European Journal of Biotechnology and Bioscience
ISSN: 2321-9122; Impact Factor: RJIF 5.44
Received: 26-08-2020; Accepted: 12-09-2020; Published: 29-09-2020
www.biosciencejournals.com
Volume 8; Issue 5; 2020; Page No. 22-27

Role of Biochemical Traits on Coffee for Drought: A Review Article

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Abstract
Plants regulate drought by using several morphological, physiological and biochemical mechanisms for control water loss and enhance water uptake. It produce key protective and structural metabolites like sugars, amino acids, polyols, amides, secondary metabolites under drought conditions. Drought tolerant coffee genotype has higher in biochemical composition: free proline, total protein content, soluble sugars, epicuticular wax, nitrate reductase activity and glycine-betaine. Hence, accumulations of these biochemicals are considered as adaptive mechanisms in drought-tolerant coffee genotypes. In general, future research direction should be focused on biochemical tolerance mechanisms of coffee to drought.

Keywords: biochemical, coffee, drought, irrigation

1. Introduction

Water stress is an abiotic stress and it is primarily caused by water deficit, i.e. drought. It is one of the largest limitations of agricultural production worldwide (Endres *et al*., 2010) [8]. Drought is a situation that lowers plant water potential and turgor to the extent that plants face difficulties for physiological functions. It affects plant water relations, stomatal closure, limits gaseous exchange, reduces transpiration and photosynthesis, mineral nutrition and metabolism. It is one of main factor limiting coffee productivity (DaMatta and Ramalho, 2006) [7].

Plants tolerate to abiotic stresses is very complex, because various morphological, physiological and biochemical mechanisms are involved (Razmjoo *et al*., 2008) [25]. Plants survive drought condition by doing a self-balance between maintaining turgor and reduction of water loss. It develops adaptation to stress by morphological, physiological and biochemical tolerance mechanisms (Pinheiro *et al*., 2004; Castro *et al*., 2007) [23, 5]. Plants develop mechanisms to tolerant abiotic stress by osmotic adjustment. It is a mechanism to maintain water relations under osmotic stress and high osmotic adjustments occur in the drought tolerant cultivars through accumulation of compatible solutes (Farooq *et al*., 2009) [9]. Plants are protecting themselves from the stress by accumulating a variety of small organic metabolites called compatible solutes. Compatible solutes are small molecules that are soluble in water and its primary function is prevent water loss to maintain cell turgor and gradient for water uptake into the cell, osmo-regulation function and protecting of enzymes (Bohnert *et al*., 1995; Papageorgiou and Murata, 1995) [4, 21].

Drought tolerant genotypes of coffee have higher in biochemical compositions: free proline, total protein content and epicuticular wax (Heuer, 1999; D' Souza *et al*., 2009; Tesfaye *et al*., 2014; Somashekhargouda *et al*., 2019) [13, 8, 36, 34]; soluble sugars (Khalid, 2006) [15]; nitrate reductase activity and glycine-betaine (Sakamoto and Murat, 2002; Ashraf and Haris, 2004; Praxedes *et al*., 2006; Giri, 2011) [3, 24, 11]. Accumulation of compatible solute in plants is important to osmoprotectants under drought conditions. In fact, in Ethiopia there is genetic variability among Arabica coffee, but there is research limitation on biochemical traits related with drought. A better understanding of biochemical variability among Arabica coffee is important for further Arabica coffee breeding programs for drought. In general, higher accumulation of biochemical components were reported under drought tolerant coffee genotypes. Therefore, the objective of this review is to review the role of bio-chemicals on coffee for drought.

1.1 Proline

Proline is compatible osmolyte and proteinogenic amino acid. It plays important role on protecting sub-cellular structures, macromolecules and osmotic adjustment (Kishor *et al*., 2005; Haudecoeur *et al*., 2009; Wubishet, 2019) [16, 12, 38]. In addition to this, it protect protein integrity, enhance the activities of different enzymes, protection of nitrate reductase during heavy metal and osmotic stress, regulate development and metabolic signaling networks controlling mitochondrial functions (Mishra and Dubey, 2006; Szabados and Savoure, 2010) [19, 35].

