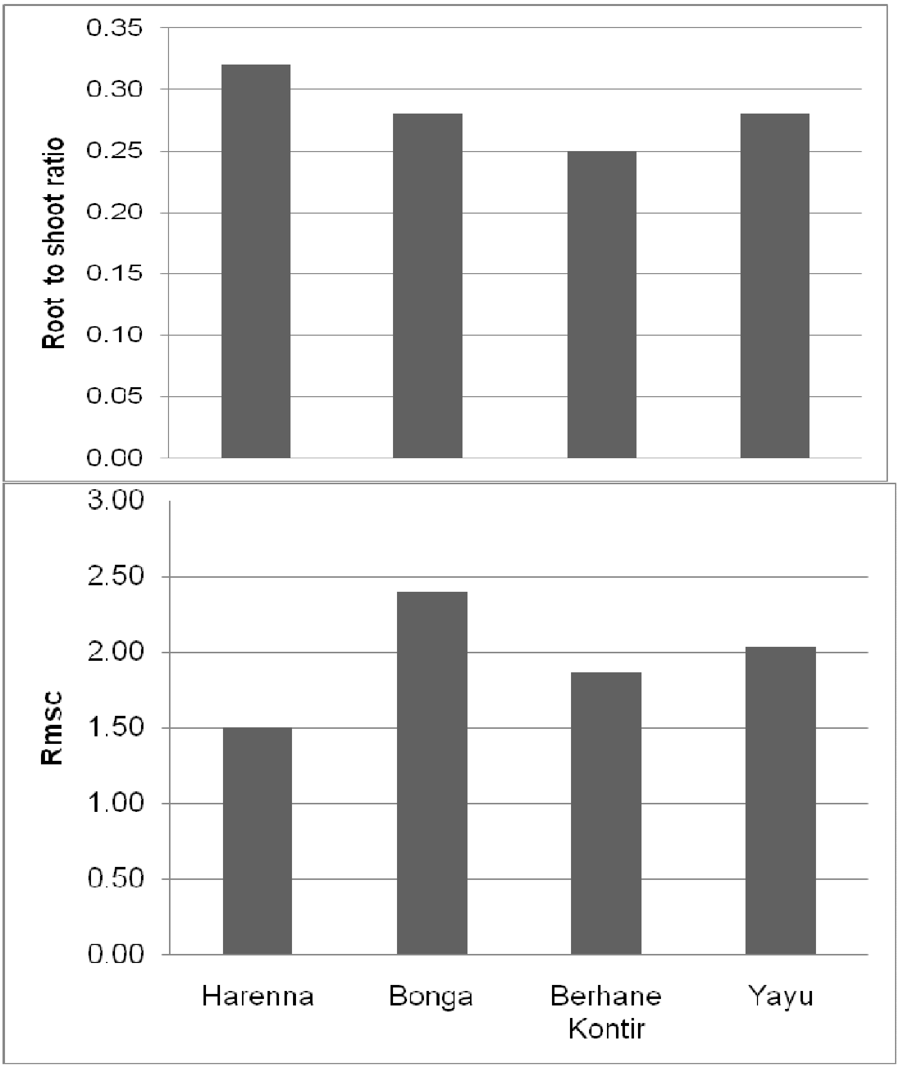

Figure 1. Influence of root to shoot growth on main stem hydraulic resistances (mean x 10^4 MPa m^2 s/kg) in seedlings of arabica coffee populations

Hydraulic resistances

There was no difference among coffee accessions in patterns of root and shoot hydraulic resistances, except for the significant difference ($p<0.05$) in main stem-cut resistance measurement. Accordingly, the lowest and highest average values for most hydraulic resistance components were found for the Harenna and Bonga, followed by Berhane-Kontir and Yayu populations. The resistances in the whole-shoot, leaves, petioles, primary branches and stem-cut were higher for the Bonga coffee populations as compared with others (Table 4a). The removal of various shoot components was observed to reduce hydraulic resistance, though the magnitude was comparable among the coffee populations. Hydraulic resistances were relatively low for the Harenna, whereas the Bonga and Berhane-Kontir populations had relatively higher resistances in the whole-shoot (Table 4a).

