IDENTIFICATION OF WATER STRESS TOLERANT AMARANTHUS GENOTYPES (*Amaranthus tricolor* L.) WITH HIGH YIELD AND QUALITY

by

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(2016-11-102)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"IDENTIFICATION OF WATER STRESS TOLERANT AMARANTHUS GENOTYPES (*Amaranthus tricolor* L.) WITH HIGH YIELD AND QUALITY"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

^0C	Degree Celsius
%	Per cent
&	And
CD (0.05)	Critical Difference at 5% level
cm	Centimetre
mg	Milligram
RBD	Randomised Block Design
DAS	Days After Sowing
et al.	And others
Fig.	Figure
g	Gram
g^{-1}	Per gram
Kg	Kilo gram
IU	International Unit
ha^{-1}	Per hectare
KAU	Kerala Agricultural University
t ha^{-1}	Tonne per hectare
kg ha^{-1}	Kilogram per hectare
kg $plot^{-1}$	Kilogram per plot
$Plant^{-1}$	Per plant
$Plot^{-1}$	Per plot

Temp.	Temperature
Via	Through
Mm	Millimetre
No.	Number
M	Molar
cv	Cultivar
RWC	Relative water content
Sl.	Serial
sp. or spp.	Species (Singular and Plural)
GCV	Genotypic Coefficient of Variation
PCV	Phenotypic Coefficient of Variation
viz.	Namely
d.f	Degrees of freedom
S. E	Standard Error
mg g^{-1}	Milligram per gram

INTRODUCTION

1. INTRODUCTION

Amaranthus (*Amaranthus tricolor* L.) is a leafy vegetable, which belongs to the family *Amaranthaceae,* comprising of 70 species, of which 17 produce edible leaves and three produce food grains. Amaranthus is one of the main species of the large and taxonomically diverse group of tropical leafy vegetables (IBPGR, 1981). It is one of the oldest crops cultivated all over the world, which is originated in America.

Amaranthus is unique in its composition, which has a good amount of lysine and dietary fibre. It is a rich source of minerals like calcium, magnesium, and copper, good source of zinc, potassium, and phosphorus and contains many essential vitamins including A, C, E, K, B5, B6, folate, niacin, and riboflavin. More than that, as a pseudo cereal, amaranthus seeds contribute considerable amount of antioxidant phytochemicals including phenols, flavonoids, anthocyanins etc. Amaranthus is a new millennium crop having nutraceutical values (Rastogi and Shukla, 2013). Its oil is cholesterol free, anti-inflammatory and prevents the cancer. The fiber and phytonutrients in amaranthus lower blood pressure and the protein is highly bioavailable. Lysine present in amaranthus helps the body for absorbing calcium, build muscles and produce energy. Though it is rich source, of minerals and nutrients the presence of antinutrients like oxalate and nitrate hinders the large-scale production and consumption of amaranthus. These antinutrients make many health problems like kidney stone and interfere with normal functioning of haemoglobin.

High variability exists for morphological characters like leaf colour, size and yield in edible amaranthus as well as wild species. Characterization and classification becomes more important in these species for further development and improvement in amaranthus.

Drought is one of the major limiting factors in crop production, and will become increasingly important due to the global climate changes. Chronic or sporadic periods of water deficit leads to the reduced growth and quality in plants,

and high losses in yield of 50 percent and more (Wang *et al.*, 2003). Water deficit is one of the most common environmental limitations of crop productivity, and it is a permanent constraint that farmers face daily (Hyman *et al.*, 2008).

Kerala has been experiencing decline in the annual and monsoon rainfall and increase in temperature during the past several years. There were significant changes in South-West monsoon rainfall with 33.7 percent deficit, and 61.7 percent deficit in the North-East monsoon. Number of rainy days has been reduced from 25 to 17 rainy days till the end of September 2016 (IMD, 2016). It becomes a major problem in agricultural sector.

The demands of an increasing world population and the threat of global warming will increase the water scarcity, resulting in a growing demand for drought tolerant and water use efficient crop plants. Climate changes may have more effect on small and marginal farmers, particularly who are mainly dependent on vegetables (FAO, 2009). Water greatly influences the yield and quality of vegetables, which are more sensitive to water stress as compared to other crops (Kumar *et al.*, 2014).

Production of water stress tolerant crops becomes more important to sustain the food security in the world. Rate of photosynthesis will decrease under water stress condition and thereby affects plant growth. Water stress drastically reduces the plant productivity due to the reduction in plant tissue water content, water potential, leaf elongation, rate of photosynthesis and the changes in protein synthesis and nitrogen metabolism (Saneoka *et al.*, 2004).

In the present scenario, collection and evaluation of amaranthus genotypes with high yield and low antinutritional contents, which can tolerate water stress, are important.

Considering these facts, the present investigation is aimed at developing breeding materials in amaranthus, which can be further utilized for the production of water stress tolerant amaranthus varieties with good quality and high yield.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Amaranthus (*Amaranthus tricolor* L.) is the most popular and widely grown leafy vegetable in Kerala due to its attractive colour, taste and nutritional value. Amaranthus is a dicotyledonous herbaceous plant which belongs to the family *Amaranthaceae*. It includes approximately 70 species, of which 17 produce edible leaves and three produce food grains. Collection, identification and characterization of different genotypes of amaranthus help in the improvement of specific characters under desired condition. Present study was undertaken to evaluate amaranthus genotypes and to identify water stress tolerant genotypes with high quality. The present investigation reviewed under following characters,

2.1. EVALUATION OF AMARANTHUS GENOTYPES

2.1.1. Biometric Characters

2.1.1.2. Stem Girth

Hamid *et al.* (1989) revealed that height and stem girth are positively correlated with yield in amaranthus, from the study of performance of some local and exotic germplasm of amaranthus.

Selvaraj (2004) reported that A56 (CO5) had the maximum stem girth (9.06 cm) from seventy four amaranthus genotypes. Whereas, the highest stem diameter (11.45cm) was observed in VA14, the lowest diameter (2.68 cm) in VA32 with an average stem girth of 6.05 cm in amaranthus (Sarker *et al.*, 2015).

Twenty three amaranthus genotypes were evaluated and the variability in stem diameter was ranged from 0.30 to 0.40 cm with mean of 0.35 cm. The genotype AMAR-23 recorded highest stem girth of 0.40 cm and AMAR- 04 showed the lowest of 0.30 cm in stem diameter (Jangde, 2016).

2.1.1.2. Length of Leaf Lamina

Amaranthus genotype A56 (CO5) had the highest leaf length (14.35 cm) at harvest stage of 30 DAS (Selvaraj, 2004). Variability in length of leaf lamina was observed by Celine *et al.* (2007) in a study of eighty nine accessions of amaranthus. The accessions Am 67 and Am 24 were had the maximum (21.1 cm) and the minimum (7.4 cm) length of leaf lamina accordingly .

Diwan (2015) evaluated ten genotypes of amaranthus in which the maximum leaf length was recorded in Arun (8.98 cm) and the minimum was recorded in AMAR-1 (4.83 cm) which varied from 4.83 cm to 8.98 cm for leaf length. The genotype AMAR- 07 showed the highest leaf length of 6.10 cm and the lowest of 3.82 cm in the genotype AMAR-14 which fluctuated from 3.82 to 6.10 cm (Jangde, 2016).

2.1.1.3. Petiole Length

The mean performance for petiole length was recorded as 4.17 cm and that for stem girth was 3.02 cm in an evaluation of 25 different vegetable amaranthusgenotypes (Varalakshmi and Reddy, 1994). Varalakshmi (2004) reported a wide range of variability in amaranthus for petiole length (3 to 9cm).

The genotype CO5 had reported the maximum petiole length (11 cm), followed by A40 (7.5 cm) and CO4 had minimum (3.38 cm) at 30 DAS (Selvaraj, 2004).

2.1.1.4 Leaf Width

Leaf width showed variability in different genotypes, Varalakshmi (2004) reported the range of 3 to 12 cm of leaf width in amaranthus. A variation of 7.91 to 3.51 cm leaf width was observed from seventy four amaranthus genotype (Selvaraj, 2004). Joshi *et al.* (2011) reported a wide range of variability in leaf width (5.2 to 12.7 cm) indicated the possible exploitation of variation for amaranthus improvement.

From the study of 23 amaranthus genotypes the genotype AMAR-07 showed the maximum leaf width of 4.82 cm, which was on par with AMAR-13 (4.53 cm), AMAR-08 (4.50 cm) and AMAR-19 (4.42 cm). The lowest leaf width was observed for AMAR-15 (3.05 cm) (Jangde, 2016).

2.1.1.5 Internodal Length

Diwan (2015) evaluated ten genotypes of amaranthus during rabi season of 2014-15, reported that the highest internodal length was in Arka Suguna (2.51 cm) followed by 2012/AMVAR-1 (2.21 cm) and the lowest internodal length was recorded in 2012/AMVAR-1 (1.36 cm) followed by 2012/AMVAR-3 (1.58 cm) with mean value ranged from 1.36 cm to 2.51 cm.

2.1.1.6. Number of Branches

Eight red amaranthus were studied by Mohideen *et al.* (1983) and revealed that types A. 144, A. 145 and local 1 were having tall growth habit and long duration with a few or no branches. But the types A. 53, A.90 and A.147 were comparatively having dwarf stature and short duration with more branches.

Jangde (2016) conducted a study on diverse 23 amaranthus genotypes in which the maximum and the minimum number of branches were recorded in AMAR-06 (3.53) and AMAR-22 (2.67) accordingly, with overall mean of 3.11.

2.1.1.7. Yield Plant^{-1}

A study by Kauffman and Gilbert (1981) was reported that RRC 241 was the top performer among *A. tricolor* accessions. According to Rajagopal *et al.* (1977) A144 was potential high yielding genotypes from sixty five diverse genotypes with good edible qualities. Yield plant^{-1} in amaranthus varied from 1.18 to 3.29 kg with an average of 2.25 kg (Shukla and Singh, 2000).

Shukla *et al.* (2004) reported that the amaranthus strain AV-41 showed highest foliage yield (5.99 kg plot^{-1}) and the heritability estimates were high for all the traits except number of branches plant^{-1} and moisture content. Accession

A57 showed the highest yield plant^{-1} (304.5 g plant^{-1}) from the study of sixty diverse genotypes while the accession A9 reported lowest yield. The significant difference among all the genotypes for different traits were observed (Priya *et al.*, 2007).

2.1.1.8. Yield Plot^{-1}

Various workers reported the yield of amaranthus ranged from 4.0 to 16.5 t ha^{-1} (Campbell and Abbott, 1982) and from 9.90 to 18.30 t ha^{-1} (Makus, 1984). Among the nineteen *Amaranthus spp.* studied by Vijayakumar *et al.* (1982) reported that the optimum stage of harvest was around 25-30 DAS to get the maximum leaf yield. Type A144 was well performed followed by A. 104 and A.56.

The highest leaf yield was observed in black seeded amaranthus whereas white seeded amaranthus gave the highest seed yield (Olufolaji and Dinakin, 1988). Sirohi and Sivakami (1995) reported Pusa Kirti (*A. tricolor*) and Pusa Kiran (*A tricolor* × *A. tristis*) recorded high yield of 50 to 55 t ha^{-1} and 35 t ha^{-1} respectively.

The broad and purple leaved multicut amaranthus variety Arka Arunima yielded 27 t ha^{-1} (IIHR, 2000). In a study conducted by Pan *et al.* (2008), red leaved line HAAMTH-48 *Amaranthus tricolor* genotype reported 3.15 kg plot^{-1} or 35.0 t ha^{-1} yield which was comparatively higher than the performance of two released varieties like Pusa Lal Chaulai and Pusa Kirti. The green leaved line HAAMTH-29 recorded a yield of 3.00 kg plot^{-1} or 33.3 t ha^{-1}.

Joshi *et al.* (2011) investigated thirteen accessions of vegetable amaranthus in which the highest leaf weight (595.0 g) was observed in IC 257792 and the maximum stem weight (4875.0 g) in IC 526828 followed by IC 257791 (3150.0g). Jangde (2016) reported that AMAR- 20 had the maximum yield plot^{-1} (602.87 kg) which ranged from 360.67 to 602.87 kg whereas the minimum yield was reported in AMAR- 14 (360.67 kg).

2.1.1.9. Leaf to Stem Ratio

Campbell and Abbot (1982) studied on different species of amaranthus and observed that *A. tricolor* had the highest leaf to stem ratio with high marketable potential. Priya (1998) conducted experiment in various genotypes of amaranthus and obtained the highest yield for Amt 193 (304.5 g plant^{-1}) and the genotype A 24 from *A. tricolor* showed the highest leaf to stem ratio of 1.57.

Selvaraj (2004) studied growth of 74 amaranthus genotypes at five different stages, in which the maximum leaf to stem ratio (1.42) was reported in A26 and the minimum (0.23) in genotype A13 at 30 days after sowing.

2.1.1.10. Days to 50% Bolting

An experiment was done by Shukla and Singh (2000) in 66 amaranthus genotypes, days to flowering ranged from 44.33-75.33 days and the plant height ranged from 31.67- 125.33 cm and number of branches from 4.33 -19.67. Selvaraj (2004) revealed that optimum stage of harvest for yield and stem yield was between 30-40 DAS.

2. 1.1.11. Plant Height

Varalakshmi and Reddy (1994) studied 25 different lines of vegetable amaranthus and obtained mean values of 35.65 cm, 7.35 cm and 10.58 cm for plant height, leaf breadth and length respectively. The significant variation among the germplasm was observed in terms of morphological characters.

Jangde (2016) recorded the range of plant height of amaranthus from 12.89 to 17.96 cm with mean of 15.88 cm. AMAR-01 had showed the maximum plant height (17.96 cm) while the minimum plant height of 12.89 cm was observed in AMAR-07.

2.1.1.12. Incidence of Leaf Blight

Celine *et al.* (2007) screened eighty nine diverse accessions of amaranthus for resistance to leaf blight caused by *Rhizoctonia solani*. *A. dubius* and *A. hypochondriacus* were found free from incidence of leaf blight, *A. tricolor*

showed varied levels of susceptibility. Scoring was done on 0 to 4 scales from which the highest incidence was obtained in Am1 (2.6). Celine *et al.* (2011) observed that superior high yielding amaranthus accessions like AD-30, AD-23, and AD-22 were field resistant to leaf blight.

Accessions of *A. dubius* and *A. hypochondriacus* were evaluated and Am78, Am83, Am85, Am 86 and Am 87 accessions of *A. dubius* were high yielding with resistance to leaf blight diseases (Celine *et al.*, 2011).

2.1.1.13. Incidence of Leaf Webber

Leaf webber (*Hymenia recurvalis*) was noticed as major pest in amaranthus (*A. tricolor* L.) field whereas red spider mite was found to be the minor pest (Muralikrishna, 2015).

2.1.2. Morphological Cataloguing

Varalakshmi (2004) described forty six germplasm of amaranthus in terms of different morphological traits reported that all the germplasm were erect, tap rooted, with no spines on the leaf axile. All the germplasm were monoecious with erect terminal inflorescence. Range of leaf colour was from green to purple, pigmented leaf veins and margins in pinkish green, lanceolate to cuneate and obovate leaf shape, green to purple and pinkish green petiole pigmentation with two lines prominent in leaf veins, low to dense and intermediate inflorescence density with colour range of green to pink, pinkish green, greenish pink and light pink.

2.2. IDENTIFICATION OF STRESS TOLERANT AMARANTHUS GENOTYPES WITH HIGH QUALITY

Red amaranthus (*Amaranthus tricolor* L.) is most widely cultivated commercial and dietary vegetable in Kerala. Amaranthus contains appreciable amount of iron, minerals, calcium and phosphorous, excellent source of

vitamin C. Red amaranthus is a very important vegetable due to its short length, quick growing habit and rich source of vitamins and minerals.

Drought is a major abiotic stress which causes crop loss worldwide. The vegetable requires large amount of water, their yield and quality adversely affected under drought condition. Water stress during early stage of growth maturity may delay, yield often reduced. Moisture stress during maturity stage drastically reduces the quality, even though total yield are not affected. The plant has some physiological adaptation to cope up with water stress condition as a part of stress tolerance mechanism. Response of plants towards the water stress condition, morphological, physiological and nutritional changes have been studied and reported by different authors. Some of the reviews are presented below,

2.2.1. Biometric Characters (under stress)

Ayodele (2000) noticed that leaf area was reduced by 20 percent in amaranthus under drought condition as compared to their respective control. Liu and Stutzel (2002) suggested that the high rate of soil water extraction in RRC 1027 (*Amaranthus* spp.) have been due to fast leaf area development in the early growth stages. Decrease in leaf area per root dry mass was observed in different amaranthus genotypes under water stress (Liu and Stutzel, 2004).

Shadakshari (2010) studied genetic divergence and drought tolerance in soybean, reported that morphological characters were reduced under water stress, soybean accessions IC 18596 and IC 9311 were drought tolerant genotypes. Difference in shoot and root development was observed by affecting root length, root to shoot ratio, root dry weight, shoot fresh and dry weight. There by total dry matter had affected under water stress. Cell division and enlargement was inhibited under stress condition leads to reduction in leaf area and stem length (Zlatev and Lidon, 2012).

Mlakar *et al.* (2012) observed that drought throughout the growing period of amaranthus resulted in grain and biomass yield reduction for 51 percent and 50 percent respectively and water deficit during inflorescence formation appears to be critical growing stage influencing grain yield. Chauhan and Abugho (2013) reported that plant height and growth of rice and *A. spinosus* were greatly affected by soil moisture content. The maximum of 79 cm height was observed in rice at 100 % field capacity and it was decreased to 68 cm at 50% field capacity. *A. spinosus* had 30 cm height at 25 percentage field capacities and the maximum height (137 cm) at 100% field capacity. *Amaranthus spinosus* produced maximum number of branches plant^{-1} at 100% field capacity, which was found decreased in field capacity below 50%. Leaf, stem and total shoot biomass of rice as well as *A. spinosus* were drastically reduced under water deficit.

2.2.2. Quality Characters

2.2.2.1. Protein Content

Protein content of *A. tricolor* ranged from 18.37 to 37.19 percent on dry matter basis in amaranthus (Mathai *et al.*, 1980).

Ramanathan and Subbaih (1983) observed that the highest crude protein was produced 27 days after sowing in amaranthus. Hemalatha *et al.* (1999) reported that amaranthus leaves have high content of protein (4.0 g), Ca (340.0 mg) and ascorbic acid (120 mg) per 100 g on fresh weight basis. A study on fifteen amaranth varieties by Calderon *et al.* (1991) revealed that A412 had 12.74 percent protein and that of A622 contains 14.65 percent.

Among seventy four genotypes of amaranthus, Selvaraj (2004) reported the range of protein varied from 12.12 to 7.13 percent. The maximum was observed in A56 and the minimum in A74. Celine *et al.* (2007) studied nine amaranthus accessions and observed that the highest vitamin C in accession am 58 and the highest protein in accession am 91. Malathy *et al.* (2012) observed that *Amaranthus tricolor* variety DOA red exhibited higher amount of

chlorophyll, anthocyanin and the greatest antioxidant activity, while the variety DOA green reported the highest percentage of crude protein.

Protein content in amaranthus showed a positive correlation with number of leaves and negative correlation with leaf thickness (Andini *et al.*, 2013). Sarker *et al.* (2015) studied 43 genotypes of amaranthus for the quality analysis, reported that VA32 had the highest protein content of 1.88% and a minimum of 1.01% in VA31. Average protein content obtained was 1.258%.

2.2.2.2 Fibre Content

Rajagopal *et al.* (1977) reported that amaranthus variety Co-2 contains 1.3 g of crude fibre and 3.5 g of protein. The highest and the lowest fibre content was observed in VA19 (9.75%) and VA26 (5.97%) respectively with an average of 7.81 %. Moreover, Selvaraj (2004) studied seventy four amaranthus genotypes in terms of morphological and nutritional qualities, reported that fibre content ranged from 8.00 (CO5) to 4.4 (A14) percent.

2.2.2.3 Vitamin A

The quality analysis of amaranthus CO3 done by Mohideen *et al.* (1985) reported that 11.04 mg of carotene in 100g of fresh matter. The variation in carotenoid content in vegetable amaranthus from 90 to 200 mg kg^{-1} was reported by Prakash and Pal (1991) from 61 accessions.

2.2.2.4. Oxalate Content and Nitrate Content

Vegetable amaranthus had 0.2 to 11.4 percent of oxalate on dry weight basis (Teutonico and Knorr, 1985). Red pigmented amaranthus lines contained higher oxalate content when compared to green pigmented amaranthus lines (Priya and Celine, 2001). Srivatstava *et al.* (2002) studied ten amaranthus genotypes (both grain and vegetable type) for different quality and anti-nutritional factors, reported that the range of oxalate and nitrate were 0.80- 1.90% and 0.29-0.89% respectively.

The high phytate production in seeds of lupins was noticed under water stress condition when compared to normal conditions. Selection for low antinutrients in plants improves mineral bioavailability there by increased nutritive value (Carvalho, 2005). Celine *et al.* (2007) observed the minimum and the maximum oxalate content in amaranthus accessions am 90 and am 76 respectively and the nitrate content varied from 0.04 percent to 1.6 percent. Least oxalate and nitrate content were reported in amaranthus A-69 (4.80%) and A-34 (0.52%) respectively (Anuja., 2012a).

2.2.3. Physiological Characters

2.2.3.1. Membrane Integrity

In foxtail millet (*Setaria italica*) seedlings salinity sensitivity was positively correlated with membrane damage (Sreenivasulu *et al.*, 2000).

Valentovic *et al.* (2006) conducted experiment on two maize cultivars, *Zea mays* L. cv. Ankora which was drought sensitive and cv. Nova which was drought tolerant. Water stress was induced by 0.3M sorbitol, lipid peroxidation was observed in Ankora with damage of cell membrane. Electrolyte leakage was observed in roots of the both cultivars, but cv. Ankora reported higher electrolyte leakage in roots than cv. Nova.

2.2.3.2. Relative Water Content

In different water potential parameters, leaf water content is to be considered as an important indicator of water status under water stressed condition (Sinclair and Ludlow, 1985).

Liu and Stutzel (2002) evaluated four genotypes of amaranthus under water stressed condition, relative water content of stressed plants was decreased nearly 0.60% in all genotypes, while RWC of well watered genotypes was much higher with a range from 0.80% to 0.90%. Re-irrigation increased RWC in all the genotypes to normal level.

Relative water content decreases with drought stress in varieties of crop plants (Nayyar and Gupta, 2006).

Kumar *et al.* (2014) studied on different rice genotypes under water stressed condition, recorded the highest value of RWC in water stress tolerant genotypes than the susceptible genotypes at reproductive genotypes.

Slabbert and Kruger (2014) conducted experiment on three species of amaranthus namely *A. tricolor*, *A. hypochondriacus* and *A. hybridus* to evaluate the responds under water stress condition, reported that RWC was decreased in all species compared to control (87- 97%), in *A. tricolor*, *A. hypochondriacus* and *A. hybridus* of RWC 77%, 33% and 48% and it was increased to 89%, 65%, and 85% upon rewatering respectively.

Chatti (2016) conducted studies on different genotypes of amaranthus and observed that the highest dry matter, relative water content with the lowest stomatal frequency at stress condition was observed in CO-1, which was significantly higher compared with Arun and Renusree.

2.2.3.3. Canopy Temperature

Jackson *et al.* (1981) used infrared thermometry to record canopy temperatures in wheat under water stress to obtain the crop water stress index.

Crop water content was monitored by using infrared thermo detector. It was observed lower canopy temperature during sufficient water condition, under water stress condition canopy temperature varied greatly according with stress tolerance of genotypes (Tanner, 1963).

Under water stress condition latent heat flux at leaf surface was decreased by increased sensible heat with large temperature difference between foliage and air (Fuchs, 1990).

Omami and Hammes (2006) observed reduced photosynthetic rate, water conductance and water loss in amaranthus species under water stress condition.

Arjunkumar (2008) reported that cotton genotype JKC 701 shown lowest transpiration rate under limited water supply, can be regarded as stress adaptive mechanism under water limited condition.

2.2.3.4. Proline Content in Leaves

Rudolph *et al.* (1986) reported the production of osmolytes under stress condition which protects and stabilizes the membrane and enzymes there by increases the stress tolerance.

Proline accumulation was observed in water stress tolerant maize cultivar Ankora when it was subjected to water stress (Valentovic *et al.*, 2006).

Slabbert and Kruger (2014) noticed proline accumulation and protective role apart from osmoregulation during stress condition in amaranthus. The enzyme activity, proline production and leaf area were indirectly correlated with leaf water status (RWC and LWP). Proline accumulation was 152 $\mu mol^{-1}g^{-1}$ and 104 $\mu mol^{-1}g^{-1}$ for *A. hybridus* and *A. hypochondriacus* respectively after 12 days of water withholding. It was increased to 380 $\mu mol^{-1}g^{-1}$ (*A. hypochondriacus*), 443 $\mu mol^{-1}g^{-1}$ (*A. hybridus*), and 71 $\mu mol^{-1}g^{-1}$ (*A. tricolor*) after 14 days of withholding water. Proline production under water stress condition was indirectly correlated with decrease in RWC.