It is reported in oxidative stress, drought, high salinity, high light, UV irradiation and heavy metals conditions. In water deficit, higher proline on coffee leaves and root were observed because of significantly increases the amount of bound of water capacity (Fig. 1a and b), respectively (Santos and Mazzafera, 2012) [29]. Similar reports on four Arabica coffee cultivars, from these Dawairi and Tessawi are better stresses tolerant due to highest levels of proline in their leaves (Fig. 3b) (Tounekti *et al*., 2018) [37]. In line with this report, drought tolerant clone of *Canephora coffee* was higher proline accumulation on leaves when compared with susceptible cultivars (Silva *et al*., 2010) [32].

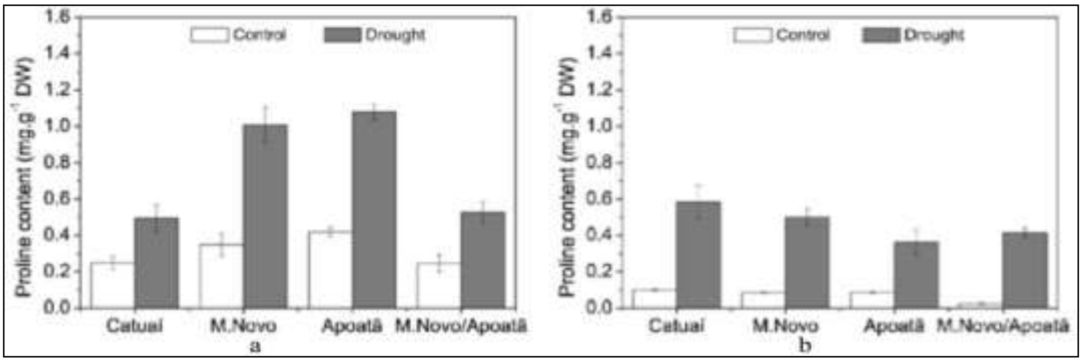
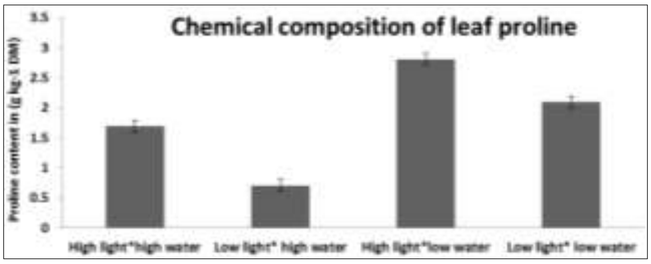


Fig 1: Proline contents in leaves (a) and roots (b) of stressed and control coffee plants. Bars indicate standard errors of the means. Source: Santos and Mazzaferab (2012) [29].

Robusta coffee clones were subjected to two treatments: well-watered control and drought-stressed. Clones IC-6 and IC-3 are drought tolerant than other clones due to higher proline accumulation and leaf proline concentration substantially increased with time of exposure of the plants to soil drying (Table 1) (Tesfaye *et al*., 2014) [36]. Similar finding reported that, higher accumulation of proline was observed under higher light and low water (Fig. 2) (Paulo *et al*., 2012). In addition to this, proline content significantly increased at water stress conditions in graft combinations as well as in scion seedlings (Somashekhargouda *et al*., 2019) [34]. Similar report on alternate drip irrigation and fixed drip irrigation were 69.6% and 204.6% higher proline content than conventional drip irrigation, respectively (Table 2) (Liu *et al*., 2016) [17].



Source: Paulo *et al*. (2012).

Fig 2: Chemical composition of leaf proline in coffee plants subjected to varied light and water conditions. Data are expressed in g kg^{-1} DM.

Table 1: Leaf water potential (LWP), leaf proline concentration (LPC), stress score values (SSV) and proportion of plants showing complete wilting symptoms (PPCWS) on day 12 of soil drying.

Clone	LWP (MPa)	LPC (μmolg-1 Fresh weight)	SSV (1-5 scale)	PPCWS
IC-2	-3.2	10.0	3.10	96.80
IC-3	-3.2	12.2	2.50	86.80
IC-4	-3.4	9.4	3.33	96.80
IC-6	-3.3	13.3	2.33	86.80
IC-8	-3.3	9.0	3.33	96.80
R-4	-3.2	9.5	3.40	96.80

Source: Tesfaye *et al*. (2014) [36]