Seedlings of the four wild coffee populations were not significantly different in the percent contributions of hydraulic resistances in roots, whole-shoot and shoot segments. However, the Bonga and Yayu populations had relatively higher root contributions. Maximum root contribution was associated with minimum shoot resistance in coffee seedlings. The lowest shoot and leaf percent resistance contributions were determined from the Bonga and Yayu population (Table 4b). A relatively maximum resistance contribution in petiole and primary branch was recorded for the Yayu and Berhane-Kontir collections. The resistance contribution of the main stem-cut to whole-shoot resistance was significantly ($P<0.05$) different among coffee populations. Significantly the lowest and the highest main stem-cut resistance contributions were measured from Bonga and Harenna accessions. The average hydraulic resistance in roots, shoot, leaf, petiole and lateral branch followed similar patterns with average percent contributions of 60.26, 39.74, 56.84, 2.08, and 10.75, respectively (Table 4b).

Table 4. Hydraulic resistance (R_h, means x10^4 MPa m^2 s/kg) in root and shoot segments (a) and their percent contributions to whole-plant and whole-shoot resistances (b) in seedlings of wild arabica coffee population

Hydraulic resistance component

Variable	Harenna	Bonga	Berhane Kontir	Yayu	Pr>F	Mean	CV (%)
R_{WP}	18.70	26.10	22.90	23.10	ns	22.70	12.65
R_r	11.37	16.03	13.80	14.10	ns	13.83	18.51
R_{WS}	7.37	10.03	9.10	9.00	ns	8.88	10.36
R_l	3.23	4.20	3.83	4.10	ns	3.84	12.54
R_p	3.07	4.00	3.67	3.90	ns	3.66	12.68
R_{br}	2.30	2.97	2.60	2.90	ns	2.69	14.55
R_{msc}	1.50	2.40	1.87	2.03	*	1.95	12.18

b) Percent hydraulic resistance contribution

Variable	Harenna	Bonga	Berhane Kontir	Yayu	Pr>F	Mean	CV (%)
Root	59.42	61.16	59.61	60.85	ns	60.26	8.87
Shoot	40.59	38.84	40.39	39.15	ns	39.74	13.44
Leaf	56.00	58.68	57.85	54.82	ns	56.84	3.93
Petiole	2.10	1.90	2.13	2.17	ns	2.08	13.48
Branch	10.57	10.08	11.26	11.09	ns	10.75	9.77
Stem-cut	10.89	6.22	8.20	9.66	*	8.74	15.19

*The symbols of hydralic resistence include: whole-plant (R_{WP}), root (R_r), whole-shoot (R_{WS}), leaf (R_l), petiole (R_p), branch (R_{br}) and main stem cut (R_{msc}). Ns = Not significant, *P<0.05.*

Relationship between hydraulic resistances and growth characters

Hydraulic resistances in roots and shoot segments showed inverse relations with most extension (Table 5a) and destructive growth parameters (Table 5b), though the degree of correlation differed. Among the extension growths, only the number of main stem nodes and main stem internode length were weakly and positively correlated with the hydraulic resistances in the whole-shoot growth and its segments. Moisture contents in leaf, stem and roots were positively correlated with the hydraulic resistances in the whole-plant, root and shoot components, while all other parameters were negatively correlated. The results reveal that main stem-cut hydraulic resistance was negatively and significantly correlated with stem fresh weight (r = -0.75**), stem volume (r = -0.81**) and root to shoot ratio (r = -0.70**) (Table 5b; Figure 1). The indirect influence of root dry weight, fresh weight and volume was highly significant in that order on hydraulic resistances in root and shoot systems. Lateral root length showed strong (P<0.05) correlations with hydraulic resistances in roots, whole shoot and whole plant. The linear relationships between hydraulic resistances in whole-plant, leaf and stem-cut and root to shoot ratio as well as total dry matter yield are presented in Figure 2. In addition, main stem diameter had inverse and significant (P<0.01) linear relationships with hydraulic resistance components in main stem-cut, whole-shoot, leaf and root parts descending in that order of coefficient of determination (Figure 3).

Table 5 Pearson correlation coefficient (r) between hydraulic resistance in the root and shoot components and (a) extension and (b) destructive growth parameters of arabica coffee seedlings

a) Extension growth parameters

	Hydraulic resistance						
Character	Root	Shoot	Leaf	Petiole	Branch	Stem-cut	Whole-plant
Ht	-0.62**	-0.47*	-0.30	-0.29	-0.22	-0.42*	-0.67***
BA	-0.53**	-0.72***	-0.67***	-0.67***	-0.64**	-0.77***	-0.69***
NMSN	-0.42*	0.11	0.11	0.12	0.08	0.03	-0.29
NPrBr	-0.12	-0.35	-0.35	-0.34	-0.29	-0.22	-0.22
NBrN	-0.27	-0.35	-0.30	-0.30	-0.33	-0.29	-0.34
PrBrIL	-0.44*	-0.37	-0.24	-0.24	-0.19	-0.40	-0.49*
MSIL	-0.09	0.05	0.08	0.10	0.14	0.14	-0.06
LN	0.01	-0.47*	-0.50*	-0.51*	-0.51*	-0.41*	-0.16
TLA/LAI	-0.19	-0.41*	-0.39	-0.39	-0.35	-0.245	-0.30