2.2.3.5. Percentage Leachate

Chaves and Oliveira (2004) found that mechanical strain on the membrane caused increased electrolyte leakage under severe drought condition.

Valentovic *et al.* (2006) reported electrolyte leakage of 11-54% in drought sensitive cultivar of maize.

Almeselmani *et al.* (2013) reported that drought tolerance was correlated with electrolyte leakage which was used to discriminate drought tolerance from drought susceptible lines. Electrolyte leakage was due to increased damage to the cell membrane.

2.2.4. Statistical Characters

2.2.4.1. Genetic Parameters viz., PCV, GCV, Heritability and Genetic Advance and Correlation Analysis

Leaf length and leaf width were positively correlated with yield, but the number of leaves were negatively correlated with leaf yield, leaf width and leaf length. Selection based on the leaf size rather than leaf number improved the leaf yield in amaranthus (Prasad *et al.*, 1980).

Mohideen and Subramanian (1974) studied the coefficient correlation between yield and other morphological characters. Relationships among all parameters studied were significant except that between petiole length and leaf weight. The values of phenotypic correlation were lower than their respective genotypic correlation. Leaf weight, stem weight, stem diameter and marketable yield showed significant positive genotypic and phenotypic correlation with yield per plant.

Shukla *et al.* (2005) studied 29 strains of vegetable amaranthus (*Amaranthus tricolor*) on different characters over different cuttings. The heritability of characters over cuttings was high with the range of 74.8% to 93.33%. Maximum genetic advance was recorded for foliage yield (42.50%). Leaf size (31.02%) and stem diameter (21.13%) also recorded high genetic advance. The study concluded that leaf size and stem diameter indirectly improved the foliage yield.

An experiment was conducted by Shukla *et al.* (2010) to observe genetic correlation of quality and agronomic traits in 39 distinct cultivars of vegetable amaranth (*A. tricolor*) and their direct and indirect effects on foliage yield. Agronomic traits like plant height and number of inflorescence and quality traits like chlorophyll a, chlorophyll b, fibre, carotenoid and ascorbic acid exhibited positive correlation between foliage yield.

Ahammed *et al.* (2012) studied twenty two diverse genotypes of stem amaranthus (*A. tricolor* L.) where, genetic variability, heritability and correlation analysis were done for yield and its attributes. Primary branches per plant observed highest PCV (87.85%) and GCV (81.67%), while lowest PCV (10.28%) was reported for plant height with lowest GCV (7.51%) for leaf width. Broad sense heritability was higher for leaf weight per plant (91.10%) with highest (49.38%) genetic advance. Positive correlation of leaves per plant, stem diameter, stem weight per plant, leaf weight per plant and plant height were reported with yield per hectare at phenotypic as well as genotypic level. The results depicted that selection based on these characters gives better response for the stem amaranthus improvement.

Anuja (2012) confirmed from hundred genotypes of amaranthus that green yield was positively correlated with leaf weight, stem weight and plant height with negative association with leaf to stem ratio, which were highly significant.

Hasan *et al.* (2013) evaluated seventeen genotypes of stem amaranth (*Amaranthus tricolor* L.) to determine genetic variability, degree of association between yield and its component traits. Moderate to high range for most of the traits were reported, vulnerability of leaf length and stem diameter towards environmental influences were concluded from high difference between PCV and GCV. High PCV (80.14%) and GCV (77.54%) observed for leaf weight while low PCV (74.47%) and GCV (74.42%) found for dry weight without rind. Additive gene effects of the traits like, number of leaf, leaf weight and marketable yield were recorded from the estimates of high genetic advance. Leaf weight, stem weight, stem diameter, dry weight with rind, dry weight without rind shown positive and significant phenotypic and genotypic correlation with yield per plant.

Moderate PCV and GCV were recorded with traits like petiole length, plant height, leaf blade length, days to 50% bolting, 1000 seed weight and days to

physiological maturity. High PCV and GCV were observed in the traits like leaf blade width, lateral spikelet length and grain yield per plant. Highest (42.73%) and lowest (11.70%) GCV were recorded with grain yield per plant and 1000 seed weight respectively, with the range of 11.60% to 42.73%. A range of 97.8% to 99.98% heritability was observed, indicates high heritability of all the traits under study. High positive significant correlation of seed yield per plant with days to 80% maturity and plant height were recorded (Yadav *et al.*, 2014).

According to Sarker *et al.* (2014), leaves per plant, diameter of stem base, fibre content and leaf area had significant positive correlation with foliage yield. Insignificant genotypic correlation was reported in nutrient and antioxidant content with foliage yield.

Diwan (2015) reported that leaf weight (35.01 and 35.65), leaf length (19.69 and 24.50) and internodal length (18.46 and 22.99) recorded high magnitude of genotypic and phenotypic coefficient of variation, which helps in the selection of traits for further improvement. Petiole length (13.59 and 14.46), stem weight (13.44 and 14.47) leaf width (13.36 and 15.12), leaf yield per plot (13.31 and 21.67), number of cutting (12.79 and 20.42) and number of leaves per plant (11.48 and 13.15) recorded moderate PCV and GCV, which also takes a part in crop improvement for some extent. Whereas, plant height (9.24 and 17.87), stem girth (9.55 and 15.46), panicle length (9.60 and 15.71), and seed yield per plant (8.99 and 14.78) recorded low PCV and GCV, which will not takes part in the crop improvement. High heritability was recorded for the traits leaf weight (96.65%), stem weight (86.2%), petiole length (86.1%), leaf width (78.1%), and number of leaves (76.2%) with moderate heritability for leaf length (64.5%), and internodal length (64.5%). 1000 seed weight (38.5%), leaf yield kg per plot (37.7%), number of cutting (37.7%), seed yield per plant (37.0%), plant weight (27.4%), plant height (26.8%) and crop duration (26.2%) recorded low heritability. Heritability of number of leaves per plant, leaf width and leaf weight was due to additive gene effect which was confirmed from high genetic advance of these traits. Significant positive correlation of plant weight and seed yield with

leaf yield kg per plot and leaf length and significant negative correlation with leaf yield per plot. Direct selection of these traits contributes amaranthus improvement.

Samuel and Odunayo (2017) conducted field experiment in sixteen amaranthus to evaluate variability, heritability and genetic advance. High heritability was observed in stem length of 95.50%, weight of dry leaf, weight of fresh and dry inflorescent were low heritable with 47.70% heritability. A strong positive correlation of stem length, stem girth, number of inflorescent, inflorescent length and width with plant height, and positive correlation number of leaves, leaf width and number of branches with plant height were recorded.

2.2.4.2. Path Coefficient Analysis

Weight of leaves and stem had highest and direct contribution to the yield was concluded from the study of diverse traits on six genotypes and thirty hybrids of amaranthus (Aruna, 2012).

Hasan *et al.* (2013) worked out the path analysis by using various morphological characters, observed that leaf number (0.008) and stem weight had highest direct positive effect on marketable yield. But, plant height and leaf weight showed negative direct effect on marketable yield with no effect with days to first flowering. The minimum negative direct effect (-0.024) of days to first flowering with marketable yield, highest negative indirect effect with marketable yield (-0.128). Plant height and leaf number showed highest negative direct (-0.008) and positive direct (0.008) with marketable yield respectively. Negative direct effect of stem diameter was counter balanced by six positive indirect effect with marketable yield and became highly significant (0.602).

Sarker *et al.* (2014) reported that high positive direct effect of foliage yield with fibre content (0.616), leaf area (0.464), diameter of stem base (0.420) and beta carotenoid (0.347). Plant height exhibited positive direct effect with foliage yield and negative direct effect with leaf size.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment entitled "Identification of water stress tolerant amaranthus genotypes (*Amaranthus tricolor* L.) with high yield and quality" was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during the year 2016-18. Two field experiments were conducted with an objective to identify high yielding genotypes of amaranthus with good quality and tolerance to water stress.

The first experimental material consists of thirty amaranthus genotypes which were collected from different parts of Kerala and were maintained at Department of Plant Breeding and Genetics, College of Agriculture, Vellayani. The thirty *Amaranthus tricolor* L. genotypes are listed in table 1. High yielding ten genotypes from experiment No. 1 was selected and were maintained under well irrigated condition up to 5 days after transplanting and there after irrigation was scheduled at a depth of 20mm at 20 CPE (Cumulative Pan Evaporation).

3.1. EXPERIMENTAL DETAILS

3.1.1. Location

Field experiment was conducted at College of Agriculture, Vellayani, situated at 8°5' N latitude and 76°9'E longitude and at an altitude of 29 m above mean sea level. Predominant soil type of the experimental site was red loam of Vellayani series, texturally classified as sandy clay loam.

3.1.2. Season

First experiment was conducted from July 2017 to August 2017 with thirty genotypes of amaranthus and the second experiment conducted from November 2017 to December 2017 with high yielding selected ten genotypes from experiment No.1.

Table 1. List of amaranthus (*Amaranthus tricolor* L.) genotypes used in the study

Genotypes No.	Name of the genotypes	Sources
A1	Elamad local	Kollam district
A2	Palakkadu local	Palakkad district
A3	Ayira local	Thiruvananthapuram district
A4	Kalliyoor local	Thiruvananthapuram district
A5	Thrissur local	Thrissur district
A6	Anachal local	Idukki district
A7	Haripad local	Alappuzha district
A8	Manacaud local	Thiruvananthapuram district
A9	Kazhakkuttom local	Thiruvananthapuram district
A10	Kannur local	Kannur district
A11	Chettikulangara local	Alappuzha district
A12	Kottembram local	Kozhikode district
A13	Thiruthi local	Kozhikode district
A14	Adoor local	Pathanamthitta district
A15	Karnataka local	Kasaragode district
A16	Kollamcode local	Kanyakumari district
A17	Trivandrum local	Thiruvananthapuram district
A18	Kumily local	Idukki district
A19	Nilamel local	Kollam district
A20	Poonkulam local	Thiruvananthapuram district

A21	Aryanadu local	Thiruvananthapuram district
A22	Madhur local	Kasaragod district
A23	Alathur local	Palakkad district
A24	Maranalloor local	Thiruvananthapuram district
A25	Nellad local	Ernakulam district
A26	Aleppy local	Alappuzha district
A27	Cherthala local	Alappuzha district
A28	Ayyanthole local	Thrissur district
A29	Kannara local	Thrissur district
A30	Kilimanur local	Thiruvananthapuram district

3.1.3. Planting Material

Amaranthus seedlings were transplanted to the main field after 25 days of sowing. Each genotype was considered as an individual treatment.

3.1.4. Layout of the Experiment

Experiment No. I

Design : RBD

Treatments : 30

Replications : 3

Spacing : 30 cm×20 cm

Plot size : 1.2 m^2

Experiment No. II

Design : RBD

Treatments : 10

Replications : 3

Planting time : November

Twenty plants were maintained in each plot.

3.2. MORPHOLOGICAL CHARACTERIZATION

Five plants were randomly taken from each plot and tagged for recording biometric characters. Observations were recorded after 30 days after transplanting and mean was worked out for further analysis.

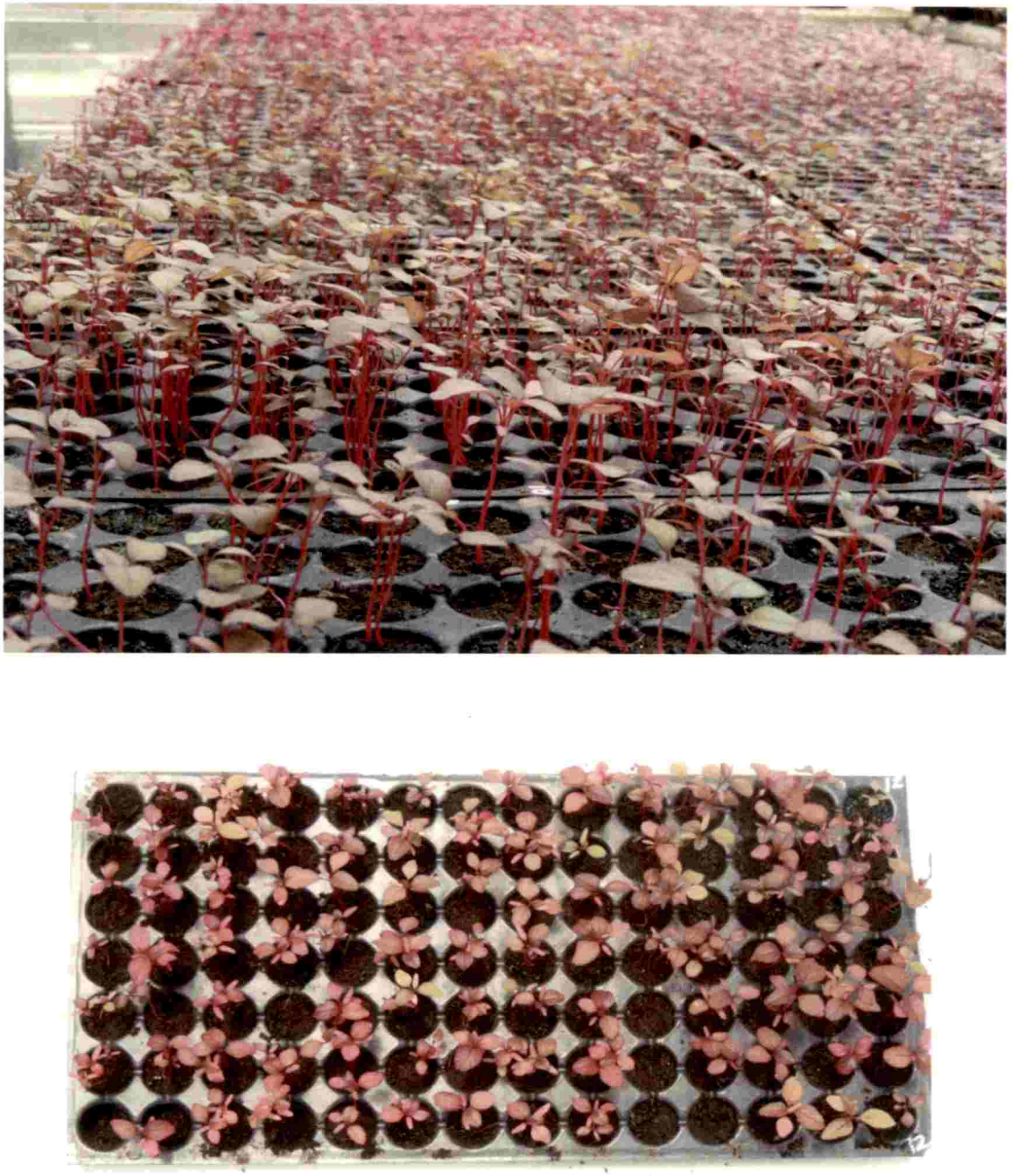


Plate 1. Amaranthus seedlings in the nursery 21 DAS

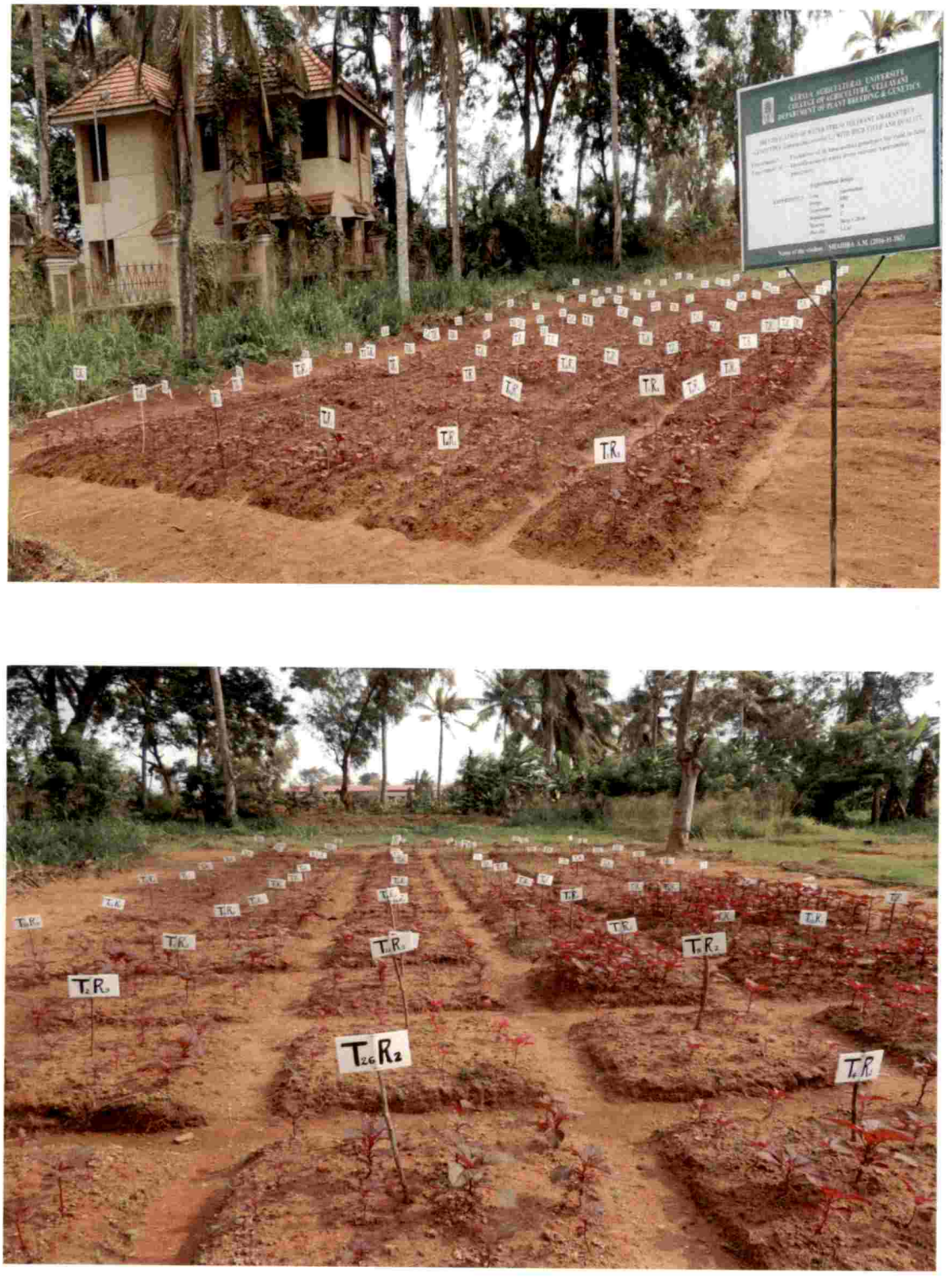
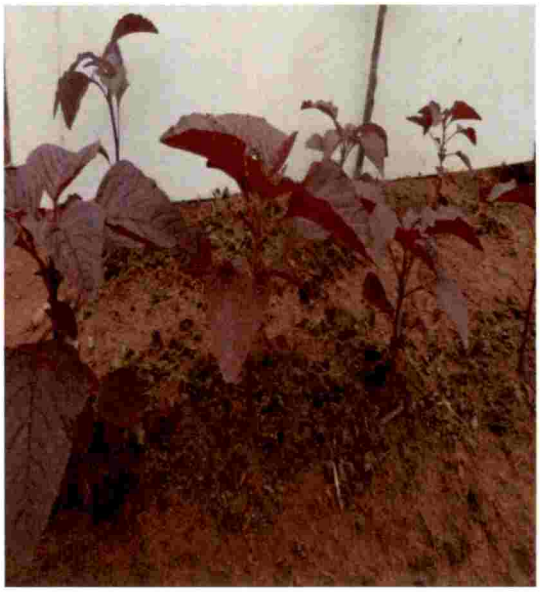
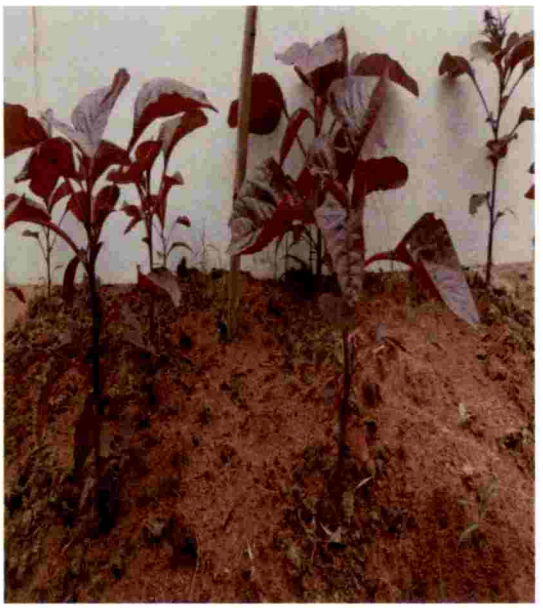


Plate 2. Field view of the first experiment

(A) MADHUR LOCAL



(B) KALLIYOOR LOCAL



(C) AYYANTHOLE LOCAL

(D) PALAKKADU LOCAL

Plate 3. High yielding selected amaranthus genotypes (A) Madhur local, (B) Kalliyoor local, (C) Ayyanthole local and (D) Palakkadu local

(E) HARIPAD LOCAL

(F) ANACHAL LOCAL

(G) ARYANADU LOCAL

(H) POONKULAM LOCAL

Plate 4. High yielding selected amaranthus genotypes (E) Haripad local, (F) Anachal local, (G) Aryanadu local and (H) Poonkulam local

(I) KAZHAKKUTTOM LOCAL

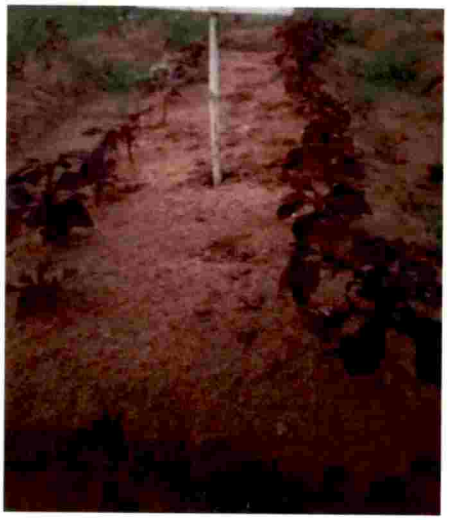
(J) KANNARA LOCAL

Plate 5. High yielding selected amaranthus genotypes (I) Kazhakkuttom local and (J) Kannara local

Plate 6. Field view of the second experiment

(A) Stage 1

(B) Stage 2



(C) Stage 3

Plate 7. Different stages of water stress in amaranthus (A) Stage 1, (B) Stage 2 and (C) Stage 3

(D) Stage 4

(E) Stage 5

Plate 8. Different stages of water stress in amaranthus (D) Stage 4 and (E) Stage 5

3.2.1. Biometric Characters

3.2.1.1. Stem Girth (cm)

The main stem girth at the collar region was taken by using a twine. Mean girth was measured and expressed in centimetres.

3.2.1.2. Length of Leaf Lamina (cm)

Length was recorded from the fifth leaf from top of the selected plants. Mean length was measured and expressed in centimetres.

3.2.1.3. Petiole Length (cm)

The petiole length of the same plant which was used for recording length was measured and the mean expressed in centimetres.

3.2.1.4. Leaf Width (cm)

The width of the same leaf of the plant which was used for recording length was measured and the mean expressed in centimetres.

3.2.1.5. Internodal Length (cm)

Internodal length of the same leaf of the plant which was used for recording length was measured and the mean expressed in centimetres.

3.2.1.6. Number of Branches

The total branches of the each observational plant were counted and average was worked out.

3.2.1.7. Yield Plant^{-1}(g)

Three cuttings were taken from each plant. The first cutting was taken at 30 days after transplanting and the subsequent two cuttings were taken at intervals of two weeks. The yield obtained cutting^{-1} was recorded and expressed in grams plant^{-1}.

3.2.1.8. Yield Plot^{-1}(kg)

Yield from the twenty plants were taken for each cuttings, total yield was expressed in kilogram plot^{-1}.

3.2.1.9. Leaf to Stem Ratio

Leaf to stem ratio was taken by dividing the weight of leaves with weight of stem. The leaf to stem ratio was worked out for the total of three cuttings.

3.2.1.10. Days to 50% Bolting

Days to 50% bolting was recorded from the plants left unharvested.

3.2.1.11. Plant Height (cm)

Plant height was recorded from each observational plant by measuring the length of main stem from ground level to the top leaf bud of plants. Mean length was measured and expressed in centimetres.

3.2.1.12. Incidence of Leaf Blight

The genotypes were monitored for the incidence and intensity of leaf blight and scoring was done on a 0-4 scale (Celine *et al.*, 2013).

0- No incidence

1- Up to 25% leaf area infected

2- Up to 50% leaf area infected

3- Up to 75% leaf area infected

4- Up to 100% leaf area infected

Scoring was done at biweekly intervals after transplanting and average score worked out.