1.2. Total Soluble Sugar and Protein

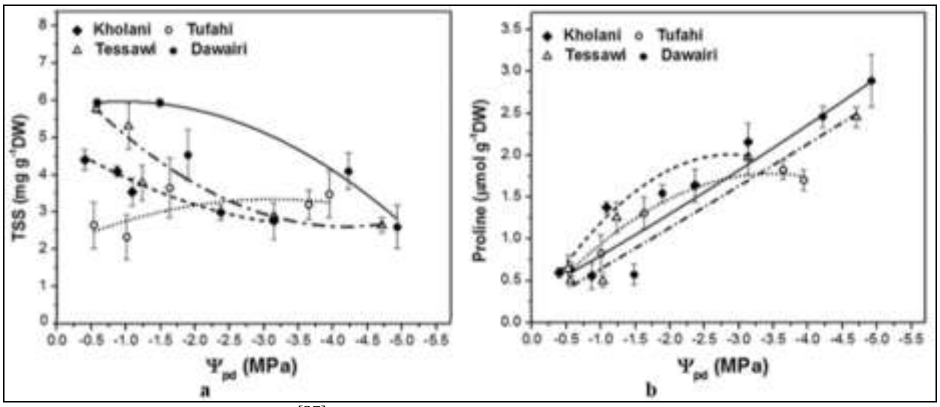
Soluble sugars (sucrose, glucose and fructose) play an important role in maintaining leaf water content, osmotic adjustment, overall structure and growth of plants under drought stress conditions (Rosa *et al*., 2009) [27]. Previous report on Arabica coffee cultivars showed that, total soluble sugar content was higher in Dawairi and Tessawi cultivars compared with others (Fig. 3a) (Tounekti *et al*., 2018) [37]. Similar report on alternate, fixed and conventional drip irrigation for leaf total soluble sugar content; the result revealed that in fixed drip irrigation with NSAP treatment were higher than other treatments (Table 2) (Liu *et al*., 2016) [17]. Hence, it improves water use efficiency due to accumulation of osmotic substances, so as to prevent dehydration of cells and tissues (Akcay, 2010) [2]. Similar report in agreement of this result was reported on other crop like wheat (Nazaarli and Faraji, 2011) [20].

Total soluble protein (TSP) increased significantly at water stress conditions; in addition to this TSP was varied significantly between scion seedlings and graft combinations (Somashekhargouda *et al*., 2019) [34]. Higher accumulation of protein content was reported on drought tolerant coffee genotype at water stress condition (Divya, 2008; D’ Souza *et al*., 2009) [30]. Similar kind of changes in soluble protein content was reported on Sorghum due to stress (Aher and Nair, 2003).

Table 2: Effect of drip irrigation method and super absorbent polymer on proline and soluble sugar on young Arabica Coffee.

Drip irrigation method	Superabsorbent polymers level	Leaf water content (%)	Proline (igg^{-1})	Soluble sugar (%)
ADI	SAP	75.72±1.14a	9.46±1.58b	1.54±0.23a
	NSAP	71.38±0.91ab	18.30±2.82b	3.35±0.73ab
FDI	SAP	72.86±1.27ab	17.33±0.95b	2.33±0.14bc
	NSAP	67.68±0.84b	32.53±2.53a	4.53±0.15a
CDI	SAP	75.75±3.35a	6.17±0.01b	1.18±0.02c
	NSAP	75.95±2.40a	10.20±0.90b	1.42±0.09c

ADI, FDI and CDI are represents alternate drip irrigation (alternate watering on both sides of the pot at each watering), fixed drip irrigation (fixed watering on one side of the pot at each watering) and conventional drip irrigation (both sides of the irrigated simultaneously at each watering). SAP and NSAP are represents added superabsorbent polymers and no superabsorbent polymers, respectively. The values are means ± standard errors (n=4). Different letters in the same column indicate significant difference (P<0.05). Source: Liu et al. (2016) [17].

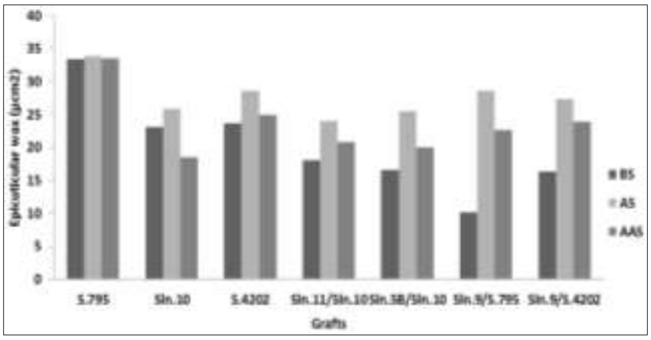


Source: Tounekti *et al*. (2018) [37].