**P<0.05; **P<0.01; ***P<0.001 significance levels (n = 12, d.f. = 10). Abbreviations: Ht = height, BA = basal area, NMSN = number of main stem nodes, NPrBr = number of primary branches, NBrN = number of branch nodes, PrBrIL = primary branch internode length, MSIL = main stem internode length, LN = leaf number, TLA = total leaf area, LAI = leaf area index.*

b) Root and shoot growth (destructive parameters)

Character	Root	Whole- shoot	Leaf	Petiole	Branch	Stem cut	Whole-plant
LFW	-0.14	-0.79***	-0.84***	-0.83***	-0.78***	-0.66***	-0.40
LDW	-0.17	-0.68***	-0.74***	-0.74***	-0.71***	-0.61**	-0.39
SFW	-0.54**	-0.83***	-0.81***	-0.80***	-0.75***	-0.81***	-0.74***
SDW	-0.50*	-0.80***	-0.79***	-0.79***	-0.76***	-0.82***	-0.69***
RFW	-0.45*	-0.72***	-0.71***	-0.71***	-0.68***	-0.72***	-0.62**
RDW	-0.37	-0.82***	-0.85***	-0.85***	-0.83***	-0.85***	-0.60**
RV	-0.48*	-0.67***	-0.66***	-0.65**	-0.63**	-0.68***	-0.63**
TRL	-0.17	-0.15	-0.22	-0.23	-0.22	-0.29	-0.19
LRN	-0.12	-0.11	-0.05	-0.04	-0.02	-0.08	-0.13
LRL	-0.46*	-0.43*	-0.36	-0.34	-0.30	-0.37	-0.53**
TDM	-0.40	-0.83***	-0.86***	-0.86***	-0.83***	-0.83***	-0.63**
R:S	-0.25	-0.54**	-0.55**	-0.57**	-0.59**	-0.70**	-0.40
LMC	0.25	0.28	0.32	0.32	0.34	0.32	0.30
SMC	0.05	0.14	0.15	0.16	0.22	0.25	0.10
RMC	0.01	0.40	0.44*	0.46*	0.49*	0.50*	0.15
SCFW	-0.54**	-0.75***	-0.65**	-0.66**	-0.64**	-0.75***	-0.70***
SCV	-0.41*	-0.82***	-0.80***	-0.79***	-0.76***	-0.81***	-0.63**

**P<0.05; **P<0.01; ***P<0.001. Abbreviations: LFW = leaf fresh weight, LDW = leaf dry weight, SFW = stem fresh weight, SDW = stem dry weight, RFW = root fresh weight, RDW = root dry weight, RV = root volume, TRL = taproot length, LRN = lateral root number, LRL = lateral root length, TDM = total dry matter, R:S = root to shoot, LMC = leaf moisture content, SMC = stem moisture content, RMC = root moisture content, SCFW = stem cut fresh weight, SCV = stem cut volume.*

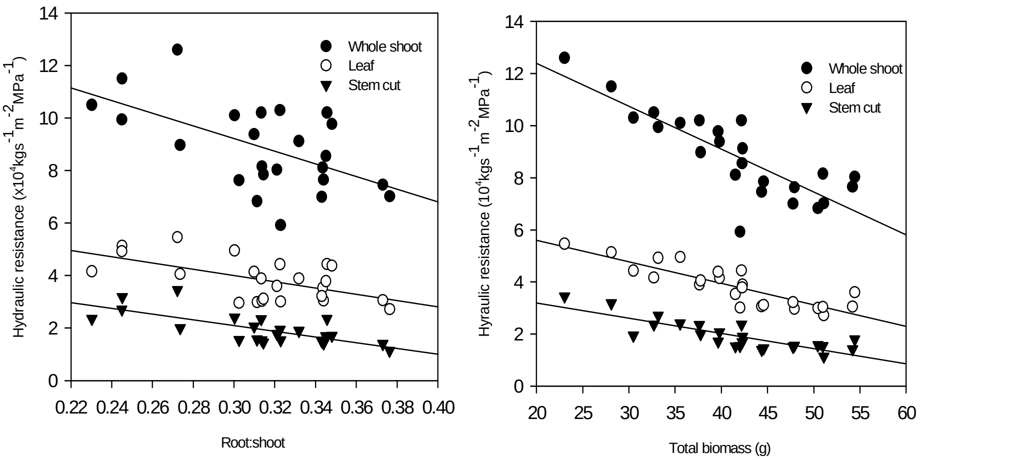

Figure 2. Whole-shoot, leaf and stem-cut hydraulic resistances as function of (a) root to shoot ratio and (b) total dry matter yield of coffee seedlings