3.2.1.13. Incidence of Leaf Webber

Incidence and intensity of leaf webber attack was observed and scored by using the following score chart (Sathy, 2006)

0- No incidence

1- Mild (25%)

2- Medium (50%)

3- Severe (75%)

4- Very severe (100%)

Scoring was done three times at fortnightly intervals after transplanting and average score was recorded.

3.2.2. Cataloguing of the Germplasm

3.2.2.1. Morphological Cataloguing

The genotypes were described morphologically by using IBPGR descriptor for amaranthus by IBPGR (IBPGR, 1981).

3.3. QUALITY CHARACTERS

3.3.1. Protein Content

Estimation of protein was done by using Bradford method (Sadasivam and Manickam, 1996).

Reagents

1. Dye concentrate: 50 ml of 95 percentage ethanol was used to dissolve 100 mg coomassive brilliant blue G 250. 100 ml concentrated orthophosphoric acid was added and made final volume of 200 ml by using distilled water. It was stored in amber bottles under refrigerated condition. Concentrated dye and distilled water was mixed in 1:4 ratios. This was filtered with Whatman No. 1 filter paper to remove the precipitate.
2. Phosphate- buffer saline (PBS)
3. Protein solution (Stock standards): 50 mg of bovine serum was dissolved in distilled water and made upto 50 ml in a standard flask.
4. Working standards: 10 ml of stock solution was diluted by adding 50 ml of distilled water. One ml of this solution contains 200µg of protein.

Procedure

500 mg of fresh leaves were ground well with pestle and mortar in 5-10 ml of the buffer. This was centrifuged and supernatant was used for protein estimation.

Working standards of 0.2, 0.4, 0.6, 0.8, and 1 ml was pipetted out into a series of test tubes. 0.1 ml sample was pipetted out in two other test tubes. The volume was made upto 1 ml in all the test tubes. 1 ml water in a test tube was used as a blank. 5 ml diluted dye was added to all test tubes and allowed for the colour formation for 5 minutes, but not more than 30 minutes. A standard curve was plot

using standard protein absorbance vs concentration by taking absorbance at 595 nm. The protein in the sample was calculated using standard curve.

3.3.2. Fibre Content

Estimation of fibre content of leaves was done by acid alkali method (Sadasivam and Manickam, 1996).

Reagents

1. Sulphuric acid solution (0.255±0.005 N): 100 ml distilled water was used to dilute 1.25 ml concentrated Sulphuric acid
2. Sodium hydroxide solution (0.313±0.005 N): 1.25g sodium hydroxide was dissolved in 100 ml distilled water.

Procedure

Two gram of dried sample and 200 ml of sulphuric acid was boiled in pumbing chips for 30 minutes. After filtering through muslin cloth it was washed with boiling water until acidic residue was removed. The residue was again boiled with 200 ml of sodium hydroxide solution for 30 minutes. Then it was filtered through muslin cloth and washed with 25 ml of boiling 1.25 percent sulphuric acid, three 50 ml portions of water and 25 ml of alcohol. Residue was transferred into a preweighed (W_1) ashing dish. Dried at 130±2°C for 2 hrs. Cooled the dish in desiccator and weighed (W_2). Then it was ignited at 600±15°C for 30 minutes. Weight (W_3) was taken after cooling in desiccator.

Percent crude fibre in ground sample

$$= \frac{\text{loss in weight on ignition}}{\text{weight of the sample}}$$

3.3.3. Vitamin A

Estimation was done by the method proposed by Srivatsava and Kumar (1998). 10-15 ml acetone and few crystals of anhydrous sodium sulphate were used to crush 5 gram of fresh sample in pestle and mortar. Supernatant was collected in a beaker, the process was repeated two times and combined supernatant was collected in a separatory funnel. Petroleum ether of 10-15 ml was added to mixture and the layer was separated out on standing. Upper layer was collected by discarding lower level in a 100 ml volumetric flask. Volume was made into 100 ml by adding petroleum ether and the optical density at 452 nm was recorded with petroleum ether as blank.

$$\beta \text{ carotene } (\mu g/100 \text{ gram}) = \frac{\text{Optical density} \times 13.9 \times 10^4 \times 100}{\text{weight of sample} \times 560 \times 1000}$$

$$\text{Vitamin A (I.U.)} = \frac{\beta \text{ carotene } (\mu g/100 \text{gram})}{0.6}$$

3.3.4. Oxalate Content

Estimation of oxalate was done by method suggested by A.O.A.C (1984).

Reagents

1. Tungsto phosphoric acid: 2.5g sodium tungstate was added to a mixture of 4 ml phosphoric acid and 50 ml water and made the volume upto 100 ml with water.
2. Wash liquid: 12.5 ml acid was made upto 250 ml with water. A pinch of calcium oxalate was added and shaken for few minutes, allowed to stand. The supernatant was decanted and filtered.

3. Acetate buffer (pH 4.5): 2.5g of anhydrous calcium chloride and 50 ml acetic acid was dissolved in 1:1 ratio and added 33g of sodium acetate volume made to 5 ml.
4. Potassium permanganate: 0.01N
5. Sulphuric acid: 2N
6. Hydrochloric acid: 0.25N

Procedure

Extraction of one gram of dried powder was done twice by 0.25N hydrochloric acid in a water bath for one hour each. Collected centrifuge in a conical flask precipitated by adding 5 ml tungsto phosphoric acid kept overnight and centrifuged. This was neutralized with dilute ammonia solution in 1:1 ratio. Precipitation was done by using 5 ml acetate buffer with calcium chloride (pH 4.5). Centrifuged and washed the precipitate two times each with 6 ml wash liquid. Precipitate was transferred into 100 ml conical flask by dissolving 10-15 ml 2N Sulphuric acid and titrated against 0.01N potassium permanganate solution at 60°C.

$$\text{Percentage Oxalate} = \frac{0.063 \times V}{1g}$$

3.3.5. Nitrate Content

Estimated by the procedure suggested by Middleton (1958)

Reagents

1. Silver sulphate: 0.35 per cent solution
2. Copper sulphate: 0.50 per cent solution
3. Calcium hydroxide- magnesium carbonate mixture: calcium carbonate and magnesium carbonate was mixed in 1:2 ratios and triturated in a mortar.

4. Sodium phosphate: 138g of sodium phosphate was dissolved in 500 ml water and the pH was maintained to 6.5 by adding strong NaOH and made upto 1 litre.
5. Ammonium hydroxide: 50 v/v per cent
6. Phenol-p-sulphonic acid: 45g of mercuric chloride was added to 225 ml of diluted Sulphuric acid. After keeping overnight 25 g of phenol and 10 ml of ethyl alcohol was added. Heated on a water bath for two hours.
7. Potassium nitrate: 0.0505 percent solution.

Procedure

Nine ml silver sulphate was added to 0.1 gram dried sample and swirled quickly. Immediately added 9 ml of silver sulphate and kept for 2 hours. After filtration, two ml of filtrate and two ml of copper sulphate were added to 15 ml centrifuge tube, mixed thoroughly and made 6 ml by the addition of water. 0.5 gram of calcium hydroxide- magnesium carbonate mixture was added allowed to stand for 1 hour and centrifuged for 5 minutes at 3000 rpm. Two ml phenol-p-sulphuric acid was mixed into a boiling tube, directly to the bottom. Swirling was done by adding 2 ml of supernatant drop by drop from above directly into the reagent. After cooling 25 ml ammonium hydroxide was added with stirring. Cooled mixture was read at 475 nm in a spectrophotometer with instrument set at zero by using water as blank.

Standard: standard solution of potassium nitrate was done by taking one to four ml of the solution and followed above procedure beginning with the addition of copper sulphate. Absorbance value of these mixtures was used to draw standard graph.

1 ml of 0.0505% potassium nitrate = 0.01 mg nitrogen

Nitrogen content (mg/100gram) can be found out from standard graph.

Nitrate content (mg/100gram sample) = Nitrogen content (mg/100gram) × 4.428

Estimated nitrate content was converted into percentage.

3.4. PHYSIOLOGICAL CHARACTERS

3.4.1. Membrane Integrity

Fully expanded leaves with their petiole are excised and intact in water to regain the turgidity by incubating in distilled water for 45 minutes. The leaves kept to wilt for three hours after taking the weight of turgid leaves. Leaf punches of 1 cm were taken after 40-60 percent loss of the fresh weight. Leaf punches are washed for 1 to 2 minutes to leach out their solutes from cut ends, blotted on a clean filter paper. Ten leaf punches were incubated in 20 ml distilled water for three hours. Initial leakage of the solute was recorded its absorbance at 273 nm. Final absorbance of the bathing medium was recoded at 273 nm after incubating in hot water bath (100°C) for 15 minutes.

$$\% \text{ Leakage} = \frac{\text{Initial absorbance of bathing medium}}{\text{Final absorbance of bathing medium}} \times 100$$

Membrane integrity (%) = 100- % leakage

3.4.2. Relative Water Content

Fresh weight, turgid weight and dry weight were measured from known number of leaf discs from observational plants. Turgid weight was taken by immersing the leaf disc in water for three hours. The dry weight was recorded by keeping the leaf discs in oven for three consecutive days at 80^0C upto a constant weight was reached.

$$\text{Relative Water Content} = \frac{\text{Fresh Weight} - \text{Dry Weight}}{\text{Turgid Weight} - \text{Dry Weight}} \times 100$$

3.4.3. Canopy Temperature

Canopy temperature was measured by using infra-red thermometer of each treatment at 12 noon and expressed in degree Celsius.

3.4.4. Proline Content of Leaves

Proline estimation was done by using method suggested by Sadasivam and Manickam (1996).

Reagents

Acid ninhydrin, Aqueous sulphosalicylic acid (3percent), Glacial acetic acid, Toluene, Proline.

Procedure

Ten ml of 3 percent aqueous salicylic acid was used to prepare extract by homogenizing 0.5 gram of plant material. After filtration, 2 ml glacial acetic acid and 2 ml acid ninhydrin were added to 2 ml of filtrate sample. The mixture was heated for 1 hour in the boiling water bath. Reaction was stopped by placing the tube in ice bath after an hour of boiling. The mixture was stirred well by adding 4 ml of toluene. Toluene layer was collected and warmed to room temperature. The red colour of toluene was read at 520 nm. A series of pure toluene standards was prepared in the same way and the standard curve was drawn. The proline present in the sample was recorded by the help of standard curve.

$$\text{Proline content (}\mu\text{moles/g tissue)} = \frac{(\mu\text{g proline/mL toluene})}{115.5} \times \frac{5}{\text{g Sample}},$$

where 115.5 is the molecular weight of proline.

3.4.5. Percentage Leachate

Leachate percentage was recorded at 573 nm.

3.5. STATISTICAL ANALYSIS

3.5.1. Analysis of Variance

Per replication mean value of each treatment is used to work out Analysis of Variance (Panse and Sukhatme, 1967).

Sources of variation	d.f	Sum of squares	Mean squares	F ratio
Replications	t-1	SSR	MSR	MSR/MSE
Treatment	r-1	SST	MST	MST/MSE
Error	(t-1)(r-1)	SSE	MSE	
Total	rt-1			

Where r= number of replications

t= number of treatments

SSR= sum of squares for replication

SST= sum of squares for treatments

SSE= sum of squares for error

Critical Difference, CD= $t_{\alpha}\sqrt{\frac{2MSE}{r}}$

Where t_{α} students't table value distribution at error d.f with level of significance α (5% or 1%).

3.5.2 Estimation of Genetic Parameters

a. Genetic Components of Variance

Phenotypic and genotypic components of variance were estimated for each character by equating expected value of mean squares (MS) to the respective variance components (Jain, 1982).

Genotypic Variance (V_G) $V_G = \frac{MST - MSE}{r}$

Environmental Variance (V_E) $V_E = MSE$

Phenotypic Variance (V_P) $V_P = V_G + V_E$

b. Coefficient of Variation

Genotypic, Phenotypic and Environmental Coefficient of Variation were estimated from V_P, V_G and V_E, expressed in percentage for each trait.

i. Genotypic coefficient of variation, $GCV = \frac{\sqrt{VG}}{X} \times 100$

ii. Phenotypic coefficient of variation, $PCV = \frac{\sqrt{VP}}{X} \times 100$

iii. Environmental coefficient of variation, $GCV = \frac{\sqrt{VE}}{X} \times 100$

Where, X= Grand mean

Sivasubrahmanian and Menon (1973) reported following categories for the range of variation.

High: >20 percent

Medium: 10-20 percent

Low: <10 percent

c. Broad Sense Heritability

Ratio of genotypic variance to the total observed variance in the population and calculation expressed in percentage.

$$H^2=\frac{VG}{VP} \times 100$$

Range of Heritability estimation (Johnson *et al.*, 1955)

High: >60 percent

Medium: 30-60 percent

Low: <30 percent

d. Genetic Advance

The expected genetic gain or improvement in the next generation by selecting superior genotype under certain amount of selection pressure. Genetic advance estimated by using Burton (1952) formula.

$$GA= KH^2\sqrt{VP}$$

Where K= selection differential

At 5% selection intensity K=2.06

H^2= Heritability

V_p= Phenotypic variance

e. Genetic Advance as Percent of Mean

GAM= GA/X ×100

GA= Genetic Advance

X= Grand Mean

Ranges of genetic advance by Johnson *et al.* (1955).

High= >20 percent

Medium= 10-20 percent

Low= 10 percent

3.5.3. Estimation of Correlation

Degree and direction of association between two variables refers the correlation. Genotypic and phenotypic correlations were calculated by using Falconer (1964) formula.

Genotypic coefficient of correlation (r_g) = $r(x_i x_j)_g = \frac{Cov((xi.xj)g}{\sqrt{v(xi)g.v(xj)g}}$

Phenotypic coefficient of correlation (r_p) = $r(x_i x_j)_p = \frac{Cov((xi.xj)p}{\sqrt{v(xi)p.v(xj)p}}$

Error coefficient of correlation (r_e) = $r(x_i x_j)_e = \frac{Cov((xi.xj)e}{\sqrt{v(xi)e.v(xj)e}}$

3.5.4. Path Coefficient Analysis

It is a standardized partial regression coefficient which separates the correlation coefficients into direct and indirect effects (Dewey and Lu, 1959).

$r_{1y} = P_{1y}r_{11} + P_{2y}r_{12} + P_{3y}r_{13} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + P_{ny}r_{1n}$

$r_{2y} = P_{2y}r_{21} + P_{2y}r_{22} + P_{3y}r_{23} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + P_{ny}r_{2n}$

$r_{ny} = P_{1y}r_{n1} + P_{2y}r_{n2} + P_{3y}r_{n3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + P_{ny}r_{nn}$

Where,

1,2……..n =independent variables

y = dependent variable

$r_{1y}, r_{2y}\ldots\ldots\ldots r_{ny}$ =coefficient of correlation between independent variables 1 to n on dependent variable y.

$P_{1y}, P_{2y}\ldots\ldots\ldots P_{ny}$ =direct effect of character 1 to n on character y.

The above equation can be written in matrix form

$$\begin{bmatrix} r_{1y} \\ r_{2y} \\ . \\ . \\ . \\ r_{ny} \end{bmatrix} \quad \begin{bmatrix} 1 & r_{12} & r_{13} & . & . & r_{1n} \\ r_{21} & 1 & r_{23} & . & . & r_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ r_{n1} & r_{n2} & r_{n3} & . & . & 1 \end{bmatrix} \quad \begin{bmatrix} P_{1y} \\ P_{2y} \\ . \\ . \\ . \\ P_{ny} \end{bmatrix}$$

Then $B=C^{-1}A$ where $C^{-1}=\begin{bmatrix} C_{11} & C_{12} & C_{13} & . & . & C_{1n} \\ C_{21} & C_{22} & C_{23} & . & . & C_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ C_{n1} & C_{n2} & C_{n3} & . & . & C_{nn} \end{bmatrix}$

Direct effects:

$P_{1y}= \sum_{i=1}^{k} c_{1i}\, r_{iy}$

$P_{2y}= \sum_{i=1}^{k} c_{2i}\, r_{iy}$

$P_{ny}= \sum_{i=1}^{k} c_{ni}\, r_{iy}$

Residual effect $PR_y = \sqrt{1 - r^2}$

Where, $r^2 = (P_{1y}r_{1y} + P_{2y}r_{2y} + P_{3y}r_{3y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + P_{ny}r_{ny})$

P_{iy} = direct effect of X_i on y

r_{iy} = correlation coefficient of X_i on y

i = 1,2,3…..n

RESULTS

4. RESULTS

4.1. EVALUATION OF AMARANTHUS GENOTYPES

4.1.1. Variability

Thirty genotypes of amaranthus were evaluated, performance of each genotype shown significant difference for the characters under study. Ten high yielding genotypes were selected for the experiment number 2.

4.1.1.1. Biometric Characters

Mean values of the 30 genotypes are described in table 2.

Stem girth was noticed to be the maximum for the genotype A9 (3.745 cm), which was on par with other genotypes like A 23 (3.537 cm), A2 (3.395 cm), A21 (3.387 cm), A19 (3.347 cm), A13 (3.327 cm), A6 (3.288 cm), A30 (3.262 cm), A4 (3.200 cm), A12 (3.113 cm), A5 (3.037 cm), A28 (3.037 cm) and A7 (3.033 cm). The minimum stem girth was noticed for the genotype A25 (1.759 cm) which was on par with A14 (1.780 cm) and A15 (2.075 cm).

Length of leaf lamina varied from 12.780 cm to 8.687 cm. The maximum was observed for A28 genotype (12.870 cm) which was on par with genotypes A10 (12.767 cm), A9 (12.445 cm), A1 (12.291 cm) and A2 (12.098 cm). The minimum length of leaf lamina was observed for the genotype A26 (8.687 cm), A29 (9.467 cm), A27 (8.913 cm) and A21 (8.723 cm) genotypes were on par with it.

The maximum petiole length was observed for the genotype A9 (5.175 cm), which was on par with A1 (4.472 cm), A24 (4.447 cm), A28 (4.373 cm) and A2 (4.353 cm). The least petiole length was noticed for the genotype A11 (2.873 cm).

The genotype A9 registered highest leaf width (8.268 cm), which was on par with other four genotypes, like A10 (8.265 cm), A1 (7.930 cm), A2 (7.778 cm) and A20 (7.587 cm).

Table 2. Mean performance of 13 biometric characters of 30 genotypes of amaranthus under field condition

SI No.	Genotypes	X 1	X2	X3	X 4	X5	X 6	X 7	X 8	X9	X 10	X 11	X 12	X13
1	A1	2.880	12.291	4.472	7.930	2.642	7.033	86.680	1.730	0.951	35.333	32.187	0.000	2.170
2	A2	2.657	12.098	4.353	7.778	2.673	6.400	109.26	2.295	1.577	31.333	30.780	0.000	0.320
3	A3	2.700	10.325	3.347	6.283	3.183	6.817	87.323	1.746	1.249	43.333	30.033	1.716	0.730
4	A4	3.200	9.1800	3.027	5.653	3.850	9.667	125.22	2.153	0.707	47.000	39.867	0.830	0.473
5	A5	3.037	10.692	3.683	6.358	3.633	9.283	82.837	1.656	0.906	39.000	33.890	1.246	2.073
6	A6	3.288	11.580	3.493	6.768	2.957	8.733	108.27	2.154	0.713	43.667	34.520	1.990	0.356
7	A7	3.033	11.000	3.700	6.320	4.267	0.000	114.42	2.278	0.491	48.333	72.500	0.846	0.340
8	A8	2.977	10.650	3.773	5.307	2.358	7.520	83.690	1.655	0.719	39.000	32.370	0.000	2.860
9	A9	2.893	12.445	5.175	8.268	2.733	6.933	97.696	1.962	1.428	39.667	33.675	0.283	0.000
10	A10	3.745	12.767	3.717	8.265	4.080	8.267	97.993	1.943	0.916	31.667	35.750	0.603	2.393
11	A11	2.953	9.9800	2.873	6.668	3.927	9.333	74.466	1.486	0.660	48.000	33.833	0.000	1.373
12	A12	3.113	10.690	3.333	6.767	2.767	8.867	95.185	1.903	0.857	44.000	40.580	0.770	1.956
13	A13	3.327	10.713	3.733	6.380	4.133	8.467	74.387	1.486	0.691	38.000	44.900	0.000	0.660
14	A14	1.780	10.653	3.433	6.433	1.643	6.933	71.873	1.437	1.224	36.000	31.087	0.280	3.080
15	A15	2.075	10.873	3.320	6.107	3.213	0.000	74.823	1.496	1.678	48.667	35.100	0.000	2.496

X1- Stem girth , X2- Length of leaf lamina, X3- Petiole length, X4- Leaf width, X5- Internodal length, X6- Number of branches, X7- Yield plant^{-1}, X8- Yield plot^{-1}, X9- Leaf to stem ratio, X10- Days to 50% bolting, X11- Plant height, X12- Incidence of leaf blight, X13- Incidence of leaf webber.

Table 2. Continued

SI No.	Genotypes	X 1	X2	X3	X 4	X5	X 6	X 7	X 8	X9	X 10	X 11	X 12	X13
16	A16	2.623	11.453	3.540	7.007	3.407	7.267	83.736	1.676	1.232	30.667	17.840	0.323	2.286
17	A17	2.900	10.653	2.927	6.480	2.380	8.533	71.796	1.436	1.281	48.333	32.113	0.630	3.260
18	A18	2.567	9.9000	3.100	6.133	2.617	8.400	64.163	1.466	0.724	47.667	33.867	0.556	2.923
19	A19	3.347	10.400	3.200	5.820	3.947	7.600	87.893	1.753	0.942	46.667	40.900	1.143	0.576
20	A20	2.707	11.747	3.813	7.587	3.000	6.600	103.09	2.063	1.530	35.000	35.300	0.890	0.000
21	A21	3.387	8.7230	3.000	5.350	4.640	11.46	106.71	2.136	0.955	49.667	40.167	0.000	0.000
22	A22	2.633	9.9700	3.007	5.627	2.513	9.667	125.92	2.513	0.620	48.000	33.033	0.000	0.253
23	A23	3.537	10.287	3.920	6.360	3.507	9.267	96.226	1.924	0.898	42.000	32.053	1.280	0.000
24	A24	3.395	10.853	4.447	6.590	3.280	7.600	82.826	1.656	1.012	42.000	34.453	0.000	2.720
25	A25	1.759	10.965	3.712	6.505	2.167	8.350	76.233	1.523	0.846	34.000	28.545	0.250	1.800
26	A26	2.487	8.6870	3.330	6.460	2.227	9.267	75.090	1.503	1.277	35.000	25.803	0.000	0.000
27	A27	2.980	8.9130	3.933	5.800	2.667	8.467	94.183	1.883	0.804	43.000	34.200	0.000	1.220
28	A28	3.037	12.780	4.373	6.813	2.820	8.200	116.98	2.339	0.607	40.000	34.133	0.000	1.720
29	A29	2.940	9.4670	3.387	5.653	3.003	8.733	97.923	1.956	0.852	42.333	40.133	1.170	0.726
30	A30	3.262	10.313	3.158	6.770	2.600	9.133	96.666	1.936	1.086	42.000	35.413	1.503	1.263
	S.E	**0.379**	**0.496**	**0.469**	**0.489**	**0.400**	**0.716**	**6.312**	**0.025**	**0.100**	**0.894**	**2.818**	**0.258**	**0.112**
	CD(0.05)	**0.760**	**0.994**	**0.940**	**0.981**	**0.803**	**1.433**	**12.638**	**0.143**	**0.227**	**2.345**	**5.643**	**0.122**	**0.201**

X1- Stem girth , X2- Length of leaf lamina, X3- Petiole length, X4- Leaf width, X5- Internodal length, X6- Number of branches, X7- Yield plant^{-1}, X8- Yield plot^{-1}, X9- Leaf to stem ratio, X10- Days to 50% bolting, X11- Plant height, X12- Incidence of leaf blight, X13- Incidence of leaf webber.

The internodal length ranged from 4.640 cm (A21) to 1.643 cm (A14). The genotype A21 was on par with A13 (4.133 cm), A10 (4.080 cm), A19 (3.947 cm), A11 (3.927 cm) and A4 (3.850 cm).

The number of branches ranged from 11.467 (genotype A21) to 0.000 (genotype A7 and A15).

The genotype A22 registered high yield plant^{-1} (125.926 g) and high yield plot^{-1} (2.513 kg) and the lowest yield plant^{-1} was reported for the genotype A18 (64.163 g) with 1.436 kg (lowest) yield plot^{-1}. The genotype A4 (125.229 g), A28 (116.986 g) and A7 (114.426 g) were on par with the genotype A22 and the genotype A26 (75.090 g), A11 (74.466 g), A15 (74.823 g), A13 (74.387 g), A14 (71.873 g) and A17 (71.796 g) were on par with genotype A18 for the character yield plant^{-1}. The genotypes A26 (1.503 kg), A15 (1.496 kg), A11 (1.486 kg), A13 (1.486 kg) A17 (1.466 kg) and A14 (1.437 kg) were on par with the genotype A18 for the character yield plot^{-1}.