Fig 3: Changes in the leaf total soluble sugars (TSS) (a) and proline contents (b) as a function of predawn leaf water potential ((Ψpd) in Arabica coffee cultivars kholari, Tessawi, Tufahi amd Dawairi subjected to drought, Bars indicate errors of the means.

1.3 Epicuticular Wax

Epicuticular wax (ECW) is one of the parameter for screening the cultivars for drought tolerance in coffee (Saraswathy *et al*. 1996) [30]. In Fig. 4, ECW increased significantly in all the graft combinations as well as pure line seedlings at water stress conditions. The research findings was reported at water stress conditions higher accumulation of ECW was observed on graft combinations of Sln.9/S.795 and Sln.9/S.4202 due to positive influence of Sln.9 rootstock on S.795 and S.4202 scion (Somashekhargouda *et al*., 2019) [34]. Similarly, it is an effective component of drought resistance in other crops like sorghum (Adelina *et al*., 1977) [1].



Source: Somashekhargouda *et al*. (2019) [34].

Fig 4: Change in epicuticular wax content in different graft combinations at different soil moisture regimes. BS, AS and AAS represents before stress, after stress and after alleviation of stress, respectively.

1.4. Nitrate Reductase Activity and Glycine betaine

Nitrate reductase activity (NAR) is important enzyme for nitrogen assimilation and protein synthesis in plant cell. It is vital for the metabolic and physiological status of plants and used as a biomarker of plant stress (Sivakumar *et al*., 2017) [33]. It is considered as an indicative parameter for the evaluation of the effect of water stress on coffee (Meguro and Magalhães, 1983) [18]. At stress conditions all the graft combinations maintained significantly high NAR compared to respective pure line scion seedlings due to drought tolerance mechanism. Higher NRA was observed at before stress and after the alleviation of stress at graft combinations due to positive influence on NRA by scions indicating usefulness of these rootstocks in inducing drought tolerance and better nitrogen assimilation (Table 3) (Somashekhargouda *et al*., 2019) [34].

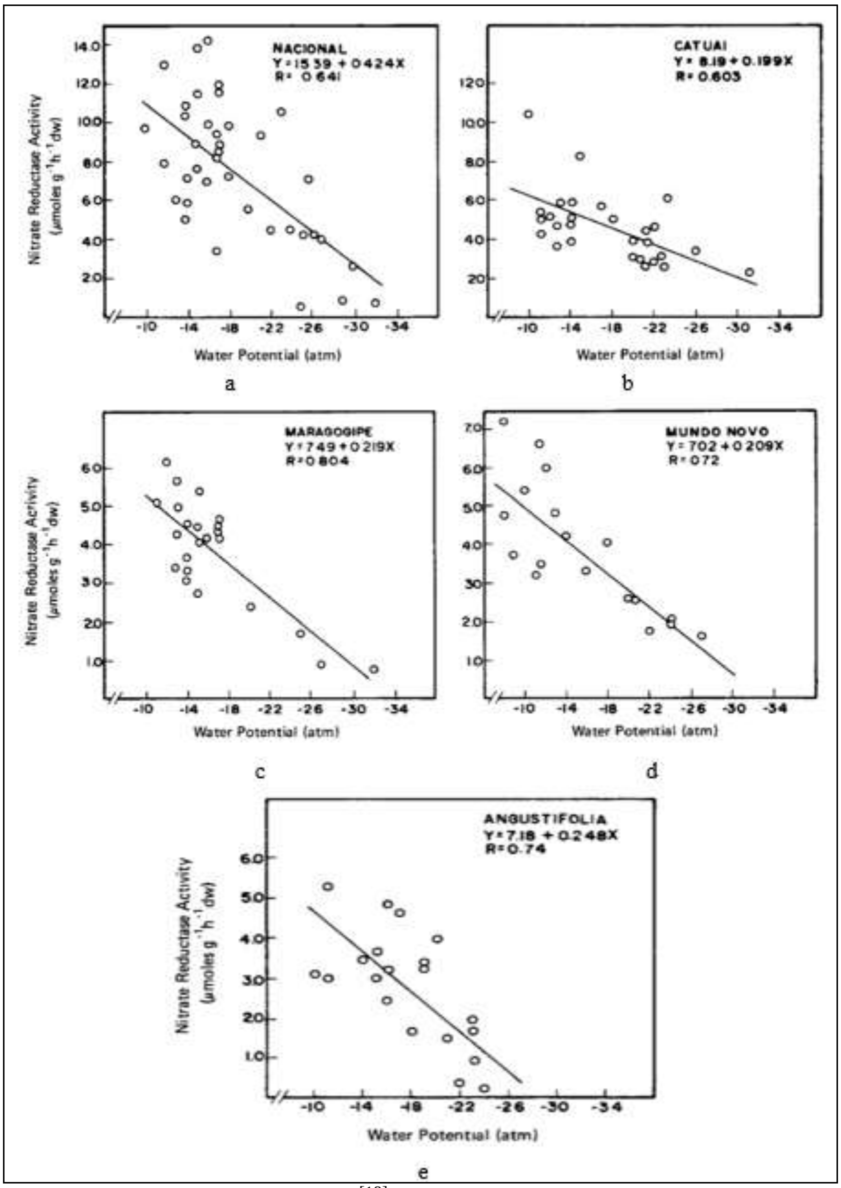
Table 3: Change in nitrate reductase activity content of graft combinations at different soil moisture regimes.