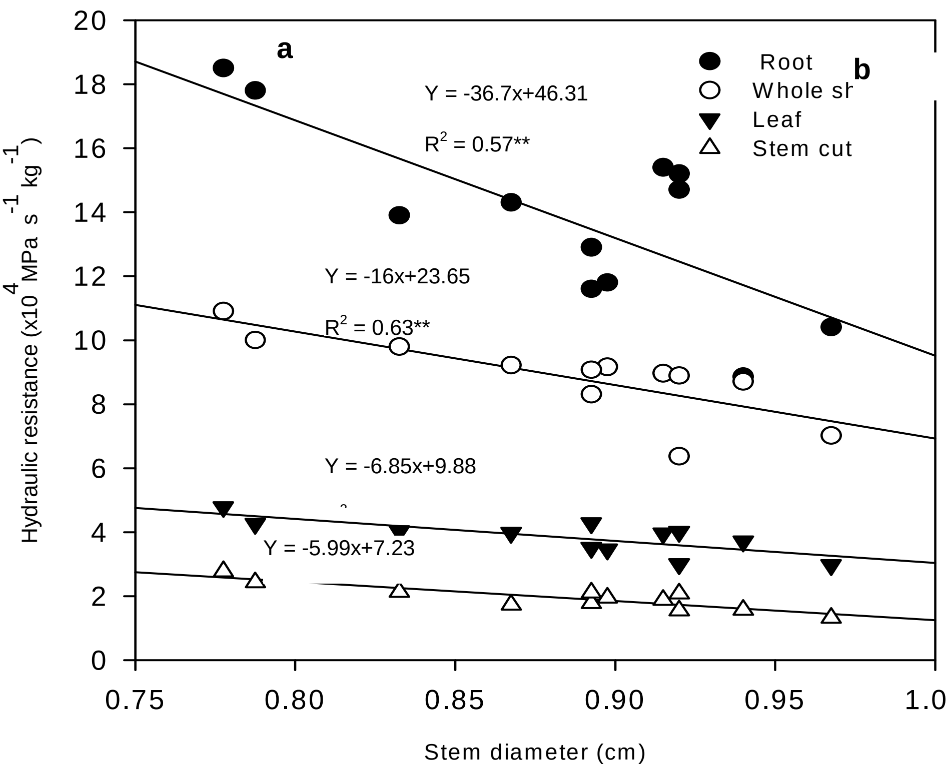

Figure 3. Relationship between main stem diameter and hydraulic resistance in root and shoot segments of arabica coffee seedlings

Discussion

There were significant differences among wild coffee populations in seedling growth characteristics with the average values in the order of Harenna>Yayu>Bonga>Berhane-Kontir accessions (Tables 2 and 3). This may reflect the genetic variations in growth rate and productivity among the coffee populations. This can be associated with the stem natures (stiff or flexible, stem density), root and leaf growth attributes in coffee (Yacob et al., 1996). The highest root growth was obtained from Harenna seedling as opposed to the significantly lowest root growth from the Berhane-Kontir population. Seedling growth responses significantly differed among the coffee accessions, possibly demonstrating the more contributions of genetic factors. This demonstrates that coffee plants can adapt to drought situations by extending the root system into deeper soil layers (Wintgens, 2004).

The results depicted that the four wild coffee populations were comparable in most hydraulic resistance components. Minimum shoot hydraulic resistances were obtained from the Harenna populations, suggesting that maximum water transport is proportional to allocation to maximum photosynthetic capacity of these accessions. In contrast, the compact coffees from Yayu and Bonga populations with short height, narrow basal area and reduced leaf surfaces had higher hydraulic resistances. This shows that these genotypes may have morphological plasticity to tolerate drought and thrive better under limited soil moisture conditions. The differences in growth habit of the Harenna and Berhane-Kontir populations with the highest values for most growth parameters (Tables 2 and 3) concurred with decreased hydraulic resistance patterns. This indicates the importance of crown architecture in detecting the hydraulic characteristics, adaptation and productivity of coffee plants.