Significant variation was observed for the character leaf to stem ratio. It was ranged from 1.678 (A15) to 0.491 (A7). The highest value was observed for the genotype A15 (1.678) which was on par with the genotypes A2 (1.577), A20 (1.530) and A9 (1.428). The lowest leaf to stem ration was recorded for the genotype A7 (0.491). The genotypes A8 (0.719), A6 (0.713), A4 (0.707), A13 (0.691), A11 (0.660) and A28 (0.607) were found to be on par with the genotype A7.

Days to 50% bolting was found to be highest for the genotype A21 (49.667) and the lowest for the genotype A16 (30. 667). The genotypes A15 (48.667), A17 (48.333), A7 (48.333), A11 (48.00) and A18 (47.667) were on par with the genotype A21. The genotype A16 was on par with A10 (31.667) and A2 (31.333).

The maximum plant height was recorded for the genotype A7 (72.500 cm). The minimum plant height was recorded for the genotype A16 (17.840 cm).

Incidence of leaf blight was scored according to 0-4 scale, the highest score was reported for the genotype A6 (1 990) and the lowest score 0 were reported for the genotypes A1, A2, A8, A11, A13, A15, A21, A22, A24, A26, A27 and A28.

Scoring for the incidence leaf webber were done with 0-4 scale, maximum score was recorded for the genotype A17 (3.260) which was on par with A14 (3.080). The score 0 was reported for genotypes A9, A20, A21, A23 and A26.

4.1.1.2. Morphological Cataloguing

All the thirty genotypes were described morphologically by using IBPGR descriptor for amaranthus (Table 3). All the genotypes were scored for 22 characters with appropriate scoring according with the scale. List descriptor for amaranthus is given in appendix 1.

All the genotypes had erect growth habit with all branches among the stem, two genotypes like A7 and A15 had no branches. Thirteen genotypes had 30-45 cm range of plant height remaining seventeen genotypes had 46-60 cm range of plant height. Fifteen genotypes had low level of stem pubescence and remaining had no pubescence in the stem. All the thirty genotypes had pink colour stem pigmentation, no spines on the leaf axil, no leaf pubescence with pink colour leaf pigmentation.

Eight genotypes had above 11 cm leaf length and 22 genotypes had the range of 5-10 cm leaf length. Leaf width of all the genotypes had a range of 5-10 cm. All the thirty genotypes had elliptical shaped leaf, seven genotypes had undulated margin remaining had entire margins on the leaf. Leaf prominence vein varied from smooth to slightly prominent. The genotypes A4 and A15 had deep purple colour of petiole pigmentation, other genotypes had purple colour of petiole pigmentation. The axillary inflorescence was present in all the thirty genotypes. Inflorescence colour varied from pink to red. Nine genotypes had red

Table 3. Morphological characterization of 30 amaranthus genotypes using IBPGR descriptors for amaranthus

SI No.	Descriptors	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
1	Growth habit	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Plant height	2	2	2	5	2	2	5	2	2	2	5	2	2	2	2
3	Branching index	4	4	4	4	4	4	1	4	4	4	4	4	4	4	1
4	Stem pubescence	0	0	3	0	0	0	3	0	3	3	0	0	3	3	0
5	Stem pigmentation	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
6	Spines in the leaf axil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Leaf length	5	5	3	3	3	5	5	3	5	5	3	3	3	3	3
8	Leaf width	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
9	Leaf pubescence	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0
10	Leaf pigmentation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	Leaf shape	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
12	Leaf margin	1	1	1	1	1	1	3	1	1	3	1	3	3	3	1
13	Prominence of leaf vein	2	2	2	2	2	2	2	2	2	2	1	2	1	1	2
14	Petiole	3	3	3	4	3	3	3	3	3	3	3	3	3	3	4

	pigmentation														
15	Presence of axillary inflorescence	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
16	Inflorescence colour	3	3	4	3	4	3	3	3	3	4	3	3	3	4	3
17	Days to 50% bolting	1	1	1	2	1	1	2	1	1	1	2	1	1	1	2
18	Seed colour	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
19	Seed coat type	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
20	Seed shape	2	2	2	1	1	2	1	1	2	1	2	1	1	1	1
21	Germination rate	1	1	2	1	2	1	1	1	1	1	1	1	2	1	1
22	Root type	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 3. Continued

SI No.	Descriptors	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30
1	Growth habit	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Plant height	2	5	5	5	2	5	5	2	2	2	2	2	2	2	2
3	Branching index	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	Stem pubescence	3	0	3	3	3	0	3	3	3	3	0	0	3	0	0
5	Stem pigmentation	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
6	Spines in the leaf axil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Leaf length	5	3	3	3	5	3	3	3	3	3	3	3	5	3	3
8	Leaf width	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
9	Leaf pubescence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Leaf pigmentation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	Leaf shape	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
12	Leaf margin	3	1	1	1	1	1	3	1	1	1	1	1	3	1	1
13	Prominence of	2	1	1	2	2	2	1	2	2	1	1	2	2	2	2

	leaf vein															
14	Petiole pigmentation	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
15	Presence of axillary inflorescence	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+
16	Inflorescence colour	3	3	3	4	3	4	3	4	4	3	4	3	3	3	3
17	Days to 50% bolting	1	2	2	2	1	2	2	1	1	1	1	1	1	1	1
18	Seed colour	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
19	Seed coat type	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
20	Seed shape	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
21	Germination rate	1	1	2	1	1	1	1	1	1	1	1	3	1	1	1
22	Root type	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

colour inflorescence, others had pink colour. All the genotypes had black colour seed and opaque seed coat type.

Ten genotypes had ovoid seed shape and others with round seed. The genotype A26 had very slow germination rate, the genotypes A3, A5 and A 18 had slow rate of germination, remaining germinated rapidly. All the thirty genotypes had tap root system.

4.2. IDENTIFICATION OF WATER STRESS TOLERANT AMARANTHUS GENOTYPES WITH GOOD QUALITY AND HIGH YIELD

4.2.1. Variability

Ten genotypes like Palakkadu local (A2), Kalliyoor local (A4), Anachal local (A6), Haripad local (A7), Kazhakkuttom local (A9), Poonkulam local (A20), Aryanadu local (A21), Madhur local (A22), Ayyanthole local (A28) and Kannara local (A29) recorded highest plant^{-1} yield of 109.26 g, 125.229 g, 108.273 g, 114.426 g, 97.993 g,103.095g, 106.713 g, 125.926 g, 116.986 g and 97.923 g respectively (Table 4).

The high yielding ten genotypes were evaluated under water stress for good quality and yield. All the characters under study showed significant difference for the genotypes.

4.2.1.1. Biometric Characters

Mean values of 10 genotypes for 13 biometric characters shown in Table 5.

The maximum stem girth was recorded for the genotype A22 (2.577 cm) which was on par with A9 (2.505 cm), A20 (2.477 cm), A6 (2.395 cm), A7 (2.308 cm), A21 (2.237 cm) and A2 (2.218 cm). The minimum stem girth was observed for the genotype A29 (1.670 cm).

The length of the leaf lamina was recorded the maximum for genotype A22 (8.663 cm) which was found to be on par with four other genotypes *viz*, A9

Table 4. List of high yielding 10 genotypes of amaranthus

Genotypes No.	Name of genotypes	Yield plant^{-1}(g)
A22	Madhur local	125.926
A4	Kalliyoor local	125.229
A28	Ayyanthole local	116.986
A7	Haripad local	114.426
A2	Palakkadu local	109.260
A6	Anachal local	108.273
A21	Aryanadu local	106.713
A20	Poonkulam local	103.095
A9	Kazhakkuttom local	97.9930
A29	Kannara local	97.9230

Table 5. Mean performance of 10 genotypes of amaranthus for 13 biometric characters under water stress condition

Genotypes	Name of genotypes	Stem girth (cm)	Length of leaf lamina (cm)	Petiole length (cm)	Leaf width (cm)	Internodal length (cm)	Number of branches	Yield plant^{-1} (g)	Yield plot^{-1} (kg)	Leaf to stem ratio	Days to 50% bolting	Plant height (cm)	Incidence of leaf blight	Incidence of leaf webber
A2	Palakkadu local	2.218^{b}	7.403^{c}	3.590^{a}	4.641^{d}	3.203^{a}	4.127^{d}	33.660^{c}	0.620^{f}	0.667^{cd}	52.333^{b}	28.670^{d}	0.257^{ef}	2.147^{b}
A4	Kalliyoor local	1.730^{c}	6.363^{d}	3.527^{a}	3.758^{ef}	1.883^{e}	2.333^{f}	27.415^{d}	0.582^{f}	0.593^{d}	57.667^{a}	38.880^{b}	0.850^{b}	1.850^{d}
A6	Anachal local	2.395^{ab}	8.333^{ab}	3.404^{ab}	5.113^{bc}	2.478^{bc}	4.897^{c}	39.673^{b}	0.792^{c}	0.828^{bc}	52.667^{b}	35.440^{c}	1.273^{a}	2.623^{a}
A7	Haripad local	2.308^{ab}	8.322^{ab}	2.403^{e}	4.513^{d}	2.737^{bc}	4.820^{c}	35.240^{c}	0.739^{d}	0.697^{cd}	58.000^{a}	33.333^{c}	0.170^{f}	1.313^{f}
A9	Kazhakkuttom local	2.505^{ab}	8.580^{ab}	2.610^{de}	5.621^{a}	2.250^{d}	6.887^{b}	43.006^{b}	0.826^{bc}	0.988^{ab}	52.333^{a}	43.093^{a}	0.437^{d}	1.637^{c}
A20	Poonkulam local	2.477^{ab}	8.455^{ab}	3.116^{bc}	5.425^{ab}	2.658^{bc}	6.683^{b}	40.626^{b}	0.846^{b}	0.929^{ab}	57.333^{a}	38.517^{b}	0.157^{g}	1.077^{g}
A21	Aryanadu local	2.237^{ab}	8.104^{b}	2.959^{cd}	3.441^{f}	2.275^{d}	4.303^{d}	34.923^{c}	0.674^{e}	0.681^{cd}	58.000^{a}	28.570^{d}	0.087^{g}	1.043^{g}
A22	Madhur local	2.577^{a}	8.663^{a}	2.467^{e}	4.641^{d}	1.858^{e}	7.527^{a}	54.160^{a}	1.083^{a}	1.033^{a}	57.667^{a}	36.362^{bc}	0.250^{e}	0.923^{g}
A28	Ayyanthole local	1.845^{c}	6.206^{d}	3.387^{ab}	3.441^{f}	1.518^{f}	2.257^{f}	23.620^{d}	0.440^{h}	0.588^{d}	58.000^{a}	33.773^{c}	0.540^{c}	2.083^{bc}
A29	Kannara local	1.670^{c}	7.060^{c}	2.531^{e}	3.902^{e}	2.900^{ab}	3.860^{e}	27.662^{d}	0.520^{g}	0.626^{d}	53.000^{b}	36.367^{bc}	0.180^{f}	1.970^{c}
	S.E	**0.121**	**0.178**	**0.131**	**0.139**	**0.110**	**0.103**	**1.437**	**0.016**	**0.057**	**0.618**	**1.215**	**0.021**	**0.041**
	CD(0.05)	**0.362**	**0.525**	**0.391**	**0.415**	**0.330**	**0.308**	**4.304**	**0.049**	**0.171**	**1.849**	**3.637**	**0.063**	**0.122**

(8.580 cm), A20 (8.455 cm), A6 (8.333 cm), and A7 (8.322 cm). The minimum length of leaf lamina was recorded in the genotype A28 (6.206 cm).

The genotype A2 showed the maximum petiole length of 3.590 cm which was on par with A4 (3.527 cm), A6 (3.404 cm) and A28 (3.387 cm). The minimum petiole length was observed for the genotype A7 (2.403 cm) which was on par with A29 (2.531 cm) and A22 (2.467 cm).

The highest leaf width was registered for the genotype A9 (5.621 cm) and the genotype A20 (5.425 cm) was on par with A9. The lowest leaf width was observed in A21 and A28 (3.441 cm).

The internodal length ranged from 1.518 cm to 3.203 cm. The highest was observed in A2 (3.203 cm) and the lowest was recorded for A28 (1.518 cm).

The genotype A22 registered highest number of branches (7.527) and the lowest observed for the genotype A28 (2.257) which was on par with the genotype A4 (2.333).

The yield plant^{-1} and yield plot^{-1} were highest for the genotype A22 of 54.160 g and 1.083 kg respectively. The lowest yield plant^{-1} was recorded for A28 (23.620 g) which was found to be on par with A29 (27.662 g) and A4 (27.415 g). The minimum yield plot^{-1} was reported for A28 (0.440 kg).

The highest leaf to stem ratio was showed for the genotype A22 (1.033) which was on par with A9 (0.988) and A20 (0.929). The lowest leaf to stem ratio was recorded for the genotype A28 (0.588) which was on par with A7 (0.697), A21 (0.681), A2 (0.667), A29 (0.626) and A4 (0.593).

The maximum days to 50% bolting was recorded for the genotypes A21, A7 and A28 (58.00), which was found to be on par with A4 (57.667), A22 (57.667) and A20 (57.333). The minimum days to 50% bolting was reported for A9 (52.333) and A2 (52.333) which was on par with A29 (53.000) and A6 (52.667).

The plant height ranged from 28.570 to 43.093 cm. The highest was observed for the genotype A9 (43.093 cm) and the lowest was recorded for A21 (28.570 cm) which was on par with A2 (28.670 cm).

Incidence of leaf webber scored with 0-4 scale, the high score was recorded for A6 (1.273) and the lowest for A21 (0.087).

The highest score for incidence of leaf webber was observed for A6 (2.623) and the lowest for A22 (0.923). The scoring was ranged from 0.923-2.623.

4.2.1.2. Quality Characters

Mean performance of 10 genotypes for quality characters were shown in table 6.

The protein content was varied from 3.358 mg g^{-1} to 1.281 mg g^{-1}. The genotype A21 reported the highest protein content (3.358 mg g^{-1}) and the genotype A9 showed the lowest protein content (1.281 mg g^{-1}). The genotypes A2 (1.363 mg g^{-1}) and A4 (1.289 mg g^{-1}) were on par with the genotype A9.

The maximum fibre content was reported for the genotype A20 (14.370%) and the genotype A28 registered lowest fibre content (7.6570%) which was on par with A6 (8.4100%).

The vitamin A content ranged from 1052.48 IU (A4) to 3764.66 IU (A22), which was significantly differed from other genotypes.

The genotype A9 observed highest oxalate content i.e, 2.87% and the lowest was reported for A22 and A28 i.e, 1.63%. The genotypes A7 (2.44%) and A21 (2.43%) were on par with A9. The genotypes A4 (2.00%), A20 (1.86%) and A2 (1.77%) were on par with the genotypes A22 and A28.

The nitrate content varied significantly, the highest was observed for the genotype A4 (1.030%), followed by A6 (0.305%). The lowest nitrate content was recorded for A29 (0.027%).

Table 6. Mean performance of 10 amaranthus genotypes for 5 quality characters under water stress condition

Genotypes No.	Name of genotypes	Protein content (mg g^{-1})	Fiber content (%)	Vitamin A (IU)	Oxalate content (%)	Nitrate content (%)
A2	Palakkadu local	1.363^{e}	12.497^{bc}	$2,600.98^{c}$	1.77^{c}	0.106^{cde}
A4	Kalliyoor local	1.289^{e}	10.653^{d}	$1,052.48^{h}$	2.00^{cs}	1.030^{a}
A6	Anachal local	1.963^{d}	8.4100^{ef}	$1,875.85^{e}$	2.25^{b}	0.305^{b}
A7	Haripad local	1.776^{d}	9.9400^{d}	$1,957.18^{de}$	2.44^{ab}	0.270^{bc}
A9	Kazhakkuttom local	1.281^{e}	9.0980^{e}	$3,224.02^{b}$	2.87^{a}	0.086^{cde}
A20	Poonkulam local	1.440^{e}	14.370^{a}	$2,600.98^{c}$	1.86^{c}	0.055^{cde}
A21	Aryanadu local	3.358^{a}	10.397^{d}	$1,805.24^{f}$	2.43^{ab}	0.054^{cde}
A22	Madhur local	2.854^{c}	11.710^{c}	$3,764.66^{a}$	1.63^{c}	0.029^{e}
A28	Ayyanthole local	2.801^{c}	7.6570^{f}	$1,262.57^{g}$	1.63^{c}	0.121^{cde}
A29	Kannara local	3.151^{ab}	12.533^{bc}	$1,333.42^{g}$	1.82^{c}	0.027^{e}
	S.E	**0.074**	**0.303**	**20.838**	**0.179**	**0.055**
	CD(0.05)	**0.222**	**0.906**	**62.393**	**0.536**	**0.166**

4.2.1.3. Physiological Characters

Mean performance of 10 genotypes for physiological characters under water stress were shown in table 7.

All the characters under study were significantly differed for the genotypes.

The percentage leachate was ranged from 1.5410% (A22) to 26.118% (A28). The maximum membrane integrity was observed for the genotype A22 (98.459 %) and the minimum was observed for A28 (73.882%)

The maximum relative leaf water content (90.58%) was reported in the genotypes A20 and A22, which was on par with the genotypes A28 (90.53%), A9 (90.43%), A6 (90.00%), A2 (89.61%), A7 (89.58%) and A21 (89.56%). The relative water content was minimum for the genotype A4 (82.26%).

Canopy temperature was highest for the genotype A4 (27.523°C). This was found to be on par with the genotypes, A28 (26.657°C), A29 (24.960°C), A7 (23.817°C), A21 (23.647°C) and A6 (23.147°C). The minimum canopy temperature was for the genotype A9 (17.307°C) and which was on par with A22 (18.307°C).

The highest proline content of the leaves was recorded for the genotype A22 (39.672 µmol g^{-1}) and the lowest proline was recorded for the genotype A28 (8.823µmol g^{-1}).

4.2.2. Genetic Parameters

The phenotypic and genotypic coefficients of variation, heritability and genetic advance were worked out and shown in Table 8.

Table 7. Mean performance of 10 genotypes of amaranthus for 5 physiological characters under water stress condition

Genotypes No.	Name of genotypes	Percentage leachate (%)	Membrane Integrity (%)	Relative Water Content (%)	Canopy temperatue (°C)	Proline content of leaves (µmoles g^{-1})
A2	Palakkadu local	16.454^{c}	83.546^{g}	89.61^{a}	22.477^{bcd}	22.833^{g}
A4	Kalliyoor local	24.663^{b}	75.2890^{h}	82.26^{c}	27.523^{a}	10.614^{i}
A6	Anachal local	10.462^{f}	89.538^{d}	90.00^{a}	23.147^{abc}	34.619^{c}
A7	Haripad local	14.905^{d}	85.095^{f}	89.58^{a}	23.817^{abc}	30.668^{e}
A9	Kazhakkuttom local	3.7970^{h}	96.203^{b}	90.43^{a}	17.307^{e}	37.628^{b}
A20	Poonkulam local	5.9430^{g}	94.057^{c}	90.58^{a}	22.477^{bcd}	32.618^{d}
A21	Aryanadu local	12.436^{e}	87.564^{e}	89.56^{a}	23.647^{abc}	24.462^{f}
A22	Madhur local	1.5410^{i}	98.459^{a}	90.58^{a}	18.307^{de}	39.672^{a}
A28	Ayyanthole local	26.118^{a}	73.8820^{i}	90.53^{a}	26.657^{ab}	8.8230^{j}
A29	Kannara local	24.711^{b}	75.3370^{h}	85.33^{b}	24.960^{abc}	18.036^{h}
	S.E	**0.383**	**0.384**	**0.874**	**1.512**	**0.081**
	CD(0.05)	**1.147**	**1.15**	**2.617**	**4.527**	**0.242**

Table 8. Genetic parameters of characters of amaranthus under water stress

Characters	Variances			GCV	PCV	Heritability	Genetic advance (as % of mean)
	V_g	V_p	V_e				
Stem girth	0.095	1.393	0.044	14.073	16.998	68.548	24.002
Length of leaf lamina	0.826	0.918	0.092	11.731	12.37	89.944	22.919
Petiole length	0.201	0.252	0.051	14.959	16.754	79.725	27.516
Leaf width	0.608	0.666	0.058	17.534	18.345	91.355	34.524
Internodal length	0.260	0.297	0.037	21.468	22.924	87.694	41.413
Number of branches	3.264	3.296	0.032	37.882	38.066	99.038	77.661
Yield per plant	77.651	83.849	6.198	24.479	25.437	92.608	48.527
Leaf to stem ratio	0.025	0.035	0.010	20.691	24.404	71.89	36.14
Days to 50% bolting	6.889	8.033	1.144	4.712	5.089	85.754	8.989
Plant height	18.70	23.13	4.427	12.252	13.625	80.864	22.696
Relative water content	7.027	9.315	2.288	2.984	3.435	75.436	18.785
Proline content of leaves	116.13	120.33	2.40	4.157	4.232	96.50	8.412
Protein content	0.680	0.696	0.016	38.766	39.231	97.64	38.234
Fiber content	4.221	4.496	0.275	19.154	19.768	93.889	84.842
Vitamin A	783728	785028.4	1300.66	41.219	41.254	99.834	28.188
Oxalate content	0.137	0.233	0.096	17.855	23.298	58.733	181.73
Nitrate content	0.122	0.206	0.084	6.66	8.65	76.99	13.73

4.2.2.1. Coefficient of Variation

4.2.2.1.1 Phenotypic Coefficient of Variation

The phenotypic coefficient of variation (PCV) ranged from 3.435% for relative water content to 41.254% for Vitamin A. High PCV was observed for vitamin A(41.254%), protein content (39.231%), number of branches (38.066%), yield plant $^{-1}$ (25.437%), leaf to stem ratio (24.404%), oxalate content (23.298%) and internodal length (22.924%). The characters like fibre content (19.768%), leaf width (18.345%), stem girth (16.998%), canopy temperature (16.81%), petiole length (16.754%), plant height (13.625%) and length of leaf lamina (12.37%) showed moderate phenotypic coefficient of variation. Low PCV recorded for the characters like nitrate content (8.65%), days to 50 % bolting (5.089%), proline content of leaves (4.232%) and relative water content (3.435%).

4.2.2.1.2. Genotypic Coefficient of Variation

The value of genotypic coefficient of variation (GCV) ranged from 41.219% for vitamin A to 2.984% for relative water content. The characters like vitamin A (41.219%), protein content (38.766%), number of branches (37.882%), yield plant^{-1} (24.479%) internodal length (21.468%) and leaf to stem ratio (20.691%) showed high value of genotypic coefficient of variation. Moderate genotypic coefficient of variation observed for the characters like fibre content (19.154%), oxalate content (17.855%), leaf width (17.534%), petiole length (14.959%), stem girth (14.073%), canopy temperature (12.381%), plant height (12.252%) and length of leaf lamina (11.731%). The characters like nitrate content (6.66%), days to 50% bolting (4.712%), proline content of leaves (4.157%) and relative water content (2.984%) recorded low values of genotypic coefficient of variation.

4.2.2.2. Heritability

High heritability was observed for vitamin A (99.834%) followed by number of branches (99.038%), protein content (97.64%), proline content of leaves (96.50%), fibre content (93.889%), yield plant^{-1} (92.608%), leaf width (91.355%) , length of leaf lamina (89.944%), internodal length (87.694%), days to 50% bolting (85.754%), plant height (80.864%), petiole length (79.725%), nitrate content (76.99%), relative water content (75.436%), leaf to stem ratio (71.89%) and stem girth (68.584%). Moderate heritability was recorded for oxalate content (58.733%) and canopy temperature (54.245%).

4.2.2.3. Genetic Advance (as Percentage of Mean)

The highest estimate of genetic advance recorded was 181.73% (oxalate content) followed by 86.373% (canopy temperature), 84.842% (fibre content), 77.661% (number of branches), 48.527% (yield plant^{-1}), 41.413% (internodal length), 38.234% (protein content) , 36.14% (leaf to stem ratio), 34.524% (leaf width), 28.188% (vitamin A), 27.516% (petiole length), 24.002% (stem girth), 22.919% (length of leaf lamina) and 22.696% (plant height). Moderate genetic advance was observed for relative water content (18.785%) and nitrate content (13.73%). The lowest value of genetic advance was recorded for days to 50% bolting (8.989%) and proline content of leaves (8.412%).

4.2.4. Correlation Coefficient Analysis

Genotypic, phenotypic and environmental correlation coefficients were studied to know the relationship between two characters. The results of correlation are presented here.

4.2.4.1. Genotypic Correlation Coefficient

The genotypic correlation coefficients are given in Table 9.