Seedlings/graft combinations	**Stress Condition**			
	Nitrate reductase activity (µ moles hr^{-1} g^{-1} dry weight)			
	BS	AS	AAS	Mean
S.795	0.64	0.30	0.67	0.54
Sln.10	0.70	0.30	0.71	0.57
S.4202	0.72	0.32	0.64	0.56
Sln.11/Sln.10	0.98	0.35	0.96	0.76
Sln.5B/Sln.10	1.00	0.34	0.89	0.74
Sln.9/S.795	1.05	0.38	0.93	0.79
Sln.9/S.4202	0.62	0.35	0.60	0.52
Mean	0.82	0.33	0.77	0.64
	SEm ±		5%	1%
Stress condition	0.023		0.064	0.086
Seedlings/graft	0.034		0.098	0.132
Interaction	0.060		0.170	NS

BS, AS and AAS are before stress, at stress and after alleviation of stress, respectively. Source: Somashekhargouda *et al*. (2019) [34].

Several studies have indicated that under water stress, NAR might be used to estimate the environmental adaptability of different genotypes (Shaner and Boyer, 1976; Heuer *et al*., 1979) [31, 14]. It is used as a suitable criterion for the evaluation of the effect of water stress on the physiology of coffee plants under *in vivo* activity. In Fig. 5, significant difference on effect of water stress on the activity of NAR was only observed between cultivars Catuai and Nacional, the former being more tolerant to water deficits in relation to nitrate reduction (Meguro and Magalhães, 1983) [18].

Glycine betaine (N, N, N -trimethyl glycine) is an amphoteric compound and it stabilizes the structures and activities of enzymes and protein complexes. It maintains the integrity of membranes against the damaging effects of several abiotic stresses. It plays an important role in the responses of plant cells to a variety of stresses (Rhodes and Hanson, 1993; Sakamoto and Murata, 2002) [21]. Physiology, genetics, biophysics and biochemistry of plants strongly suggests that glycine betaine (GB), is an amphoteric quaternary amine and it plays an important role as a compatible solute in plants under various types of environmental stress (Farooq *et al*., 2008). Plant cells accumulate compatible solutes such as glycine-betaine in their cytosols in response to abiotic stresses (Giri, 2011) [11]. It also play an important role in the response of plant cells to a variety of stresses (Sakamoto and Murat, 2002; Ashraf and Haris, 2004) [3].



***Source*:** (Meguro and Magalhães, 1983) [18].

Fig 5: *In vivo leaf nitrate reductase activity of Coffea arabica cultivars subjected to different water potentials.*

Summary and Conclusion

Coffee is one of cash crop in Ethiopia. Its production is affected by different factors; from this drought is major one. Drought tolerance is a multigenic trait that involves many complex mechanisms. Plants have tolerate to drought is very complex, because various morphological, physiological and biochemical mechanisms are involved. Knowledge of morpho-physiological and biochemical responses to drought is important for knowing plant resistance mechanisms. Higher biochemical composition on drought tolerant coffee genotypes has been reported in different country, but in Ethiopia, there is research limitation on biochemical mechanisms to drought tolerance. Therefore, further research should be need on biochemical tolerance mechanisms to drought.