The low whole-plant hydraulic resistance for the Harenna population may attribute to high rates of transpiration in the presence of sufficient water and increased water-use efficiency. Unlike in the root system, hydraulic resistance tended to decline in the whole shoot and its various components in the shade seedlings. The resistance contributions across root and shoot components followed the order of root>leaf>whole-shoot>branch> petioles of coffee seedlings. This could indicate the increased susceptibility to loss of hydraulic conductivity and xylem vulnerability to drought-stress conditions. This is in line with the variations in the growth natures of coffee accessions and other related traits, including leaf water potential, stomatal characteristics and accumulation of ions in wild coffee populations under field and common garden conditions (Taye and Burkhardt, 2011). The pattern of hydraulic resistance and vulnerability segmentation guarantees high water flow and/or water-use efficiency when soil water is sufficient (Tsuda and Tyree, 1997; Tausend *et al*., 2000). Clark *et al*. (2005) reviewed the progress and opportunities of sensing the physical and nutritional status of the root environment in the field.

The hydraulic architecture of coffee seedlings may also support the existence of a trade-off between xylem conductivity and resistance to cavitation (Zimmermann, 1983). Similarly, Tsuda and Tyree (1997) described a trade-off between vulnerability patterns and whole-plant resistance, as plants with low whole-plant resistance tend to be more vulnerable to cavitation and exhibit vulnerability segmentation when compared with plants with high whole-plant resistance. The difference between root and shoot parts can be accounted for the resistance of the xylem and by the physical location of the two organs in the soil-plant-atmosphere continuum. Whitehead (1998) short-term changes in stomatal conductance are linked closely to the hydraulic properties of the conducting system to minimize loss of hydraulic conductivity through xylem by cavitation.

The correlation result is invaluable to the breeder in selecting desirable traits. The simple correlation between seedling growth and hydraulic resistances showed different magnitude of relationships. The correlations between root growth parameters and root hydraulic resistance were strong and indirect in well-irrigated coffee seedlings. Burkhardt *et al*. (2006) described that wild Arabica coffee populations with extensive root system were more vulnerable to light and soil moisture stresses, possibly due to genetic variations in their hydraulic systems and stomatal behaviour. Seedlings with better root systems showed significantly higher root hydraulic conductance and were more productive under adequate soil moisture conditions (Taye and Burkhardt, 2011). This was observed from accessions originated from the drier Harenna forests. This provides insights into the inherent adaptive mechanisms and mitigation strategies among and within coffee populations for withstanding drought-stress environments. This corroborates with the work done by Tausend *et al*. (2000) on the water balance of *Coffea arabica*.

Hydraulic resistance components were negatively associated with fresh main stem density, suggesting high hydraulic resistances with increased stem water storage and decreased stem size. The more productivity of Harenna accessions could confirm the accumulation of more biomass with age and development of more xylem elements that can contribute to low stem resistance. Meinzer and Grantz (1990) pointed out that coffee genotypes with greater soil-to-leaf hydraulic conductance can deplete soil moisture more rapidly and experience symptoms of physiological stress earlier when water is withhold. Santiago *et al*. (2004) found a proportional decrease in leaf specific conductivity and leaf area with increasing wood density. The main stem diameter was strongly and negatively correlated with hydraulic resistances in main stem-cut, whole-shoot, leaf and root parts in a descending order, perhaps suggesting trade-offs between hydraulic capacity and photosynthetic rate in coffee plants. This corroborates with Sack *et al*. (2005) and may suggest the importance of seedling growth stages and habits in evaluating and selecting coffee genotypes under varying environments. The results are in agreement with the *in-situ* hydraulic resistances in the wild coffee trees, suggesting the importance of hydraulic properties in identifying suitable coffee genotypes against the possible impacts of climate change and variability.

In conclusion, the present findings demonstrate the genetic variability among wild arabica coffee populations in growth and hydraulic resistance characteristics. The contributions of seedling growth natures and parts were noted in detecting hydraulic resistances. The practical implication of optimum management options and pruning practices was highlighted by considering both genetic and environmental factors. However, in depth investigations are required to identify and develop drought tolerant Arabica coffee genotypes for specific locality. Hence, sustainable conservation and full exploitation of coffee genetic gene pools requires, among other things, studies on seasonal variations in hydraulic properties with other relevant functional traits in arabica coffee breeding strategy of Ethiopia, its birth country.

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