The stem girth had positive correlation with length of leaf lamina (0.992), leaf width (0.850), number of branches (0.950), yield plant^{-1}(0.985), yield plot^{-1}

Table 9. Genotypic correlation coefficients among the characters of amaranthus under water stress condition

Characters	X 1	X2	X3	X 4	X5	X 6	X 7	X 8	X9	X 10	X 11	X 12	X13	X 14	X15	X16	X 17	X 18	X19	X20	X21	X 22	X23
X1	1.000																						
X 2	0.992**	1.000																					
X3	-0.311	-0.564**	1.000																				
X 4	0.850**	0.740**	-0.184	1.000																			
X 5	0.116	0.287	-0.061	0.379*	1.000																		
X 6	0.950**	0.923**	-0.574**	0.790**	0.149	1.000																	
X 7	0.985**	0.904**	-0.462*	0.677**	-0.003	0.947**	1.000																
X 8	0.959**	0.883**	-0.464**	0.673**	-0.036	0.921**	0.999**	1.000															
X 9	0.900**	0.896**	-0.504**	0.857**	-0.066	0.025**	0.029	0.979**	1.000														
X 10	-0.056	-0.141	-0.113	-0.495**	-0.561**	-0.138	-0.052	0.052	-0.115	1.000													
X 11	0.128	0.133	-0.288	0.546**	-0.324	0.383*	0.263	0.306	0.540**	-0.157	1.000												
X 12	-0.467**	-0.491**	0.599**	-0.029	0.144	-0.537**	-0.501**	-0.539**	-0.450*	-0.644**	-0.028	1.000											
X 13	-0.131	-0.210	0.556**	0.115	-0.310	-0.279	-0.109	-0.077	-0.061	-0.269	0.287	0.718**	1.000										
X 14	-0.025**	-0.945**	0.403*	-0.761**	-0.060	-0.955**	-0.966**	-0.938**	-0.001**	0.085	-0.274	0.508**	0.145	1.000									
X 15	0.026**	0.946**	-0.407*	0.761**	0.061	0.956**	0.966**	0.938**	0.001**	-0.086	0.272	-0.508**	-0.147	-1.000**	1.000								
X 16	0.837**	0.668**	-0.216	0.467**	0.047	0.611**	0.559**	0.478**	0.579**	-0.008	-0.208	-0.245	-0.226	-0.662**	0.662**	1.000							
X 17	-0.948**	-0.939**	0.612**	-0.831**	-0.119	-0.043**	-0.014	-0.918**	-0.045**	0.324	-0.399*	0.446*	0.275	0.013**	-0.013**	-0.668**	1.000						
X 18	0.995**	0.991**	-0.526**	0.809**	0.232	0.942**	0.935**	0.913**	0.955**	-0.226	0.266	-0.377*	-0.092	-0.947**	0.948**	0.630**	-0.987**	1.000					
X 19	-0.248	-0.104	-0.345	-0.643**	-0.264	-0.134	-0.092	-0.139	-0.197	0.276	-0.429*	-0.201	-0.290	0.177	-0.176	0.077	0.148	-0.171	1.000				
X 20	0.121	0.200	-0.105	0.216	0.568**	0.333	0.209	0.234	0.207	-0.008	-0.016	-0.428*	-0.563**	-0.192	0.192	-0.147	-0.169	0.146	-0.112	1.000			
X 21	0.911**	0.771**	-0.413*	0.700**	0.082	0.907**	0.921**	0.856**	0.943**	-0.172	0.224	-0.464**	-0.301	-0.891**	0.891**	0.643**	-0.076**	0.829**	-0.185	0.275	1.000		
X 22	0.446*	0.499**	-0.385*	0.358	0.119	0.260	0.178	0.188	0.223	-0.247	0.329	-0.090	0.082	-0.376*	0.375*	0.191	-0.360	0.440*	-0.304	-0.411*	0.113	1.000	
X23	-0.478**	-0.485**	0.476**	-0.244	-0.281	-0.519**	-0.358	-0.249	-0.421*	0.210	0.257	0.267	0.582**	0.426*	-0.426*	-0.814**	0.586**	-0.440*	-0.448*	-0.182	-0.501**	0.060	1.000

* Significant at 5% ** Significant at 1%

X1- Stem girth , X2- Length of leaf lamina, X3- Petiole length, X4- Leaf width, X5- Internodal length, X6- Number of branches, X7- Yield plant^{-1}, X8- Yield plot^{-1}, X9- Leaf to stem ratio, X10- Days to 50% bolting, X11- Plant height, X12- Incidence of leaf blight, X13- Incidence of leaf webber, X14- Percentage leachate, X15- Membrane integrity, X16- Relative water content, X17- Canopy temperature, X18- Proline content of leaves, X19- Protein content, x20-Fibre content, X21- Vitamin A, X22- Oxalate content, X23- Nitrate content.

(0.959), leaf to stem ratio (0.900), relative water content (0.837), proline content of leaves (0.995), vitamin A (0.911). Stem girth was negatively correlated with incidence of leaf blight (-0.467), canopy temperature (-0.948) and nitrate content (-0.478).

Positive correlation was recorded for length of leaf lamina with leaf width (0.740), number of branches (0.923), yield plant^{-1}(0.904), yield plot^{-1}(0.883), leaf to stem ratio (0.896), membrane integrity (0.946), relative water content (0.668), proline content of leaves (0.991), vitamin A (0.771) and oxalate content (0.499). Significant negative correlation was observed with petiole length (-0.564), incidence of leaf blight (-0.491), percentage leachate (-0.945), canopy temperature (-0.939) and nitrate content (-0.485).

Petiole length showed significant positive correlation with incidence of leaf blight (0.599), incidence of leaf webber (0.556), canopy temperature (0.612) and nitrate content (0.476). Number of branches (-0.574), yield plant^{-1}(-0.462), yield plot^{-1} (-0.464) and proline content of leaves (-0.526) were significant negatively correlated with petiole length.

The interrelationship of leaf width with number of branches (0.790), yield plant^{-1} (0.677), yield plot^{-1} (0.673), leaf to stem ratio (0.857), plant height (0.546), membrane integrity (0.761), relative water content (0.467), proline content of leaves (0.809) and vitamin A (0.700) were found to be having significant positive correlation. Days to 50 % bolting (-0.495), percentage leachate (-0.761), canopy temperature (-0.831) and protein content (-0.643) had significant negative correlation with leaf width.

Internodal length showed significant positive correlation with fibre content (0.568) and significant negative correlation with days to 50 % bolting (-0.561).

Correlation of number of branches with yield plant^{-1} (0.947), yield plot^{-1} (0.921), membrane integrity (0.956), relative water content (0.611), proline content of leaves (0.542) and vitamin A (0.907) were positively significant.

Significant negative correlation was recorded for incidence of leaf blight (-0.535), percentage leachate (-0.955) and nitrate content (-0.519) with number of branches.

Yield plant^{-1} had positive correlation with yield plot^{-1} (0.999), membrane integrity (0.966), relative water content (0.599), proline content of leaves (0.935) and vitamin A (0.921). Negative correlation was recorded with incidence of leaf blight (-0.501) and percentage leachate (-0.966).

Yield plot^{-1} was positively correlated with leaf to stem ratio (0.979), membrane integrity (0.938), relative water content (0.478), proline content of leaves (0.913) and vitamin A (0.856). Incidence of leaf blight (-0.539), percentage leachate (-0.398) and canopy temperature (-0.918) showed significant negative correlation with yield plot^{-1}.

Leaf to stem ratio showed positive correlation with plant height (0.540), relative water content (0.579), proline content of leaves (0.955), and vitamin A (0.943). Significant negative correlation was observed with incidence of leaf blight (-0.450) and nitrate content (-0.421).

Days to 50 % bolting showed negative correlation with incidence of leaf blight (-0.644). Plant height had negative correlation with canopy temperature (-0.399) and protein content (-0.429).

Positive significant correlation was observed with incidence of leaf blight and incidence of leaf webber (0.718), percentage leachate (0.508) and canopy temperature (0.446). Negative significant correlation was observed with membrane integrity (-0.508) and vitamin A (-0.464).

Nitrate content (0.582) showed significant positive correlation with incidence of leaf webber. Fibre content (-0.563) and incidence of leaf webber were negatively correlated.

Percentage leachate had significant positive correlation with nitrate content (0.426). Membrane integrity (-1.000), relative water content (-0.662),

proline content of leaves (-0.947), vitamin A (-0.891) and oxalate content (-0.376) had negative correlation with percentage leachate.

Relative water content (0.662), proline content of leaves (0.948), vitamin A (0.891) and oxalate content (0.375) showed significant positive correlation with membrane integrity. Nitrate content (-0.426) had negative significant correlation with membrane integrity.

Relative water content showed significant and positive correlation with proline content of leaves (0.630) and vitamin A (0.643). Canopy temperature (-0.668) and nitrate content (-0.814) had significant and negative correlation with relative water content.

Canopy temperature was positively correlated with nitrate content (0.586) and negatively correlated with proline content of leaves (-0.987). Proline content of leaves had positive correlation with vitamin A (0.829) and negative correlation with nitrate content (-0.440). Protein content was showed negative correlation with nitrate content (-0.448). Fibre content had positive correlation with oxalate content (0.411). Vitamin A showed significant negative correlation with nitrate content (-0.501).

4.2.4.2. Phenotypic Correlation Coefficient

The phenotypic correlation coefficients are given in Table 10.

The interrelationship of stem girth was positive with the characters, length of leaf lamina (0.810), leaf width (0.598), number of branches (0.765), yield plant^{-1} (0.738), yield plot^{-1} (0.742), leaf to stem ratio (0.667), membrane integrity (0.858), relative water content (0.646), proline content of leaves (0.823) and vitamin A (0.756). Negative association was observed with percentage leachate (-0.859) and canopy temperature (-0.684).

Length of leaf lamina showed positive correlation with leaf width (0.673), number of branches (0.877), yield plant^{-1} (0.802), yield plot^{-1} (0.825), leaf to stem ratio (0.715), membrane integrity (0.902), proline content of leaves (0.939) and

Table 10. Phenotypic correlation coefficients among the characters of amaranthus under water stress condition

Characters	X 1	X2	X3	X 4	X5	X 6	X 7	X 8	X9	X 10	X 11	X 12	X13	X14	X15	X16	X17	X18	X19	X20	X 21	X22	X 23
Xi	1.000																						
X 2	0.810**	1.000																					
X3	-0.253	-0.469**	1.000																				
X 4	0.598**	0.673**	-0.140	1.000																			
X 5	0.106	0.263	-0.093	0.295	1.000																		
X 6	0.765**	0.877**	-0.529**	0.752**	0.150	1.000																	
X 7	0.738**	0.802**	-0.415*	0.636**	-0.009	0.909**	1.000																
X 8	0.742**	0.825**	-0.408*	0.639**	-0.018	0.906**	0.959**	1.000															
X 9	0.667**	0.715**	-0.280	0.691**	-0.052	0.853**	0.788**	0.829**	1.000														
X 10	-0.061	-0.088	-0.055	-0.421*	-0.536**	-0.127	-0.044	0.057	-0.157	1.000													
X 11	0.070	0.152	-0.206	0.457*	-0.220	0.347	0.247	0.297	0.446*	-0.138	1.000												
X 12	-0.357	-0.462*	0.533**	-0.041	0.126	-0.535**	-0.480**	-0.530**	-0.380*	-0.599**	-0.040	1.000											
X 13	-0.080	-0.199	0.501**	0.104	-0.283	-0.276	-0.109	-0.083	-0.047	-0.259	0.244	0.710**	1.000										
X 14	-0.859**	-0.902**	0.355	-0.730**	-0.054	-0.946**	-0.921**	-0.924**	-0.860**	0.073	-0.248	0.505**	0.144	1.000									
X 15	0.858**	0.902**	-0.352	0.730**	0.055	0.946**	0.922**	0.924**	0.860**	-0.075	0.250	-0.504**	-0.145	-1.000**	1.000								
X 16	0.646**	0.513**	-0.113	0.414*	-0.018	0.497**	0.458*	0.423*	0.503**	-0.041	-0.160	-0.187	-0.207	-0.581**	0.582**	1.000							
X 17	-0.684**	-0.636**	0.356	-0.577**	-0.077	-0.742**	-0.702**	-0.662**	-0.709**	0.342	-0.201	0.277	0.175	0.741**	-0.742**	-0.492**	1.000						
X 18	0.823**	0.939**	-0.471**	0.774**	0.215	0.937**	0.901**	0.902**	0.809**	-0.208	0.237	-0.374*	-0.092	-0.945**	0.945**	0.547**	-0.726**	1.000					
X 19	-0.237	-0.098	-0.309	-0.597**	-0.239	-0.133	-0.063	-0.127	-0.182	0.253	-0.361	-0.197	-0.293	0.176	-0.174	0.083	0.129	-0.169	1.000				
X 20	0.030	0.154	-0.116	0.193	0.504**	0.324	0.214	0.228	0.134	0.003	-0.034	-0.414*	-0.551**	-0.177	0.178	-0.151	-0.059	0.141	-0.100	1.000			
X 21	0.756**	0.734**	-0.373*	0.666**	0.081	0.902**	0.884**	0.845**	0.797**	-0.162	0.205	-0.462*	-0.298	-0.888**	0.888**	0.551**	-0.787**	0.828**	-0.183	0.267	1.000		
X 22	0.204	0.421*	-0.202	0.312	0.101	0.218	0.137	0.126	0.203	-0.193	0.140	-0.067	0.079	-0.284	0.285	0.013	-0.311	0.337	-0.225	-0.350	0.083	1.000	
X23	-0.351	-0.430*	0.367*	-0.211	-0.272	-0.483**	-0.338	-0.237	-0.323	0.209	0.190	0.253	0.550**	0.396*	-0.402*	-0.644**	0.460*	-0.417*	-0.432*	-0.194	-0.481**	0.042	1.000

* Significant at 5% ** Significant at 1%

X1- Stem girth , X2- Length of leaf lamina, X3- Petiole length, X4- Leaf width, X5- Internodal length, X6- Number of branches, X7- Yield plant^{-1}, X8- Yield plot^{-1}, X9- Leaf to stem ratio, X10- Days to 50% bolting, X11- Plant height, X12- Incidence of leaf blight, X13- Incidence of leaf webber, X14- Percentage leachate, X15- Membrane integrity, X16- Relative water content, X17- Canopy temperature, X18- Proline content of leaves, X19- Protein content, x20-Fibre content, X21- Vitamin A, X22- Oxalate content, X23- Nitrate content

vitamin A (0.734). Petiole length (-0.469), percentage leachate (-0.902), canopy temperature (-0.636) and nitrate content (-0.430) had negative correlation with length of leaf lamina.

Petiole length had positive correlation with incidence of leaf blight (0.533), incidence of leaf webber (0.501) and nitrate content (0.367). Negative correlation was observed with number of branches (-0.529), yield plant^{-1} (-0.415), yield plot^{-1} (-0.408) and proline content of leaves (-0.471).

Yield plant^{-1} (0.636), number of branches (0.752), yield plot^{-1} (0.639), leaf to stem ratio (0.691) and vitamin A (0.666) were found to be positive significant correlated with leaf width. Percentage leachate (-0.730), canopy temperature (-0.577) and protein content (-0.597) had negative significant correlation with leaf width.

Internodal length showed positive correlation with fibre content (0.504) and significant negative correlation with days to 50 % bolting (-0.536).

Interrelationship with number of branches and yield plant^{-1} (0.909), yield plot^{-1} (0.906), leaf to stem ratio (0.853), membrane integrity (0.946), relative water content (0.497), proline content of leaves (0.937) and vitamin A (0.902) were significantly positive correlated. Negative correlation was observed with number of branches and incidence of leaf blight (-0.535), percentage leachate (-0.946), canopy temperature (-0.742) and nitrate content (-0.483).

Yield plant^{-1} had significant positive correlation with yield plot^{-1} (0.959), leaf to stem ratio (0.788), membrane integrity (0.922), proline content of leaves (0.901) and vitamin A (0.884). Incidence of leaf blight (-0.535), percentage leachate (-0.946), canopy temperature (-0.742) and nitrate content (-0.483) had significant negative correlation with yield plant^{-1}.

Positive correlation was recorded for yield plot^{-1} with leaf to stem ratio (0.829), membrane integrity (0.924), proline content of leaves (0.902) and vitamin A (0.845). Significant negative correlation was observed with incidence

of leaf blight (-0.530), percentage leachate (-0.924) and canopy temperature (-0.662).

Leaf to stem ratio was positively correlated with membrane integrity (0.860), relative water content (0.503), proline content of leaves (0.809) and vitamin A (0.797). Negative correlation was observed with percentage leachate (-0.860) and canopy temperature (-0.709).

Days to 50% bolting was significant negative correlated with incidence of leaf blight (-0.599). Incidence of leaf blight had positive correlation with incidence of leaf webber (0.710), percentage leachate (0.505) and negatively correlated with membrane integrity (-0.504).

Incidence of leaf webber showed positive correlation with nitrate content (0.550) and negative correlation with fibre content (-0.551).

Percentage leachate was positively correlated with canopy temperature (0.741) and negatively correlated with membrane integrity (-1.000), relative water content (-0.581), proline content of leaves (-0.945) and vitamin A (-0.888).

Membrane integrity had positive correlation with relative water content (0.582), proline content of leaves (0.945) and vitamin A (0.888). Negative association was observed with canopy temperature (-0.742).

Relative water content showed positive correlation with proline content of leaves (0.547) and vitamin A (0.551) negative correlation with canopy temperature (-0.492) and nitrate content (-0.644).

Canopy temperature was negatively correlated with proline content of leaves (-0.726) and vitamin A (-0.787). Proline content of leaves had significant positive correlation with vitamin A (0.828). Nitrate content (-0.481) was negatively correlated with vitamin A.

4.2.5. Path Coefficient Analysis

Path coefficient analysis splits correlation coefficient into direct and indirect effects. The estimate of direct and indirect effects of component characters on yield was determined by path coefficient analysis.

Highly significant correlated eight characters like petiole length (-0.462), leaf width (0.667), number of branches (0.947), yield plot^{-1} (0.999), percentage leachate (-0.966), membrane integrity (0.966), proline content of leaves (0.935) and vitamin A (0.921).

Genotypic correlation coefficient among eight characters presented in the table 11. The path correlation coefficients representing the direct and indirect effects are given in Table 12.

Petiole length showed a positive direct effect on yield plant^{-1} (0.30). A negative indirect effect was showed through number of branches (-0.17), proline content of leaves (-0.16), yield plot^{-1} (-0.14) membrane integrity (-0.12), vitamin A (-0.12) and leaf width (-0.06). Positive indirect effect was showed through percentage leachate (0.12). Petiole length showed negative correlation of -0.462 with yield plant^{1}.

The direct effect of leaf width on yield plant^{-1} was negative (-0.41). A positive indirect effect was observed through the characters petiole length (0.08) and percentage leachate (0.32). Indirect negative effect through number of branches (-0.33), proline content of leaves (-0.33), membrane integrity (-0.32), vitamin A (-0.29) and yield plot^{-1} (-0.28), and it showed a positive genotypic correlation with yield plant^{-1} (0.677).

Number of branches showed high positive direct effect on yield plant^{-1} (0.66). The indirect effect through membrane integrity (0.63), proline content of leaves (0.62), yield plot^{-1} (0.60), vitamin A (0.59) and leaf width (0.52) were positive. Indirect effect through percentage leachate (-0.63) and petiole length

Table 11. Genotypic correlation coefficient of among selected characters of amaranthus under waters stress condition

Characters	X3	X4	X6	X8	X14	X15	X18	X21
X3	1.000							
X4	-0.184*	1.000						
X6	-0.574**	0.790**	1.000					
X8	-0.464**	0.673**	0.921**	1.000				
X14	0.403**	-0.761**	-0.955**	-0.938**	1.000			
X15	-0.407**	0.761**	0.956**	0.938**	-1.000**	1.000		
X18	-0.526**	0.809**	0.942**	0.913**	-0.947**	0.948**	1.000	
X21	-0.413**	0.700**	0.907**	0.856**	-0.891**	0.891**	0.829**	1.000

* Significant at 5% ** Significant at 1%

X3- Petiole length, X4- Leaf width, X6- Number of branches, X8- Yield plot^{-1}, X14- Percentage leachate, X15- Membrane integrity, X18- Proline content of leaves, X21- Vitamin A

Table 12. Direct and indirect effects of highly correlated characters of amaranthus on yield plant^{-1}

characters	X3	X4	X6	X8	X14	X15	X18	X21	Genotyyic correlation
X3	0.30	0.08	-0.38	-0.25	0.07	0.15	-0.34	-0.09	-0.462
X4	-0.06	-0.41	0.52	0.36	-0.12	-0.28	0.53	0.16	0.677
X6	-0.17	-0.33	0.66	0.49	-0.16	-0.36	0.61	0.21	0.947
X8	-0.14	-0.28	0.60	0.53	-0.15	-0.35	0.59	0.19	0.999
X14	0.12	0.32	-0.63	-0.50	0.16	0.37	-0.62	-0.20	-0.966
X15	-0.12	-0.32	0.63	0.50	-0.16	-0.37	0.62	0.20	0.966
X18	-0.16	-0.33	0.62	0.49	-0.16	-0.35	0.65	0.19	0.935
X21	-0.12	-0.29	0.59	0.46	-0.15	-0.33	0.54	0.23	0.921

X3- Petiole length, X4- Leaf width, X6- Number of branches, X8- Yield plot^{-1}, X14- Percentage leachate, X15- Membrane integrity, X18- Proline content of leaves, X21- Vitamin A

(-0.38) were negative. Number of branches recorded a positive correlation with yield plant^{-1} (0.947).

Yield plot^{-1} recorded high positive direct effect on yield plant^{-1} (0.53). Negative indirect effect through percentage leachate (-0.50) and petiole length (-0.25). Indirect effect through characters such as membrane integrity (0.50), number of primary branches (0.49), proline content of leaves (0.49) vitamin A (0.46) and leaf width (0.36) were positive. The genotypic correlation between Yield plot^{-1} and yield plant^{-1} was highly significant and positive (0.999).

Percentage leachate had positive direct effect (0.16) on yield plant^{-1}. Negative indirect was showed through number of branches (-0.16), membrane integrity (-0.16), proline content of leaves (-0.16), vitamin A (-0.15), yield plot^{-1} (-0.15) and leaf width (-0.12). A low positive indirect effect was observed through petiole length (0.07). It had a high negative genotypic correlation with yield plant^{-1} (-0.966).

Membrane integrity had a negative direct effect on yield (-0.37). Indirect effect through number of branches (-0.36), yield plot^{-1}(-0.35), proline content of leaves (-0.35), vitamin A (-0.33) and leaf width (-0.28), was found negative. Positive indirect effect through percentage leachate (0.37) and petiole length (0.15) on yield plant^{-1}. In addition, the character showed a significant high positive correlation with yield plant^{-1} (0.966).

Proline content of leaves showed high positive direct effect on yield plant^{-1}(0.65). The indirect effect of percentage leachate (-0.62) and petiole length (-0.34) were negative. Positive indirect effect through the characters like membrane integrity (0.62), number of branches (0.61), yields plot^{-1}(0.59), vitamin A (0.54) and leaf width (0.53). The genotypic correlation between proline content of leaves and yield plant^{-1} was positive and significant (0.935).

The direct effect of vitamin A on yield plant^{-1} was positive (0.23). The indirect effect through other characters like percentage leachate (-0.23) and

petiole length (-0.09) were negative. Indirect positive effect through vitamin A (0.23), number of branches (0.21), membrane integrity (0.20), yield plot^{-1} (0.19) leaf width (0.16) and proline content of leaves (0.19). Vitamin A showed a positive significant correlation with yield plant^{-1} (0.921).

The residual effect obtained was 0.027.

4.2.6. Selection Index

The selection index for all the genotypes were calculated based on yield, quality and the physiological characters contributing to good quality and stress tolerance. Ranking of all the genotypes were done from the calculated score. The scores were calculated for each genotype and are given in Table 13.

The genotype A22 (Madhur local) was ranked first with a score 3934.50, followed by A9 (3383.00), A20 (2757.70) and A2 (2747.60).

Table 13. Selection index for ten amaranthus genotypes under water stress conditions

Genotypes No.	Genotypes Name	Score
A22	Madhur local	3934.5
A9	Kazhakkuttom local	3383.0
A20	Poonkulam local	2757.7
A2	Palakkadu local	2747.6
A6	Anachal local	2029.7
A7	Haripad local	2104.9
A21	Aryanadu local	1951.5
A29	Kannara local	1471.9
A28	Ayyanthole local	1395.7
A4	Kalliyoor local	1190.0

MADHUR LOCAL

KAZHAKKUTTOM LOCAL

POONKULAM LOCAL

PALAKKADU LOCAL

Plate 9. Selected superior amaranthus genotypes with good quality under water stress condition

MADHUR LOCAL

Under irrigated condition

Under stress condition

Plate 10. Comparison of high yielding water stress tolerant amaranthus genotype Madhur local (A22) under irrigated and water stressed condition

DISCUSSION

5. DISCUSSION

The evaluation, selection and characterization of variability present in the population are the main steps towards the success of any breeding programme. The present study was conducted under two experiments for evaluation of amaranthus genotypes and identification of water stress tolerant amaranthus with high yield and quality at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani.