References

1. Adelina E, Blum A, Jordan WR. A rapid colorimetric method for epicuticular wax content of sorghum leaves. Crop Science. 1977; 17(1):179-180.
2. Akcay U, Ercan O, Kavas M, Yildiz L, Yilmaz C, Oktem H, *et al*. Drought induced oxidative damage and antioxidant responses in peanut (*Arachis hypogea*) seedlings. Plant Growght Regulator. 2010; 61(1):21-28.
3. Ashraf M, Haris PJ. Potential biochemical indicators of salinity tolerance in plants. Plant Science. 2004; 166(1):3-16.
4. Bohnert HJ, Nelson DE, Jensen RG. Adaptations to environmental stresses. The plant cell. 1995; 7(7):1099.
5. Castro G, Giovannelli A, Deslauriers A, Fragnelli G, Scaletti L, Rossi S, *et al*. Evaluation of drought response of two poplar clones (Populus× canadensis Mönch 'I-214'and P. deltoides Marsh.'Dvina') through high resolution analysis of stem growth. Journal of Experimental Botany. 2007; 58(10):2673-2683.
6. D'Souza GF, Renukaswamy NS, Anand CG, Awati MG, Lamani B. Biochemical and physiological changes in two arabica coffee genotypes in relation to drought tolerance. Journal of Coffee Research. 2009; 37(1& 2):26-42.