In the present investigation, thirty diverse *Amaranthus tricolor* L. germplasm available in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani and from other sources were morphologically described and evaluated for yield under field condition. Ten high yielding genotypes were selected for inducing water stress by restricting irrigation in the second experiment. The promising water stress tolerant genotypes identified in the study can be utilized for further crop improvement programmes for developing water stress tolerant varieties.

5.1. EVALUATION OF AMARANTHUS GENOTYPES

5.1.1. Variability

5.1.1.1. Biometric Characters

A wide range of observations were reported for different genotypes in terms of biometric characters which indicates the extent of variability present in the germplasm. In the present study, under first experiment thirteen biometric characters were studied for thirty genotypes and all the characters showed considerable variation among the genotypes evaluated.

Analysis of variance showed significant differences for all the 13 traits of 30 genotypes indicating the significant variability for all the characters of amaranthus under study which could be exploited through selection. Similar results were noticed in amaranthus by Selvaraj (2004), Shukla *et al.* (2005), Pan *et al.* (2008), Diwan (2015) and Jangde (2016).

The greatest variability was recorded for yield plant^{-1} which could be used as selection criteria for crop improvement in *Amaranthus tricolor* L. Supporting evidences were given by Shukla *et al.* (2005) and Celine *et al.* (2007) in amaranthus.

The highest range of variation was recorded for number of branches, length of leaf lamina, yield plant^{-1}, days to 50% bolting, plant height, incidence of leaf webber in amaranthus. Supporting evidences were given by Sathy (2006) and Celine *et al.* (2007) in amaranthus.

The genotype A22 (Madhur local) recorded the highest yield plant^{-1} followed by A4 (Klliyoor local), A28 (Ayyanthole local), A7 (Haripad local), A2 (Palakkadu local), A6 (Anachal local), A21 (Aryanadu local), A20 (Poonkulam local) A9 (Kazhakkuttom local) and A29 (Kannara local). These high yielding ten genotypes were selected for conducting the second experiment.

5.1.1.2. Morphological Cataloguing

Diversity in the morphological characters were also indicates presence of variability in the amaranthus genotypes that could be used for the documentation of different morphological characters present in the existing germplasm. The thirty genotypes were described using IBPGR descriptor for amaranthus (IBPGR, 1981).

The scoring was done according to different scale prescribed in the IBPGR descriptor for amaranthus. Twenty two different characters were used for describing thirty genotypes. The greatest morphological variation was observed for stem pubescence, leaf length, leaf margin, prominence of leaf vein, inflorescence colour, days to 50% bolting, germination rate and plant height. Similar results were reported by Varalakshmi *et al.* (2004), Sathy (2006) and Andhini *et al.* (2013) in amaranthus.

5.2. IDENTIFICATION OF WATER STRESS TOLERANT AMARANTHUS GENOTYPES WITH GOOD QUALITY AND HIGH YIELD

5.2.1. Variability

5.2.1.1. Biometric Characters

The each genotype performed differently under water stress condition. The yield plant^{-1} and yield plot^{-1} reduced by more than 50% under water stress condition. Reduction in the yield is shown in table 14. Similar result was reported by Mlakar *et al.* (2012) in amaranthus.

All the biometric characters were reduced under water stress condition due to shortage of water. Reduction in plant leaf area, leaf width, petiole length might be to enhance the mechanism that minimise the transpiration rate, plant height, internodal length also reduced. Similar results were reported by Ayodele (2000), Omami and Hammes (2006) and Shadakshari (2010) in amaranthus.

The duration of crop was increased under water stress condition because of the shortage water for normal development in plants. Similar observation was reported by Omami and Hammes (2006). Water stress caused increase in days to 50% bolting in amaranthus it might be due to the slow growth of plants under stress condition, the result were in contrary with Eid (2009) in wheat the days 50% heading was reduced under drought condition.

The maximum yield under water stress was recorded for A22 (Madhur local) followed by A9 (Kazhakkuttom local), A20 (Poonkulam local), A2 (Palakkadu local).

5.2.1.2. Quality Characters

The quality characters significantly varied in all the genotypes. Protein content ranged from 1.281 mg g^{-1} to 3.358 mg g^{-1}. Protein content was varied under water stress condition when compared with normal irrigation. Similar

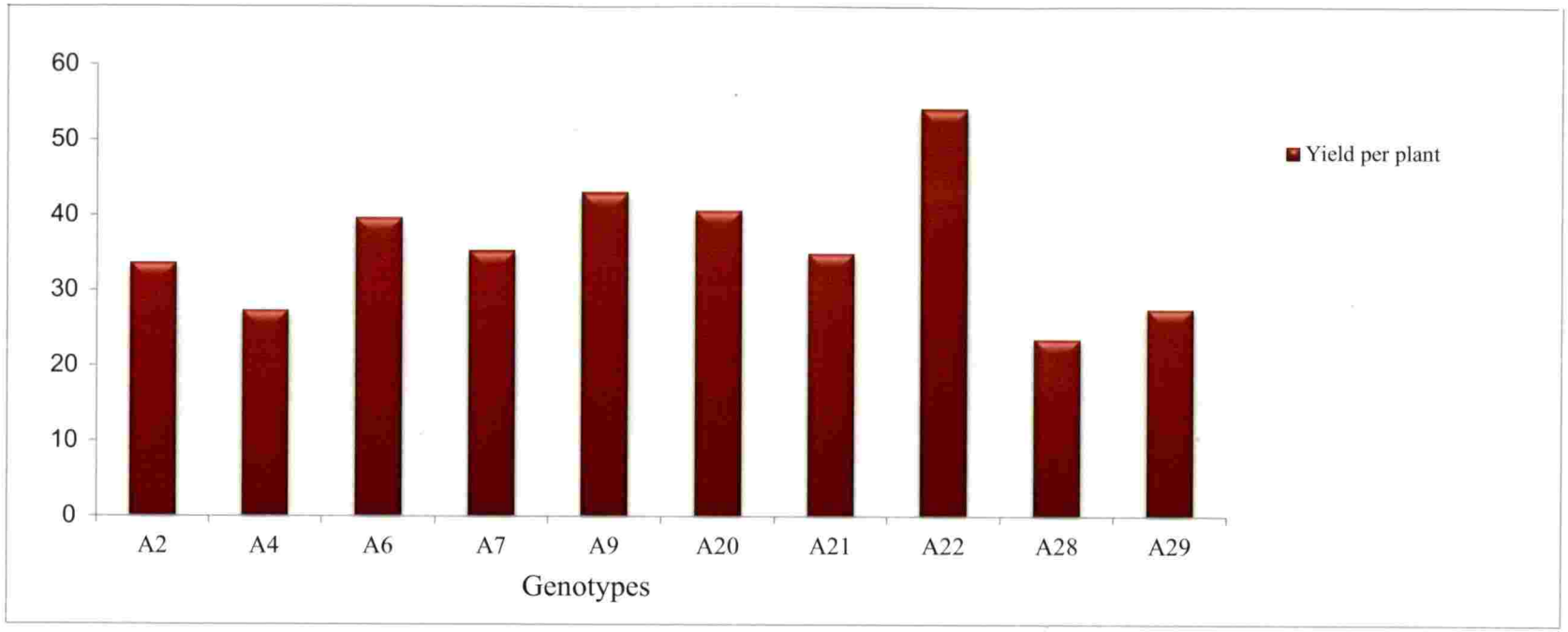


Fig. 1. Comparative mean yield performance of ten genotypes of amaranthus under water stress condition

A2 Palakkadu local
A4 Kalliyoor local
A6 Anachal local
A7 Haripad local
A9 Kazhakkuttom local
A20 Poonkulam local
A21 Aryanadu local
A22 Madhur local
A28 Ayyanthole local
A29 Kannara local

Table 14. Comparison of 10 amaranthus genotypes yield under irrigated and water stress condition.

Genotype No.	Name of the genotypes	Yield plant^{-1} (under irrigated condition)	Yield plant^{-1} (under water stress condition)	Yield reduction (%)
A22	Madhur local	125.926	54.160	57.00
A4	Kalliyoor local	125.229	27.415	78.11
A28	Ayyanthole local	116.986	23.620	79.81
A7	Haripad local	114.426	35.240	69.22
A2	Palakkadu local	109.260	33.660	69.20
A6	Anachal local	108.273	39.673	63.36
A21	Aryanadu local	106.713	34.923	67.28
A20	Poonkulam local	103.095	40.626	60.60
A9	Kazhakkuttom local	97.993	43.006	56.11
A29	Kannara local	97.923	27.662	71.76

results were obtained by Modi (2007) in amaranthus under high temperature condition.

The fibre content of amaranthus ranged from 7.627% to 14.37% which showed greatest variability in different genotypes. The results were in accordance with the results of Rajagopal *et al.* (1977) in amaranthus.

The Vitamin A content showed highest variability from 1052.48IU to 3764.66IU which showed varied quality of leaves. The oxalate and nitrate content varied from 1.63% to 2.87% and 0.027% to 1.030% under water stress condition which were higher than the results obtained by Anuja (2012a), Srivatstava *et al.* (2002). A high antinutrients production under water stress was reported the results of Carvalho (2005) in lupins. Increased production of antinutrients might be depends on the environmental variation but that can be reduced by boiling of leaves before use (Rastogi and Shukla, 2013).

5.2.1.3. Physiological Characters

Study on different physiological characters helps in understanding the stress adaptation mechanism in the plants. Low value of percentage leachate was observed in A22 (Madhur local) which was recorded highest yield and the membrane integrity was high. It might be due to the less damage of cell membrane under water stress condition. Similar results were reported by Ahmadizadeh *et al.* (2011) and Almeselmani *et al.* (2015) in wheat. Relative water content is the main indicator of water status in plants which were reduced under water stress condition for all the genotypes. These results were in accordance with results obtained by Sinclair and Ludlow (1985), Sairam *et al.* (2000), Siddique *et al.* (2000) and Almeselmani *et al.* (2015) in wheat.

Canopy temperature and proline content of leaves varied greatly under water stress condition. Accumulation of proline might be considered as a stress tolerance mechanism in plants. Similar results were reported by Slabbert and Kruger (2014) in amaranthus, Elizabeth (2017) in tomato,

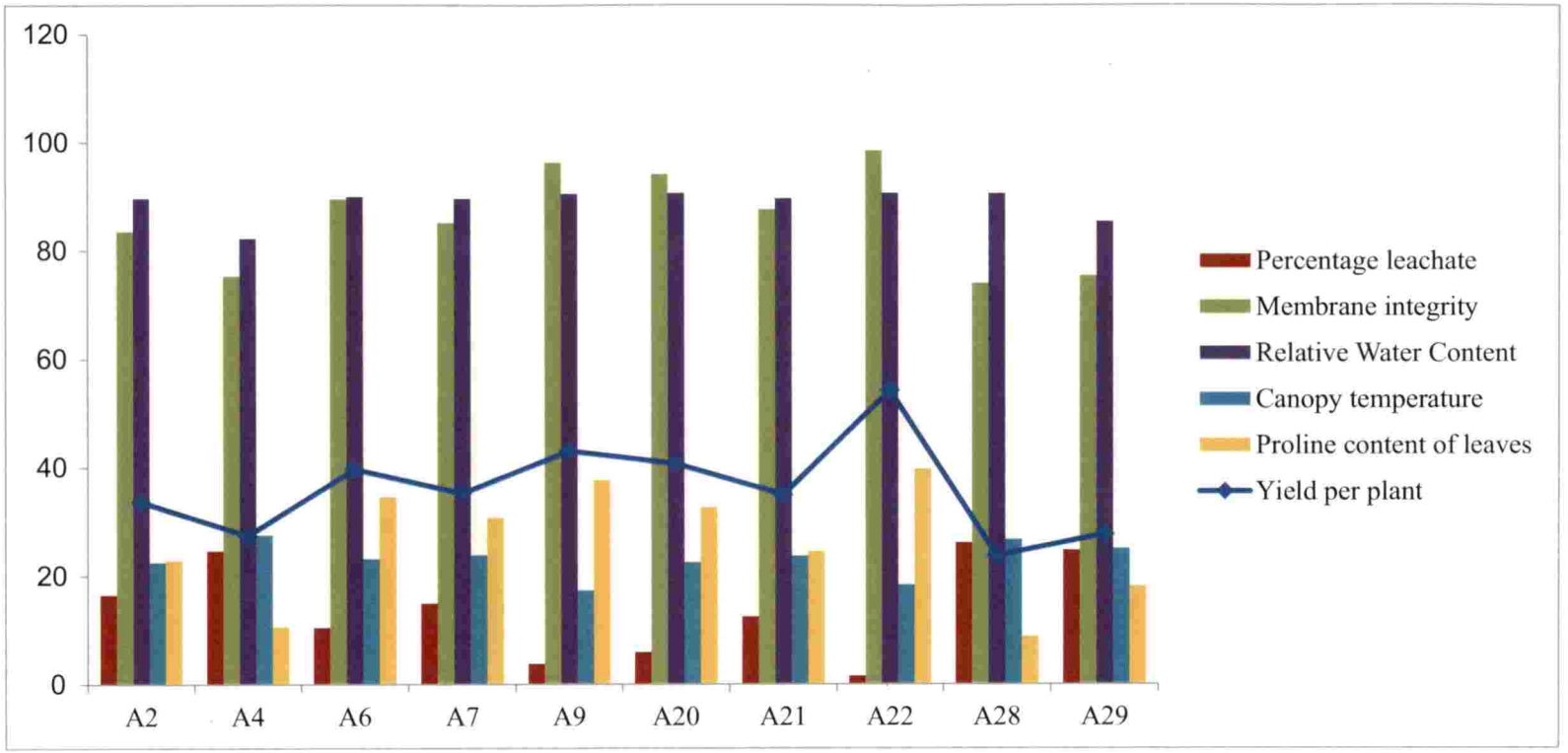


Fig.2. Comparative mean performance of genotypes of amaranthus based on yield and physiological characters contributing to water stress tolerance

A2 Palakkadu local
A4 Kalliyoor local
A6 Anachal local
A7 Haripad local
A9 Kazhakkuttom local
A20 Poonkulam local
A21 Aryanadu local
A22 Madhur local
A28 Ayyanthole local
A29 Kannara local

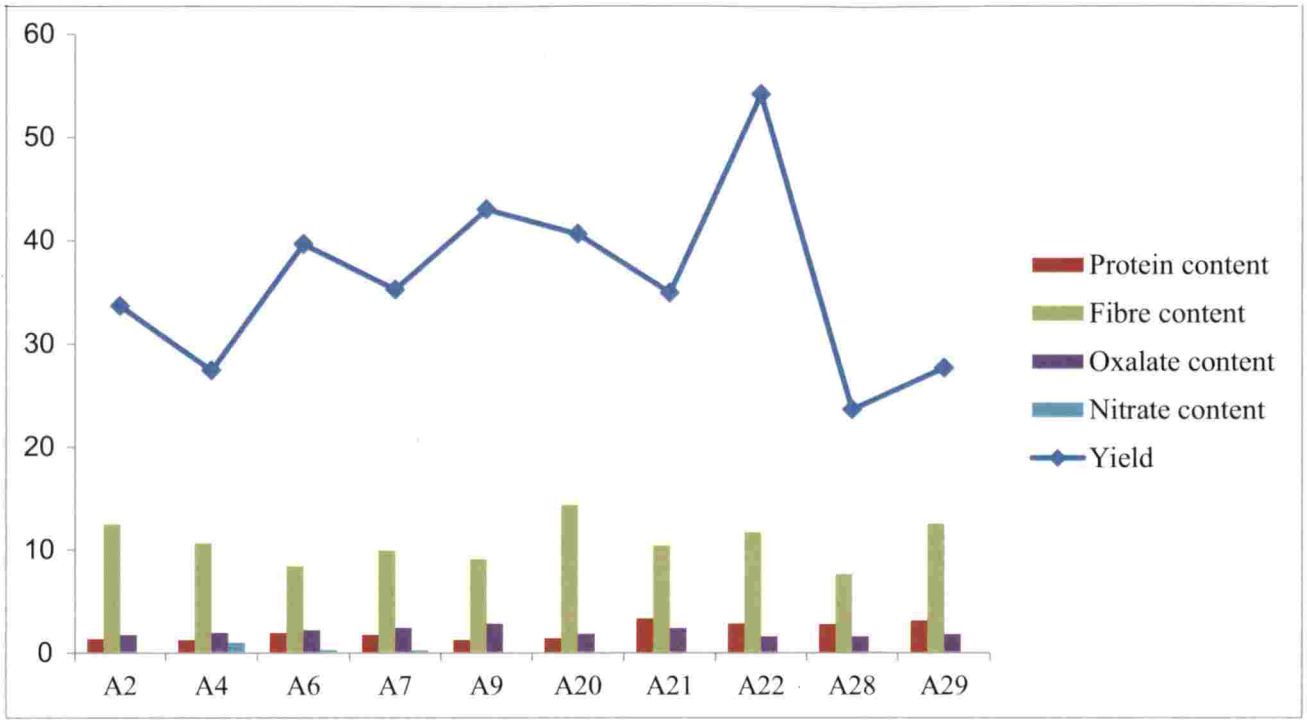


Fig.3. Comparative mean performance of genotypes of amaranthus based on yield and quality characters under water stress

A2 Palakkadu local
A4 Kalliyoor local
A6 Anachal local
A7 Haripad local
A9 Kazhakkuttom local
A20 Poonkulam local
A21 Aryanadu local
A22 Madhur local
A28 Ayyanthole local
A29 Kannara local

5.2.2. Coefficient of Variation

The variability plays a vital role in the selection and improvement of crops in any breeding programme. The exploitation of these variability results in the success of crop improvement. To understand the nature of variability present in the germplasm, the genetic parameters like genotypic coefficient of variation (PCV), phenotypic coefficient of variation (GCV), environmental coefficient of variation (ECV), heritability in broad sense (H^2_b) and genetic advance as percent of mean are estimated and the results are discussed here,

The value of genotypic coefficient of variation was smaller than phenotypic coefficient of variation, but small difference was recorded between PCV and GCV indicated that environment had less contribution towards the trait expression. Supporting evidence was given by Revanappa and Madalageri (1998) in amaranthus, Shukla *et al.* (2005) in *Amaranthus tricolor* L. Kaushik *et al.* (2011), Rani and Anitha (2011) and Chernet *et al.* (2013).

The value of genotypic coefficient of variation (GCV) ranged from 2.984 for relative water content to 41.219 for vitamin A. High value of GCV and PCV were recorded for vitamin A, number of branches, yield plant^{-1}, leaf to stem ratio, internodal length and protein content which revealed that total variation present in genotypes were contributed by genetic component. Therefore, selection could be done for these characters. These results were in accordance of the results obtained in amaranthus by Ahammed *et al.* (2012) and Yadav *et al.* (2014).

Moderate GCV and PCV was recorded for stem girth, length of leaf lamina, petiole length, leaf width, plant height, canopy temperature and fibre content which indicated that the variation present in the germplasm for these characters were moderately contributed by genetic constitution of genotypes. So, there is a greater scope for the selection of those traits for better crop improvement. Similar results were obtained by Hasan *et al.* (2013) Sarker *et al.* (2014) and Diwan (2015) in amaranthus.

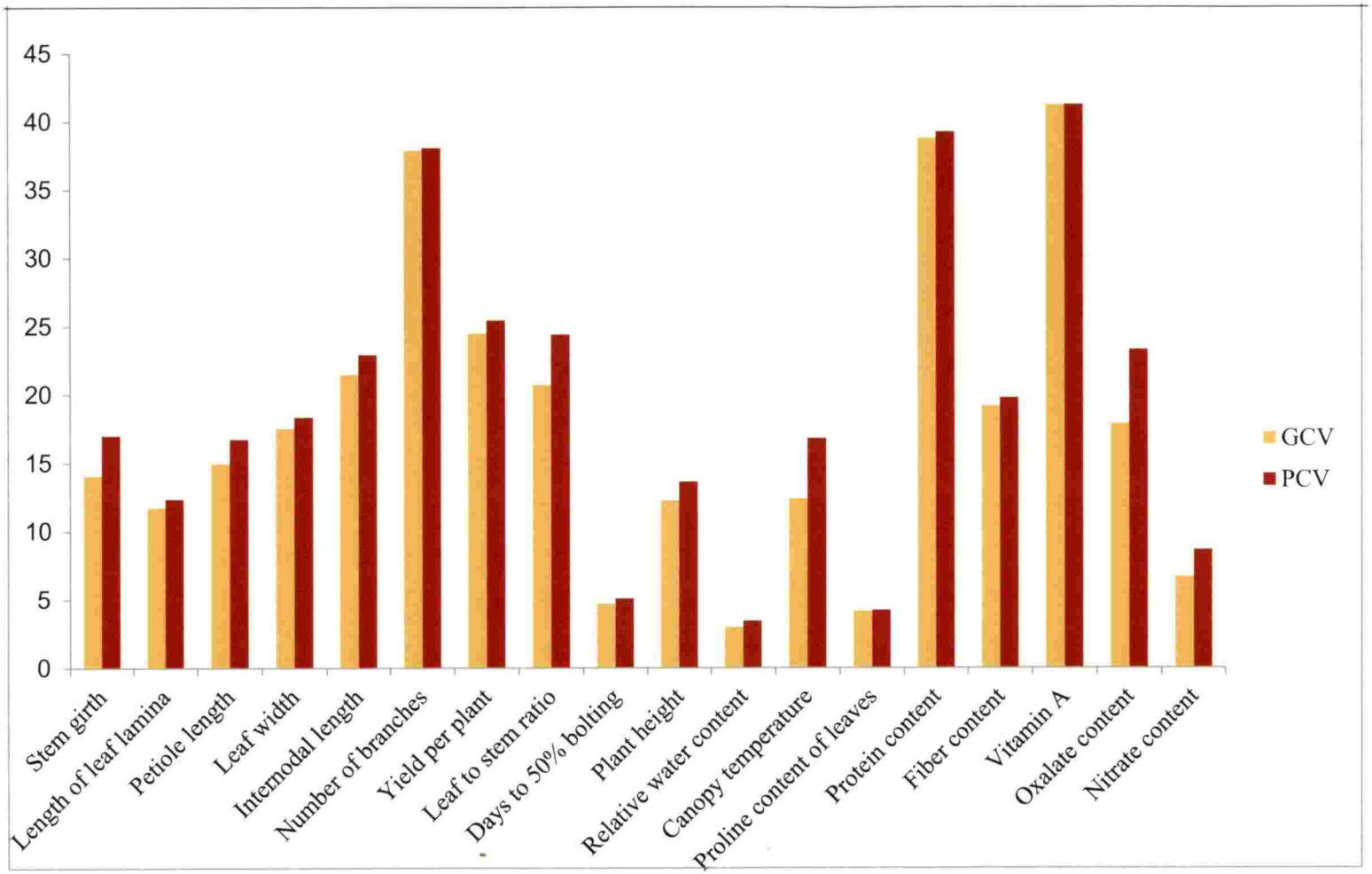


Fig. 4.GCV and PCV for the characters of amaranthus under water stress

Moderate GCV and high PCV were observed for oxalate content. Low value of GCV and PCV observed for days to 50% bolting, relative water content, proline content of leaves and nitrate content.

5.2.3. Heritability and Genetic Advance as Percentage of Mean.

Heritability is the heritable portion of the phenotypic variance of the characters. It indicates the degree at which a character is transmitted from the parent to its offspring. A high value of the heritability indicates the low influence of environment on the character and selection for the such character will be effective. Higher broad sense heritability value of the character measures the greater proportion genotypic variance on the heritable characters rather than phenotypic effect.

In the study, the heritability estimates ranged from 54.243% for canopy temperature to 99.834% for vitamin A. High heritability was obtained for stem girth, length of leaf lamina, petiole length, leaf width, internodal length, number of branches, yield plant^{-1}, leaf to stem ratio, days to 50% bolting, plant height, relative water content, proline content of leaves, protein content, fibre content, vitamin A and nitrate content. Moderate heritability was observed for canopy temperature and oxalate content.

Plant height, stem diameter, leaf to stem ratio and yield plant^{-1} showed high heritability in broad sense, in accordance with the results of Uzzman (2013) in amaranthus. This revealed that these traits were least affected by environmental interaction and selection based on the phenotypic performance would be reliable. High heritability of leaf area, leaf to stem ratio and yield plant^{-1} observed, similar results were reported by Hasan *et al.* (2013) and Jangde (2016) in amaranthus.

High heritability with high estimates of genetic gain was observed for stem girth, length of leaf lamina, petiole length, leaf width, internodal length, number of branches, yield plant^{-1}, leaf to stem ratio plant height, protein content, fibre content and vitamin A. High heritability coupled with high genetic advance for

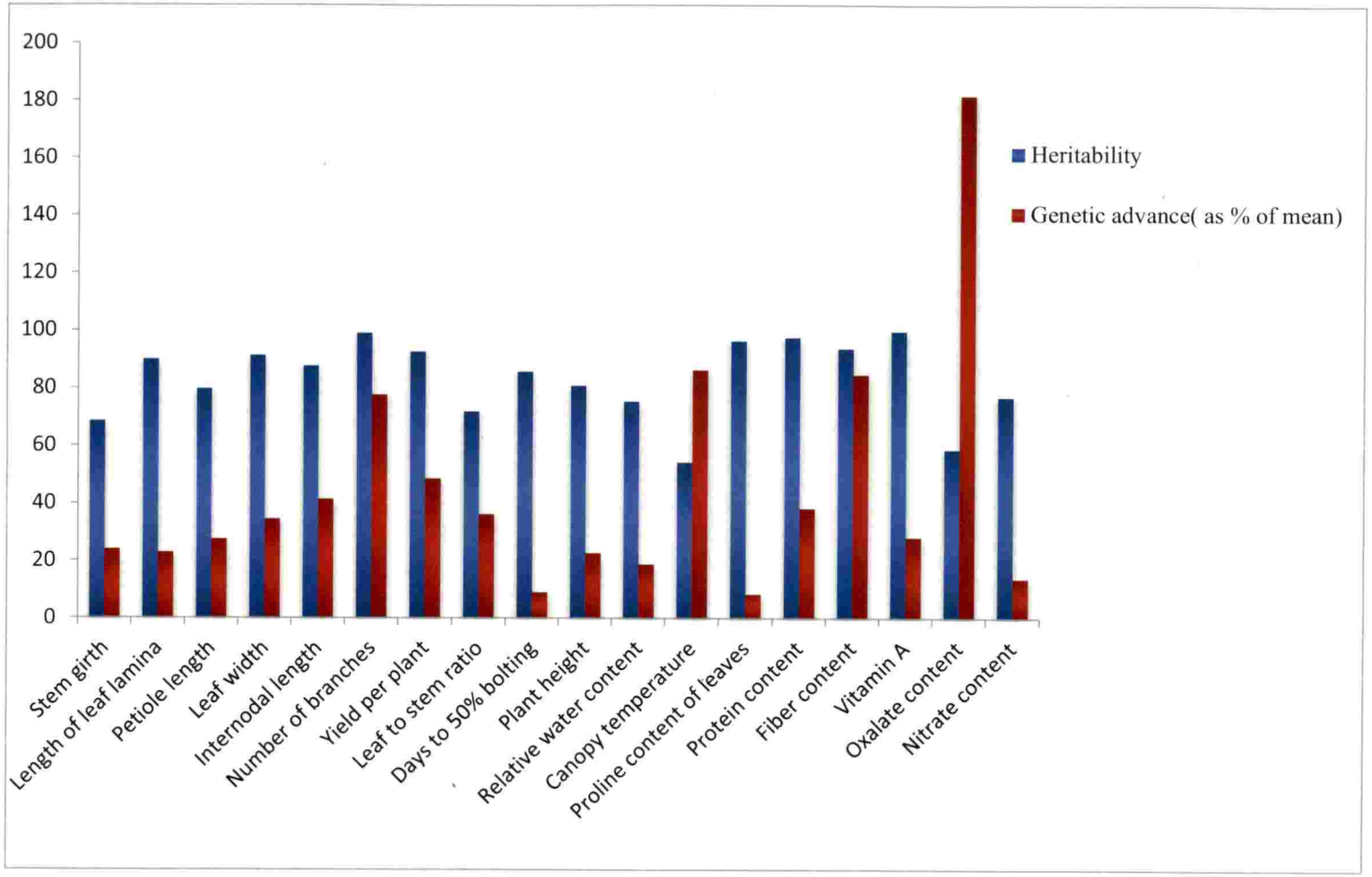


Fig. 5. Heritability and Genetic Advance for the characters of amaranthus under water stress

all biometric and quality characters were reported by Sathy (2006) and Pan *et al.* (2008) in amaranthus.

In the present study, high heritability and moderate genetic advance were recorded for relative water content and nitrate content. High heritability with low genetic advance was observed for the characters days to 50% bolting and proline content of leaves. Which indicted that even though it is highly heritable traits the improvement over mean population is less because of the presence of non-additive effects and it can be exploited through heterosis breeding. Same results were reported by Eid (2009) in wheat under water stress condition.

5.2.4. Correlation Coefficient Analysis

Correlation analysis gives an idea about interrelationship between two characters. It may be positive or negative correlation which depends on the nature of the traits. A number of biometric, quality and physiological characters were studied in the present investigation. Correlation analysis between the characters showed that genotypic correlation coefficient were higher than the respective phenotypic correlation coefficient due to the presence of environmental effect on two traits. More over the difference between phenotypic and genotypic correlation were small, which indicated the environment had a little effect on those characters.

Positive genotypic correlation is mainly occurs due to the coupling phase of linkage and the negative genotypic correlation occurs due to repulsion phase of linkage of two genes governing the traits (Salini *et al.*, 2010).

From the present investigation stem girth, length of leaf lamina, leaf width, number of branches, yield plot^{-1}, membrane integrity, relative water content, proline content of leaves and vitamin A had highest positive correlation with yield plant^{-1}. The results were accordance with Mohideen and Subramanian (1974) who reported positive correlation of leaf length with yield in amaranthus, Mohideen and Muthukrishnan (1979) reported correlation of leaf width with yield,

Varalakshi and Reddy (1997) recorded positive correlation of number of branches with yield in amaranthus and Rahman *et al.* (2005) reported high positive correlation stem diameter with yield. Comparable results were obtained by Bayoumi *et al.* (2008) for positive correlation (r=0.84) of relative water content with yield. Similar results were obtained for relative water content and proline content in tomato by Elizabeth (2017).

Proline content of leaves was significantly and positively correlated with yield plant^{-1}. These results were also obtained by Saeedipour (2013) in wheat, Slabbert and Kruger (2014) in amaranthus that proline accumulation was high in drought tolerant genotypes. Similar results were obtained by Ghiabi *et al.* (2013) in chickpea that proline content exhibited positive significant correlation with yield under water stress condition. Siddique *et al.* (2015) also quoted that accumulation of proline content may lead to better osmotic adjustment in heat tolerant faba bean genotypes. Proline accumulation can be considered as a selection criteria for stress tolerance in plants (Jaleel *et al.*, 2007). Identical results were achieved by Jaleel *et al.* (2007) in periwinkle, Hassanzadeh *et al.* (2009) in sesame and Farshadfar *et al.* (2012) in wheat.

Proline content and yield plant^{-1} were positively correlated. On contradiction with the result Parchin *et al.* (2014) reported that wheat seed yield and proline content were negatively non-significant under water stress condition. Accumulation of proline content under water deficit can be considered as drought tolerance mechanism of genotypes but could not be used as drought tolerance parameters. But, Amini *et al.* (2014) and Elizabeth (2017) suggested that proline accumulation as a trait to select drought tolerant genotypes in safflower and tomato correspondingly. In plant stress tolerance proline accumulation is found to have adaptive roles (Verbruggen and Hermans, 2008).

Relative water content showed positive significant correlation with yield plant^{-1}. The comparable results were drawn from study of Schonfeld *et al.* (1988) and Bayoumi *et al.* (2008).

Relative water content showed significant difference among the genotypes studied. The difference in ability of absorption of water from soil or ability of stomata to reduce the loss of water from the plant might be the reason for difference in RWC of cultivars under drought stress. These results were in accordance with results of Sinclair and Ludlow (1985). In wheat, increased RWC was observed in drought tolerant cultivars by Schonfeld *et al.* (1988).

A positive significant correlation was observed in membrane integrity and negative significant correlation in percentage leachate with yield plant^{-1}. A similar result for percentage leachate was reported by Bajji *et al.* (2001) in wheat. Water stress modifies the chemical composition and physical structure of the biological membrane and had direct effect on electrolyte leakage (Knowles *et al.*, 2001). The decrease in membrane integrity depends on the duration of stress and the species (Anjum *et al.*, 2011). Membrane integrity was observed highest in Madhur local (A22) which yielded maximum under water stress. The membrane integrity and percentage leachate was negatively correlated. Electrolyte leakage could be used as a predictive criterion of putative water stress tolerance in plants (Bajji *et al.*, 2001). It is reciprocal to cell membrane injury, widely used physiological index for evaluation of stress tolerance in plants (Premachandra *et al.*, 1991).

Canopy temperature was negatively correlated yield plant^{-1}. It might be due to the increase in transpiration by absorbing water from deep layer of soil. Similar result were obtained by Geundouz *et al.* (2012) in wheat that canopy temperature and grain yield had negative correlation ($r = -0.32$) under stress condition. Similar results were achieved by Hirayama *et al.* (2006) and Talebi (2011) in wheat.

Vitamin A was significantly positive correlated with yield plant^{-1}. Increase in vitamin A content under stress condition might be due to the production of antioxidants such as beta carotene which confer reduction in damage of cellular organelles from free radicals. Comparable results were obtained by Randome *et al.* (2017).

5.2.5. Path Coefficient Analysis

Genotypic correlation between yield and yield components were partitioned into direct and indirect effects and measures relative importance of the causal factor individually. Path coefficient divides the correlation coefficients into direct and indirect effects. From the genotypic correlation the highly correlated yield components like petiole length, leaf width, number of branches, yield plot^{-1}, percentage leachate, membrane integrity, proline content of leaves and vitamin A were taken as independent characters for the path coefficient analysis for better interpretation. This measures the direct and indirect contribution of independent characters on dependent character (Fig.6).

In the present study, characters like petiole length, number of branches, yield plot^{-1}, percentage leachate, proline content of leaves and vitamin A had high positive direct effect on yield. Corresponding evidence of direct positive influence of number of branches on yield plant^{-1} was reported earlier by Verma and Sarnaik (2000) in tomato under water stress. Direct effect of membrane injury on yield was reported by Rekha and Reddy (2017) in mung bean. Similar results were obtained by Elizabeth (2017) in case of proline content in tomato under water stress condition.

Characters like leaf width and membrane integrity showed a negative direct effect on yield plant $^{-1}$ and positive genotypic correlation indicated the indirect effect through the other independent variable.

All the traits included in the study explained almost all variability towards yield could be concluded from low residual effect.

The study revealed that the accumulation of proline in leaves is an important mechanism contributing to water stress tolerance in amaranthus. The promising genotypes identified in the study can be utilized further for crop improvement programmes to develop water stress tolerant varieties.

The results of the study imply that in order to select high yielding good quality amaranthus genotypes under water stress conditions, emphasis must be given on important characters like petiole length, number of branches, yield plot^{-1}, percentage leachate, membrane integrity, relative water content, proline content of leaves and vitamin A.

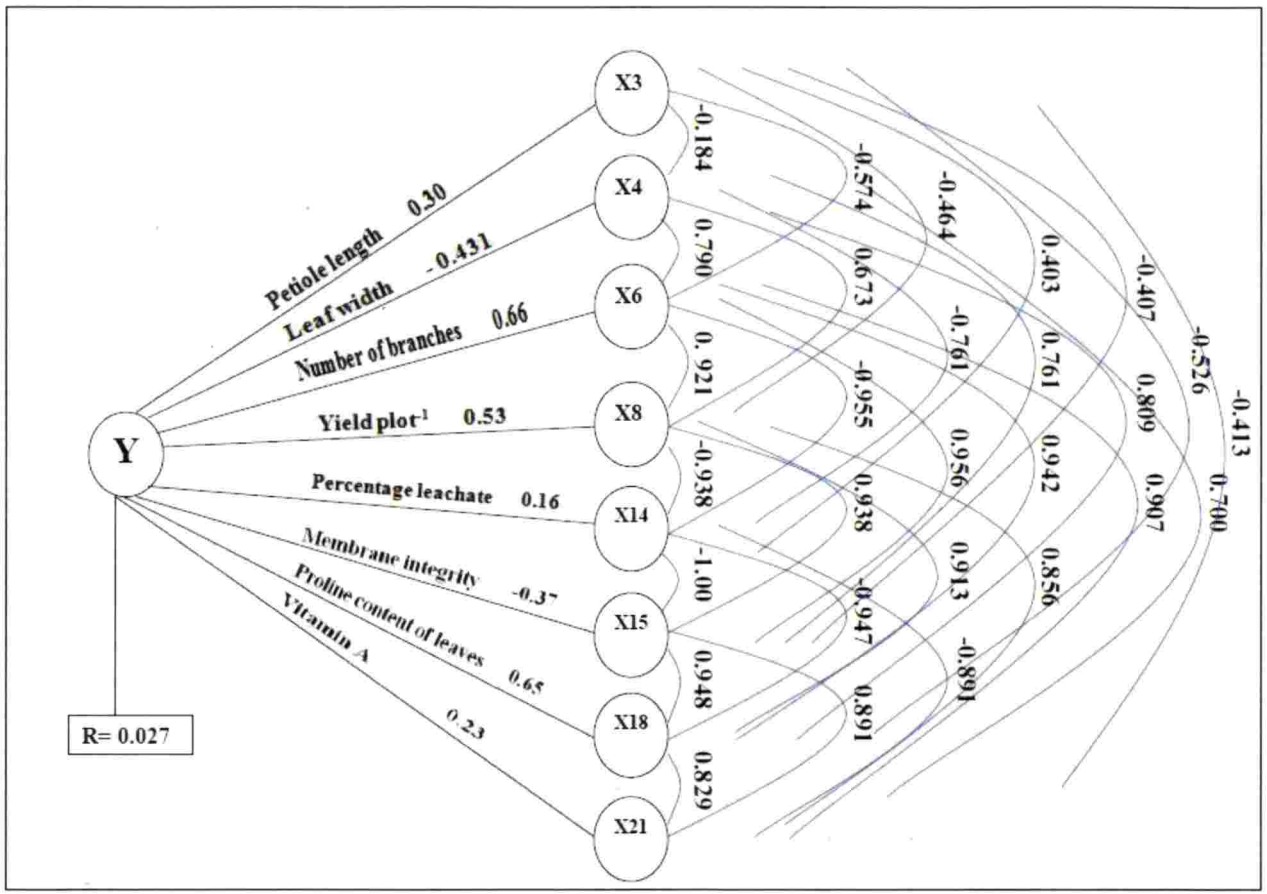


Fig. 6. Path diagram showing direct and indirect effect of different characters of amaranthus on yield

SUMMARY

6. SUMMARY

The present study on identification of water stress tolerant amaranthus genotypes (*Amaranthus tricolor*. L) with high yield and quality was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, during 2016-18 with an objective to identify the high yielding genotypes of amaranthus with good quality and tolerance to water stress.

The present investigation was conducted under two experiments. The first experiment was done with thirty genotypes of amaranthus which were available in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani and collected from other sources were evaluated in the field in a Randomized Block Design (RBD) with three replications during 2016-17. The amaranthus seedlings were raised in the nursery in protrays. Twenty five days old seedlings were transplanted to the main field with a spacing of 30 x 20 cm. A total of 20 plants were maintained in each plot and each genotype was considered as each treatment.

The thirty genotypes were morphologically described by using IBPGR descriptors for amaranthus (IBPGR, 1981). Each genotype was scored according to the scale given in the descriptors. A total of 22 characters were used for describing 30 genotypes of amaranthus. The greater variability was observed in case of plant heights, stem pubescence, leaf length, leaf width, leaf pubescence, leaf margin, prominence of leaf vein, inflorescence colour, 50% bolting, seed shape and germination rate.

From the first experiment the biometric characters of 30 geneotypes were observed and all the genotypes showed significant variation. Madhur local (A22) recorded highest yield of 125.926 g plant^{-1} followed by Kalliyoor local (A4), Ayyanthole local (A28), Haripad local (A7), Palakkadu local (A2), Anachal local (A6), Aryanadu local (A21), Poonkulam local (A20), Kazhakkuttom local (A9) and Kannara local (A29), were the high yielding 10 genotypes selected from

experiment No. 1 based on yield. These selected 10 genotypes were used as 10 treatments in experiment No. 2.

Second experiment was done with high yielding 10 genotypes selected from experiment No. 1. Twenty five days old seedlings were transplanted in to main field during November 2017 in Randomized Block Design (RBD) with three replication. Twenty plants were maintained in each plot with spacing of 30 x 20 cm. The seedlings were maintained under well irrigated condition up to 5 days after transplanting. There after irrigation was scheduled at a depth of 20 mm at 20 mm CPE (Cumulative Pan Evaporation). The genotypes were evaluated for biometric characters, quality characters and physiological characters. Statistical analysis were also carried out. Analysis of variance showed presence of significant variation in the germplasm for the characters evaluated.

The mean performance all the characters studied of 10 genotypes revealed that the genotype A22 (Madhur local) was superior in terms of yield plant^{-1} (54.160 g), yield plot^{-1} (1.083 kg), stem girth (2.577 cm), number of branches (7.527), length of leaf lamina (8.663 cm), leaf to stem ratio (1.083), membrane integrity (98.459%), relative water content (90.58%), proline content of leaves (39.672 µmoles/g), vitamin A(3764.66 IU) with lowest oxalate content (1.63%) and percentage leachate (1.5410%).

The character vitamin A recorded highest GCV (41.22%) and PCV (41.25%). High GCV and PCV were observed for internodal length, number of branches, field plant^{-1}, leaf to stem ratio, protein content and Vitamin A. High PCV for oxalate content (23.298%). Moderate PCV and GCV observed for stem girth, length of leaf lamina, petiole length, leaf width, plant height, canopy temperature, fibre content and oxalate content. Days to 50% bolting, proline content of leaves, nitrate content were recorded lowest GCV and PCV. The characters like stem girth, length of leaf lamina, petiole length, leaf width, internodal length, number of branches, yield plant^{-1}, leaf to stem ratio, plant

height, protein content, fibre content and vitamin A had high heritability with high genetic advance.

Yield plant^{-1} was significantly and positively correlated with leaf width, number of branches, yield plot^{-1}, membrane integrity, proline content of leaves and vitamin A both at genotypic and phenotypic levels. Petiole length and percentage leachate were found to be negatively correlated with yield plant^{-1}. Path analysis revealed that number of branches, yield plot^{-1} and proline content of leaves had maximum positive direct effect on yield plant^{-1}.

The selection index was calculated by on yield, quality and physiological characters which were positively correlated with yield plant^{-1}. The rank were given to each genotype according to the score obtained. The first rank was for A22 (Madhur local) followed by A9 (Kazhakkuttom local), A20 (Poonkulam local) and A2 (Palakkadu local).

The results of the present study showed that A22 (Madhur local) was superior in yield performance under water stress condition followed by the genotype A9 (Kazhakkuttom local), A20 (Poonkulam local), and A2 (Palakkadu local). The genotype A22 (Madhur local) also recorded the maximum stem girth, number of branches, length of leaf lamina, leaf to stem ratio, membrane integrity, relative water content and proline content of leaves with high vitamin A and low oxalate content. Presence of proline in the leaves might be considered as an important water stress tolerance mechanism. The genotypes identified from the study can be used further for the improvement in amaranthus to develop water stress tolerant genotypes.

REFERENCES

7. REFERENCES

Ahammed, A.U., Rahman, M.M., and Mian, M.A.K. 2012. Genetic variability and correlation in stem amaranth (*Amaranthus tricolor*). *Bangladesh J. Pl. Breed. Genet.* 25(2):25-32.

Ahmadizadeh, M., Nori, A., Shahbazi, H., and Habibpour M. 2011. Effects of drought stress on some agronomic and morphological traits of durum wheat (*Triticum durum* Desf.) landraces under greenhouse condition. *Afr. J. Biotechnol.* 10:14097-14107.

Almeselmani, M., Saud, A., Hareri, F., Nassan, M., Ammar, M.A., Kanbar, O.Z., and Al-Naseef, H. 2013. Physiological traits associated with yield improvement under rainfed condition in new wheat varieties. *Jordan J. Agric. Sci.* 9:12-22.

Almeselmani, M., Saud, A., Al-Zubi, K., Al-Ghazali, S., Hareri, F., Al-Nassan, M., Ammar, M.A., Kanbar, O.Z., Al-Naseef, H., Al-Nator, A., Al-Gazawy, A., and Da Silva, J. 2015. Evaluation of physiological traits, yield and yield components at two growth stages in 10 durum wheat lines grown under rainfed conditions in southern Syria. *Agron. Res. Moldova.* 48(2):29-49.

Amini, H., Arzani, A., and Karami, M. 2014. Effect of water deficiency on seed quality and physiological traits of different safflower genotypes. *Turkish J. Biol.* 38:271-282.

Andhini, A., Yoshida, S., Yoshida, Y., and Ohsawa, R. 2013. Amaranthus genetic resources in Indonesia: morphological and protein content assessment in comparison with worldwide amaranthus. *Genet. Resour. Crop Evol.* 60:2115–2128.

Anjum A.S., Xie, X., Wang, L., Saleem, M.F., Man, C., and Lei, W. 2011. Morphological, physiological and biochemical responses of plants to drought stress. *Afr. J. Agric. Res.* 6:2026–2032.

Anuja, S. 2012. Evaluation of amaranthus germplasm for green leaf yield (*Amaranthus spp.*). *Adv. Plant Sci.* 25(2):463-466.

Anuja, S. 2012a. Germplasm evaluation for quality attributes in amaranthus (*Amaranthus spp.*). *Adv. Plant Sci.* 25(2):443-447.

A.O.A.C. 1984. *Official and Tenative Methods of Analysis*. Association of Official Analytical Chemists, Washington D.C., p.350.

Arjunkumar. 2008. Physiological evaluation of drought tolerance in cotton (*Gossypium spp.*) genotypes. M.Sc. (Ag.) thesis, Tamil Nadu Agricultural University, 109p.

Aruna, P. 2012. Correlation and path analysis in amaranthus. *J. of Agric. Sci.* 4(3): 50-54.

Ayodele, V.I. 2000. Influence of soil water stress at different physiological stages on growth and seed yield of *amaranthus species*. *Acta Hortic.* 537:767-772.

Bajji, M., Kinet, J.M., and Lutts, S. 2001. The use of the electrolyte leakage method for assessing cell membrane stability as a water stress tolerance test in durum wheat. *Plant Growth Reg.* 00:1–10.

Bayoumi, T.Y., Eid, M.H., and Metwali, E.M. 2008. Application of physiological and biochemical indices as a screening technique for drought tolerance in wheat genotypes. *Afri. J. Biotechnol.* 7(14):2341-2352.

Burton, G.W. 1952. *Proc. 6th Int. Grassl. Cong.* 1:277-283.

Calderon, E., Gonzalez, J.M., and Bressani, R. 1991. Agronomic, physical, chemical and nutritional characteristics of fifteen amaranth varieties. *Turrialba* 41:458-464.

Campbell, T.A. and Abbott, J.A. 1982. Field evaluation of vegetable amaranth (*Amaranthus spp.*). *Hort. Sci.* 17:407-409.

Carvalho, I.S. 2005. Effect of water stress on the proximate composition and mineral contents of seeds of two lupins (*Lupines albus* and *Lupines mutabilis*). *J. Food Qual.* 28(4):1745-4557.

Celine, V. A., Girija V.K., Sreelathakumary, I., and Vahab, A.M. 2013. Selection of amaranth genotypes for resistance to *Rhizoctonia solani*. *Int. J. Veg. Sci.* 19:157-163.

Celine, V.A., Shankaran, S.S., Seema, S., Deepa, S.N., Sreelathakumary, I., and Vahab, A.M. 2007. Characterization and evaluation of vegetable amaranthus (*Amaranthus tricolor* L.) for high yield, quality and resistance to *Rhizoctonia solani*. *ISHS Acta Hortic.* 752:81

Celine, V.A., Sindhu, L., and Rajamony, L. 2011. Evaluation of vegetable amaranthus (*Amaranthus dubius* Mart. Ex Thell.), *Indian J. Hort.* 68 (1):131-135.

Chatti, D. 2016. Carbon dioxide enrichment induced drought tolerance responses in tomato (*Solanum lycopersicum*) and amaranthus (*Amaranthus bicolor*) M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur, 170p.

Chauhan, B. S. and Abugho, S. B. 2013. Effect of water stress on the growth and development of *Amaranthus spinosus*, *Leptochola chinenesis*, and rice. *Am. J. Plant Sci.* 4:989-998.

Chaves, M.M. and Oliveira M.M. 2004. Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. *J. Exp. Bot.* 55: 2365-2384.

Chernet, S., Belew, D., and Abay, F. 2013. Genetic variability and association of characters in tomato (*Solanum lycopersicum* L.) genotypes in northern Ethiopia. *Int. J. Agric. Res.* 8(2):67-76.

Dewey, D.R. and Lu, K.H. 1959. A correlation and path-coefficient analysis of components of crested wheatgrass seed production. *Agron. J.* 51:515-518.

Diwan, I.S. 2015. Genetic variability in amaranthus (*Amaranthus sp.*) germplasm. M.Sc.(Ag) thesis, college of agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, 81p.