7. DaMatta FM, Ramalho JDC. Impacts of drought and temperature stress on coffee physiology and production: a review. Brazilian Journal of Plant Physiology. 2006; 18(1):55-81.
8. Endres L, Pompelli MF, Barata-Luís R, Vitorino HS, Gonçalves ER, Rolim EV, *et al*. Photosynthesis, photoprotection and antioxidant activity of purging nut under drought deficit and recovery. Biomass and Bioenergy. 2010; 34(8):1207-1215.
9. Farooq M, Basra SMA, Wahid A, Cheema ZA, Cheema MA, Khaliq A, *et al*. Physiological Role of Exogenously Applied Glycinebetaine to Improve Drought Tolerance in Fine Grain Aromatic Rice (Oryza sativa L.). Journal of Agronomy and Crop Science. 2008; 194(5):325-333.
10. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. Plant drought stress: effects, mechanisms and management. In Sustainable agriculture, Springer, Dordrecht, 2009, 185-212.
11. Giri J. Glycinebetaine and abiotic stress tolerance in plants. Plant signaling and behavior. 2011; 6(11):1746-1751.
12. Haudecoeur E, Planamente S, Cirou A, Tannieres M, Shelp BJ, Morera S, *et al*. Proline antagonizes GABA-induced quenching of quorum-sensing in Agro-bacterium tumefaciens. Proceedings of the National Academy of Sciences. 2009; 106(34):14587-14592.
13. Heuer B. Osmoregulatory role of proline in plants exposed to environmental stresses. In Hand book of Plant and Crop Stress, Second edition, 1999, 675-695.
14. Heuer B, Plaut Z, Federman E. Nitrate and nitrite reduction in wheat leaves as affected by different types of water stress. Physiologia Plantarum. 1979; 46(4):318-23.
15. Khalid KHA. Influence of water stress on growth, essential oil and chemical composition of Herb (Ocimum sp.). Institute of Agrophysics. 2006; 20(4):289-296.
16. Kishor PK, Sangam S, Amrutha RN, Laxmi PS, Naidu KR, Rao KRSS, *et al*. Regulation of proline biosynthesis, degradation, uptake and transport in higher plants: its implications in plant growth and abiotic stress tolerance. Current Science. 2005; 88(3):424-438.
17. Liu X, Li F, Yang Q, Wang X. Effects of alternate drip irrigation and superabsorbent polymers on growth and water use of young coffee tree. Journal of Environmental Biology. 2016; 37(4):485.
18. Meguro NE, Magalhães AC. Water stress affecting nitrate reduction and leaf diffusive resistance in Coffea arabica L. cultivars. Journal of Horticultural Science. 1983; 58(1):147-152.
19. Mishra S, Dubey RS. Inhibition of ribonuclease and protease activities in arsenic exposed rice seedlings: role of proline as enzyme protectant. Journal of Plant Physiology. 2006; 163(9):927-936.
20. Nazarli H, Faraji F. Response of proline, soluble sugars and antioxidant enzymes in wheat (Triticum aestivum L.) to different irrigation regimes in greenhouse condition. Cercetari agronomice in Moldova. 2011; 44(4):27-33.
21. Papageorgiou GC, Murata N. The unusually strong stabilizing effects of glycine betaine on the structure and function of the oxygen-evolving photosystem II complex. Photosynthesis Research. 1995; 44(3): 243-252.
22. Paulo CC, Oliveira AA, Morais LE, Martins SC, Sanglard LM, DaMatta FM, *et al*. Could shading reduce the negative impacts of drought on coffee? A morphophysiological analysis. Physiologia plantarum. 2012; 144(2):111-122.
23. Pinheiro HA, DaMatta FM, Chaves ARM, Fontes EPB, Loureiro ME. Drought tolerance in relation to protection against oxidative stress in clones of Coffea canephora subjected to long-term drought. Plant Science. 2004; 167(6):1307-1314.
24. Praxedes SC, DaMatta FM, Loureiro ME, Ferrao MA, Cordeiro AT, *et al*. Effects of long-term soil drought on photosynthesis and carbohydrate metabolism in mature robusta coffee (Coffea canephora Pierre var. kouillou) leaves. Environmental and experimental botany. 2006; 56(3):263-273.
25. Razmjoo K, Heydarizadeh P, Sabzalian MR. Effect of salinity and drought stresses on growth parameters and essential oil content of Matricaria chamomile. Intnational Journal of Agriculture Biology. 2008; 10(4):451-454.
26. Rhodes D, Hanson AD. Quaternary ammonium and tertiary sulfonium compounds in higher plants. Annual Review of Plant Physiology and Plant Molecular Biology. 1993; 44(1):357-384.
27. Rosa M, Prado C, Podazza G, Interdonato R, González JA, Hilal M, *et al*. Soluble sugars: Metabolism, sensing and abiotic stress: A complex network in the life of plants. Plant Signal and Behavior. 2009; 4(5):388-393.
28. Sakamoto A, Murata N. The role of glycine betaine in the protection of plants from stress: clues from transgenic plants. Plant, Cell and Environment. 2002; 25(2):163-171.
29. Santos AB, Mazzafera P. Dehydrins are highly expressed in water-stressed plants of two coffee species. Tropical plant biology. 2012; 5(3):218-232.
30. Saraswathy VM, Venkataramanan D, D'Souza GF, Anand CG. Effect of water stress on epicuticular wax, solute accumulation and relative water content in coffee seedlings. In Proceedings of international symposium on plantation crops. Journal of Plantation Crops. 1996; 24:530-537.
31. Shaner DL, Boyer JS. Nitrate reductase activity in maize (Zea mays L.) leaves. II. Regulation by nitrate flux at low leaf water potential. Plant Physiology. 1976; 58(4):505-509.
32. Silva VA, Antunes WC, Guimarães BLS, Paiva RMC, Silva VF, Ferrão MAG, *et al*. Physiological response of Conilon coffee clone sensitive to drought grafted onto tolerant rootstock. Pesquisa Agropecuária Brasileira. 2010; 45(5):457-464.
33. Sivakumar R, Nandhitha GK, Chandrasekaran P, Boominathan P, Senthilkumar M. Impact of Pink Pigmented Facultative Methylotroph and PGRs on Water Status, Photosynthesis, Proline and NR Activity in Tomato under Drought. International Journal of Current Microbiology and Applied Sciences. 2017; 6(6):1640-1651.
34. Somashekhargouda P, D'Souza GF, Umesh DK, Rudragouda C. Rootstock scion interaction effects on biochemical and gas exchange drought tolerant traits in Arabica (Coffea arabica L.) coffee. Plant Physiology

Reports. 2019; 24(3):316-327.
35. Szabados L, Savoure A. Proline: a multifunctional amino acid. Trends in plant science. 2010; 15(2):89-97.
36. Tesfaye SG, Ismail MR, Ramlan MF, Marziah M, Kausar H. Effect of soil drying on rate of stress development, leaf gas exchange and proline accumulation in Robusta coffee (Coffea scanephora Pierre ex Froehner) clones. Experimental agriculture. 2014; 50(3):458-479.
37. Tounekti T, Mahdhi M, Al-Turki TA, Khemira H. Water relations and photo-protection mechanisms during drought stress in four coffee (Coffea arabica L.) cultivars from southwestern Saudi Arabia. South African journal of Botany. 2018; 117:17-25.
38. Wubishet Tamirat. Review on role of proline on coffee under drought conditions. Journal of Environment and Earth Science. 2019; 9(10):1-6.