Elizabeth, N. 2017. Evaluation tomato (*Solanum lycopersicum* L.) genotypes for yield under water stress conditions. M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur, 92p.

Eid, M.H. 2009. Estimation of heritability and genetic advance of yield traits in wheat (*Triticum aestivum* L.) under drought condition. *Int. J. Genet. Mol. Biol.* 1(7): 115-120.

Falconer, D.S. 1964. Introduction to Quantitative Genetics. Longmann, London and New York. pp. 294-300.

FAO [Food and Agriculture Organization]. 2009. *Global agriculture towards 2050.* Issues Brief. High level expert forum, Rome, 4p.

Farshadfar, E., Jalali, S., and Saeidi, M. 2012. Introduction of a new selection index for improvement of drought tolerance in common wheat (*Triticum aestivum* L.). *Eur. J. Exp. Bio.*2 (4):1181-1187.

Fuchs, M. 1990. Infrared measurement of canopy temperature and detection of plant water stress. *Theor. Appl. Climatol.* 42(4): 253-261.

Ghiabi, S., Sharafi, S., and Talebi, R. 2013. Morphophysiological and biochemical alternation responses in different chickpea (*Cicer arietinum* L.) genotypes under two constructing water regimes. *Int. J. Biosci.* 3(8):57-65.

Guendouz, A., Guessoum, S., Maamri, K., Benidir, M., and Hafsi, M. 2012. Canopy temperature efficiency as indicators for drought tolerance in durum wheat (*Triticum durum* Desf.) in semi-arid conditions. *J. Agric. Sustain.* 1(1): 23-38.

Hamid, M.M., Ahmed, N.U., and Hossain, S.M.M. 1989. Performance of some local and exotic germplasm of amaranth. *Argic. Sci. Digest* 9:202-204.

Hasan, M., Akther, C.A., and Raihan, M.S. 2013. Genetic variability, correlation and path analysis in stem amaranth (*Amaranthus tricolor* L.) genotypes. *The Agric.* 11(1):1-7.

Hassanzadeh, M., Ebadi, M., Panahyan, E., Kivi, M., Jamaati, E., and Somarin, S.H. 2009. Evaluation of drought stress on relative water content and chlorophyll content of sesame (*Sesamum indicum* L.) genotypes at early flowering stage. *Res. J. Environ. Sci.* 3:345–350.

Hemalatha, G., Sundharaiya, K., and Ponnuswamy, V. 1999. Comparative analysis of nutritive value in some leafy vegetables. *S. Indian Hortic.* 47(1-6):295.

Hirayama, M., Wada, Y., and Nemoto, H. 2006. Estimation of drought tolerance based on leaf temperature in upland rice breeding. *Breed. Sci.*56:47-54.

Hyman, G., Fujskaka, S., Jones, P., Wood, S., and Dixon, J. 2008. Strategic approaches to targeting technology generation: Assessing the coincidence of poverty and drought-prone crop production. *Agric. Syst.* 98 (1): 50-61.

IBPGR [International Board for Plant Genetic Resources]. 1981. *Genetic resources of amaranthus- a global plan of action*. International Board for Plant Genetic Resources, Rome, Italy, 62p.

IIHR [Indian Institute of Horticultural Research]. 2000. *Annual Report 1999-2000.* Indian Institute of Horticultural Research, Banglore, 181 p.

IMD [India Meteorological Department]. 2016. *Performance of North-East monsoon 2016 over Kerala*. Meteorological Centre, Thiruvananthapuram, 16p.Available:http://imdtvm.gov.in/images/cumulative%20rainfall%20for%20kerala%20-%20ne%20monsoon%202016. pdf [12 Nov. 2016].

IMD [India Meteorological Department]. 2016. *Performance of South-West monsoon 2016 over Kerala*. Meteorological Centre, Thiruvananthapuram, 16p.Available:http://imdtvm.gov.in/images/cumulative%20rainfall%20for%20kerala%20-%20sw%20monsoon%202016. pdf [12 Nov. 2016].

Jackson. R.D., Idso, S.B., Reginato, R.J., and Pinter, P.J. 1981. Canopy temperature as a crop water stress indicator. *Water Resour. Res.* 17(4):1133-1138.

Jain, J. P. 1982. *Statistical techniques in quantitative genetics.* Tata Mc Graw Hill Publishing Company, New Delhi, p.103.

Jaleel, C. A., Gopi, R., Sankar, B., Manivannan, P., Kishorekumar, A., Sridharan, R., and Panneerselvam, R. 2007. Studies on germination, seedling vigour, lipid peroxidation and proline metabolism in *Catharanthus roseus* seedlings under salt stress. *S. Afr. J. Bot.* 73:190–195.

Jaleel, C.A., Manivannan, P., Sankar, B., Kishorekumar, A., Gopi, R., Somasundaram, R., and Panneerselvam, R. 2007. Water deficit stress mitigation by calcium chloride in *Catharanthus roseus*: Effects on oxidative stress, proline metabolism and indole alkaloid accumulation. *Colloids Surfaces Biointerfaces.* 60:110–116.

Jangde, B. 2016. Variability and association studies for foliage yield components and its quality parameters in vegetable amaranthus (*Amaranthus tricolor* L.). M.Sc. (Hort) thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, 123p.

Johnson H. W., Robinson, H. F. and Comstock, R. E. 1955. Estimation of genetic and environmental variability in soybean. *Agric. J.* 47:314-318.

Joshi, V., Vijaya, M., Sireesha, K., and Latha, P. M. 2011. Characterization and preliminary evaluation of vegetable amaranth (*Amaranthus spp.*). *Veg. Sci.* 38 (2):239-240.

Kauffmann, C.S. and Gilbert, L. 1981. *Vegetable amaranth summary.* Rodale Press Inc., Emmaus, 25 p.

Kaushik, S.K., Tomar, D.S., and Dixit, A.K. 2011. Genetics of fruit yield and its contributing characters in tomato (*Solanum lycopersicon*). *J. Agri. Biotechnol. Sustain. Dev.* 3(10):209-213.

Knowles, L., Trimble, M.R., and Knowles, N.R. 2001. Phosphorus status affects postharvest respiration, membrane permeability and lipid chemistry of European seedless cucumber fruits (*Cucumis sativus* L.). *Postharvest Biol. and Technol.* 21: 179–188.

Kumar, S., Dwivedi, S. K., Singh, S. S., Jha, S. K., Lekshmy, S., Elanchezhian, R., Singh, O. N., and Bhatt, B.P. 2014. Identification of drought tolerant rice genotypes by analyzing drought tolerance indices and morpho-physiological traits. *SABRAO J. Breed. Genet.* 46(2): 217-230.

Liu, F. and Stutzel, H. 2002. Leaf water relations of vegetable amaranth (*Amaranthus spp.*) in response to soil drying. *Eur. J. Agron.* 16: 137–150.

Liu, F. and Stutzel, H. 2004. Biomass partitioning, specific leaf area, and water use efficiency of vegetable amaranth (*Amaranthus* spp.) in response to drought stress. *Sci. Hortic.* 102: 15–27.

Makus, D.J. 1984. Evaluation of amaranth as a potential green crop in the mid-south. *Hort. Sci.* 19: 881-883.

Malathy, P., Suraweera, D.D., Daundasekara, W.A.M., Nilanthi, W.D.G.P., and Wahundeniya, K.B. 2012. Determination of yielding ability, free radical scavenging activity, protein and carotenoid contents of selected genotypes of *Amaranthus tricolor*. *APCBEE Procedia* 4: 243–247.

Mathai, P.J., Ramachander, P.R., and Chandravadana, M.V. 1980. Relation between yield and some nutritive constituents in amaranthus. *S. Indian Hort.* 28: 124-125.

Middleton, K. R. 1958. A new procedure for rapid determination of nitrate and a study of the preparation of phenol- sulphonic acid reagent. *J. Appl. Chem.* 8: 505-508.

Mlakar, G.S., Bavec, M., Jakop, M., and Bavec, F. 2012. The effect of drought occurring at different growth stages on productivity of grain amaranth *Amaranthus cruentus* G6. *J. Life Sci.* 6: 283-286.

Modi, A.T. 2007. Growth temperature and plant age influence on nutritional quality of amaranthus leaves and seed germination capacity. *Water S.Afr.* 33(3):0378-4738.

Mohideen, K.M., Muthukrishnan, C.R., Shanmugavelu, K.G., Rengaswami, P., and Vadivel, E. 1983. Evaluation of grain amaranth type at Coimbatore. *S. Indian Hortic.* 31:11-14.

Mohideen, K.M., Rangaswamy, P., Mehta, V.A., Shanmughavelu, K.G., and Muthukrishnan, C.R. 1985. A note on CO 3 amaranthus. *S. Indian Hortic.* 33: 127-128.

Mohideen, M. K. and Muthukrishnan, C.R. 1979. Studies on correlation, multiple regression and path analysis as related to yield of vegetable amaranth (*Amaranthus tricolor*). In: Proceedings of second amaranth conference, Rome, Rodale Press. pp. 74-78.

Mohideen K.M. and Subramanian, A.S. 1974. Correlation studies in amaranthus. *S. Indian Hortic.* 22:132-133.

Muralikrishna, P. 2015. Management of pest and pesticide residue in vegetable amaranthus (*Amaranthus tricolor* L.). Msc. (Agri.), Kerala Agricultural University, Thrissur, 216p.

Nayyar, H. and Gupta, D. 2006. Differential sensitivity of C3 and C4 plants to water deficit stress: association with oxidative stress and antioxidants. *Environ. Exp. Bot.* 58:106-113.

Olufolaji, A.O. and Dinakin, M.J. 1988. Evaluation of yield components of selected amaranth cultivars. *Tests of Agrochemicals and Cultivars.* 9: 100-101.

Omami, E.N. and Hammes, P.S. 2006. Interactive effects of salinity and water stress on growth, leaf water relations, and gas exchange in amaranth (*Amaranthus spp.*) *N.Z. J. Crop Hortic. Sci.* 34(1):33-44.

Pan, R.S., Singh, A.K., Kumar, S., and Rai, M. 2008. Genetic variation and character association in vegetable amaranth (*Amaranthus tricolor* L.). *Veg. Sci.* 35 (1): 81-83.

Panse, V.G. and Sukhatme, P.V. 1967. Statistical Methods for Agricultural Workers (2nd Edn.), Indian Council of Agricultural Research, New Delhi. p.381.

Parchin, R.A., Najaphy, A., Shaban, M., Mohebodini, M., Vaseghi, A., Sohrabi-Babahadi, F., and Mostafaie, A. 2014. Comparing protein pattern and drought tolerant indicators as screening techniques for drought tolerance in common wheat genotypes. *Int. J. Plant Anim. Environ Sci.* 4 (2): 251-258.

Prakash, D. and Pal, M. 1991. Nutritional and antinutritional composition of vegetable and grain leaves. *J. Sci. Food Agric.* 57: 573-583.

Prasad, R., Bajpaye, N.K., Srivastava, B.P., and Srivastava, J.P. 1980. Note on the interrelationship and heritability in amaranth. *Indian J. Agric. Sci.* 50(2): 183-186.

Premachandra, G.S., Saneoka, H., Kanaya, M., and Ogata, S. 1991. Cell membrane stability and leaf surface wax content as affected by increasing water deficits in maize. *J. Exp. Bot.* 42, 167–171.

Priya, V.P. 1998. Screening amaranth genotypes (*Amaranthus spp.*) for yield, quality and resistance to biotic stress. M.Sc. (Hort) thesis, Kerala Agricultural University, Thrissur, 103p.

Priya, V.P. and Celine, V.A. 2001. Variability, heritability and genetic advance for yield, quality and biotic stress in leaf amaranthus. In: Das, M.R. (ed.), *Proceeding of the Thirteenth Kerala Science Congress,* 29-31 January 2001, Thrissur. Kerala Institute of Local Administration, Government of Kerala, pp. 363-366.

Priya, V.P., Celine, V.A., Gokulapalan, C., and Rajamony, L. 2007. Screening amaranth genotypes (*Amaranthus* spp.) for yield and resistance to leaf blight caused by *Rhizoctonia solani*, *Pl. Gene. Resour. Newsl.* 149: 1-4.

Rahman, M. M., Islam, A. K. M. A., and Hossain, S.I. 2005. Genetic variability, correlation and path analysis in amaranth (*Amaranthus tricolor* L.). *Bangladesh J. Life Sci.* 17(1): 129-134.

Rajagopal, A., Muthukrishnan, C.R., Mohideen, M. K., and Syed, S. 1977. Co.2 amaranthus an early vigorous variety. *S. Indian Hortic.* 25: 102-105.

Ramanathan, K.M. and Subbiah, K. 1983. Influence of stages of harvest on the crude protein, carotene, ascorbic acid and chlorophyll contents of amaranthus. *S. Indian Hort.* 31: 244-245.

Randome, I., Basu, S., and Pereira, A. 2017. Effect of different stress treatments on mature green tomatoes (*Solanum lycopersicum*) to enhance fruit quality. *Afr. J. Food Agric. Nutr. Dev.* 17(4): 12547-12556.

Rani, K. and Anitha, V. 2011. Studies on variability, heritability and genetic advance in tomato (*Solanum esculentum* M.). *Int. J. Bio-Resour. Stress. Manag.* 2(4):382-385.

Rastogi, A. and Shukla, S. 2013. Amaranth: A new millennium crop of nutraceutical values. *Crit. Rev. Food Sci. Nutr.* 53 (2): 109-125.

Rekha, K.S. and Reddy, D.M. 2017. Path analysis of morphological and drought related traits under water stress condition in mungbean. *Int. J. Pure App. Biosci.* 5 (2): 836-841.

Revanappa and Madalageri, B.B. 1998. Genetic variability studies regarding quantitative traits in amaranthus. *Karnataka J. Agric. Sci.* 11: 139–142.

Rudolph, A.S., Crowe, J.H., and Crowe, L.M. 1986. Effects of three stabilizing agents- proline, betaine, and trehalose- on membrane phospholipids. *Arch. Biochem. Biophys.* 245: 134-143.

Sadasivam , S. and Manickam, A. 1996. *Biochemical Methods for Agricultural Sciences*. Wiley Eastern Ltd., New Delhi, p. 246.

Saeedipour, S. 2013. Relationship of grain yield, ABA and proline accumulation in tolerant and sensitive wheat cultivars as affected by water Stress. In:

Proceedings of the National Academy of Sciences, India Section B: Biological Sciences. July-September 2013, 83(3):311–315.

Sairam, R.K., Srivastsva, G.C., and Saxena, D.C. 2000. Increased antioxidant activity under elevated temperatures: a mechanism of heat stress tolerance in wheat genotypes. *Biologia Plantarium* 43(2): 245-251.

Salini, K., Nirmalakumari, A., Muthiah, A. R., and Senthil, N. 2010. Evaluation of proso millet (*Panicum miliaceum* L.) germplasm collections. *Electr. J. Plant Breed.* 1(4): 489-499.

Samuel and Odunayo. 2017. Phenotypic evaluation of heritability, agro morphological, and yield characters of sixteen amaranthus genotypes. *Am. J. Agric. Biol. Sci.* 12(3): 113-122.

Saneoka, H., Moghaieb, R.E., Premachandra, G.S. and Fujita, K. 2004. Nitrogen nutrition and water stress effects on cell membrane stability and leaf water relations in *Agrotis palustris* Huds. *Environ. Exp. Bot.* 52(2): 131-138.

Sarker, U., Islam, T., Rabbani, G., and Oba, S. 2014. Genotypic variability for nutrient, antioxidant, yield and yield contributing traits in vegetable amaranth. *J. Food Agric. Environ.* 12(3): 168-174.

Sarker, U., Islam, M. T., Rabbani, M. G., and Oba, S. 2015. Variability, heritability and genetic association in vegetable amaranth (*Amaranthus tricolor* L.). *Spanish J. Agric. Res.* 13(2):e0702.

Sathy, S.S. 2006. Characterization and evaluation of landraces of Amaranthus (*Amaranthus spp.*). M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 113p.

Schonfeld, M.A., Johnson, R.C., Carver, B.F., and Mornhinweg, D.W. 1988. Water relations in winter wheat as drought resistant indicators. *Crop Sci.* 28: 526-531.

Selvaraj, D.G. 2004. Variability studies in amaranthus. M.Sc. (Hort.) Thesis, Tamil Nadu Agricultural University, 119p.

Shadakshari, T.V. 2010. Studies on genetic divergence and drought tolerance in soybean (*Glycine max* (L.) Merrill). M.Sc. (Ag.) thesis, Tamil Nadu Agricultural University, 120p.

Shukla, S. and Singh, S.P. 2000. Studies on genetic parameters in vegetable amaranth. *J. Genet.* 54: 133-135.

Shukla, S., Bhargava, A., Chatterjee, A., Pandey, A.C., Rastogi, A., and Kumar, A. 2010. Genetic interrelationship among nutritional and quantitative traits in the vegetable amaranth. *Crop Breed. Appl. Biotechnol.* 10: 16-22.

Shukla, S., Bhargava, A., Chatterjee, A., Srivatsava, A., and Singh, S.P. 2005. Estimates of genetic variability in vegetable amaranth (*Amaranthus tricolor*) over different cuttings. *Hort. Sci.* 32(2):60-67.

Shukla, S., Bhargava, A., Chatterjee, A., and Singh, S. P. 2004. Estimates of genetic parameters to determine variability for foliage yield and its different quantitative and qualitative traits in vegetable amaranth (*A. tricolor*). *J. Genet. Plant Breed.* 58(2): 169-176.

Siddiqui, M.H., Al-Khaishany, M. Y., Al-Qutami, M. A., Al-Whaibi M. H., Grover A., Ali, H. M., and Al-Wahib, M. S. 2015. Morphological and physiological characterization of different genotypes of faba bean under heat stress. *Saudi J. Biol. Sci.* 22:656–663.

Siddique, M.R.B., Hamid, A., and Islam, M.S. 2000. Drought stress effects on water relations of wheat. *Bot. Bull. Acad. Sinica.* 41: 35-39.

Sinclair, T.R. and Ludlow, M.M. 1985. Who taught plants thermodynamics? The unfulfilled potential of plant water potential. *Aust. J. Plant Physiol.* 12: 213-217.

Sirohi, P.S. and Sivakami, N. 1995. Vegetable amaranth varieties from Indian Agricultural Research Institute. *Indian Hort.* 40: 17-20.

Sivasubramanian, S. and Menon, M. 1973. Genotypic and phenotypic variability in rice. *Madras Agric. J.* 60:1093-1096.

Slabbert, M.M. and Kruger, G.H.J. 2014. Antioxidant enzyme activity, proline accumulation, leaf area and cell membrane stability in water stressed amaranthus leaves. *S. Afr. J. Bot.* 95: 123–128.

Sreenivasulu, N., Grimm, B., Wobus, U., and Weschke, W. 2000. Differential response of antioxidant compounds to salinity stress in salt tolerant and salt-sensitive seedlings of foxtail millet (*Setaria italica*). *Physiol. Plant* 109: 435-442.

Srivatsava, R.P. and Kumar, S. 1998. *Fruit and Vegetable Preservation-Principles and Practices*. Second edition. International Book Distributing Co., Lucknow, p. 444.

Srivastava, A., Prakash, D., and Tewari, S.K. 2002. Evaluation of neutraceutical composition of vegetable and grain amaranthus species. *J. Med. Aromat. Plant Species*. 24(4):1050-1055.

Talebi, R. 2011. Evaluation of chlorophyll content and canopy temperature as indicators for drought tolerance in durum wheat (*Triticum durum* Desf.). *Aust. J. Basic Appl. Sci.* 5: 1457-1462.

Tanner, C.B. 1963. Plant temperatures. *Agron. J.* 55: 210-211.

Teutonico, R.A. and Knorr, D. 1985. Amaranth : composition, properties and applications of a rediscovered food crop. *Food Technol.* 39: 49-60.

Uzzman, A.M.D. 2013. Morphological characterization and performance of thirty one red amaranth germplasm. M.Sc. (Hort) thesis, Bangladesh Agriculture University, Bangladesh, 56p.

Valentovic, P., Luxova, M., Kolarovic, O., and Gasparikova. 2006. Effect of osmotic stress on compatible solutes content, membrane stability and water relations in two maize cultivars. *Plant Soil Environ.* 52(4):186-191.

Varalakshmi, B. 2004. Characterization and prelimi[illegible]valuation of vegetable amaranth (*Amaranthus spp.*) germplasm [illegible]*ne. Resour. Newsl.* 137: 55-57.

Varalakshmi, B. and Reddy, P.V.V. 1994. Variability, heritability and correlation studies in vegetable amaranthus. *S. Indian Hortic.* 42:361-364.

Varalakshmi, B. and Reddy, P.V.V. 1997. Variability, heritability and correlation studies in vegetable amaranth. *Indian J. Hortic.* 54(2): 167-170.

Verbruggen, N. and Hermans, C. 2008. Proline accumulation in plants: a review. *Amino Acids*. 35: 753-759.

Verma, S.K. and Sarnaik. D.A. 2000. Path analysis of yield components in tomato (*Lycopersicon esculentum* Mill). *J. Appl. Biol.* 26(3): 242-249.

Vijayakumar, R., Shanmugavelu, K.G., and Mohideen, M. K. 1982. Studies on growth and development of certain types of amaranthus. *S. Indian Hortic.* 30(4): 256-260.

Wang, W., Vinocur, B., and Altman, A. 2003. Plant responses to drought and extreme temperatures: Towards genetic engineering for stress tolerance. *Planta.* 218 (1): 1-14.

Yadav, R., Rana, J.C., and Ranjan, J.K. 2014. Analysis of variability parameters for morphological and agronomical traits in grain amaranth (*Amaranthus sp.*) genotypes. *The Bioscan.* 9(4): 1661-1665.

Zlatev, Z. and Lidon, F.C. 2012. An overview on drought induced changes in plant growth, water relations and photosynthesis. *Emirates J. Food Agric.* 24(1):57-72.

Identification of water stress tolerant amaranthus genotypes (*Amaranthus tricolor* L.) with high yield and quality

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ABSTRACT

The present study entitled "Identification of water stress tolerant amaranthus genotypes (*Amaranthus tricolor* L.) with high yield and quality" was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2016-2018, with an objective to identify high yielding genotypes of amaranthus with good quality and tolerance to water stress.

The study was conducted under two experiments. In the first experiment thirty accessions of *Amaranthus tricolor* L. available in the Department of Plant Breeding and Genetics and collected from other sources were evaluated for yield under field condition and morphologically described using IBPGR descriptor for the amaranthus. Madhur local (A22) recorded highest yield plant^{-1}(125.926g) followed by Kalliyoor local (A4), Ayyanthole local (A28), Haripad local (A7), Palakkadu local (A2), Anachal local (A6), Aryanadu local (A21), Poonkulam local (A20), Kazhakkuttom local (A9) and Kannara local (A29). In the second experiment, these ten genotypes selected based on the yield were evaluated in a Randomized Block Design (RBD) with three replications during November 2017-December 2017. Water stress was imposed after 5 days of irrigation to water holding capacity to the transplanted seedlings by scheduling the irrigation at a depth of 20mm at 20mm CPE (Cumulative Pan Evaporation). Analysis of variance was calculated for all the characters under study and was found to be significant for all the genotypes evaluated.

The mean performance of the genotypes for the characters were studied. The maximum yield was observed for the genotype A22 (Madhur local) followed by the genotype A9 (Kazhakkuttom local), genotype A20 (Poonkulam local) and genotype A2 (Palakkadu local) and the minimum yield was recorded for genotype A4 (Kalliyoor local). The genotype A22 (Madhur local) showed the highest mean values for stem girth, number of branches, length of leaf lamina, leaf to stem ratio, membrane integrity, relative water content, proline content of leaves, vitamin A and lowest oxalate content.

The character Vitamin A content registered the highest GCV (41.22%) and PCV (41.25%). High heritability coupled with high genetic advance was observed for leaf width, number of branches, yield plant^{-1}, protein content, fibre content and vitamin A. The yield plant^{-1}was found to be significantly and positively correlated with leaf width, number of branches, yield plot^{-1}, membrane integrity, proline content of leaves and vitamin A both at genotypic and phenotypic levels. Petiole length and percentage leachate were found to be negatively correlated with yield plant^{-1}. Path analysis revealed that number of branches, yield plot^{-1}and proline content of leaves had the maximum positive direct effect on yield plant^{-1}.

The results of the present study showed that genotype A22 (Madhur local) was superior in yield performance under water stress condition followed by the genotype A9 (Kazhakkuttom local), genotype A20 (Poonkulam local) and the genotype A2 (Palakkadu local). The genotype A22 (Madhur local) also recorded the maximum stem girth, number of branches, length of leaf lamina, leaf to stem ratio, membrane integrity, relative water content and proline content of leaves with high Vitamin A and low oxalate content. Presence of proline in the leaves might be considered as an important water stress tolerance mechanism.

APPENDICES

Appendix 1

Amaranthus Descriptor (IBPGR, 1981)

1. PLANT, STEM, LEAF AND ROOT CHARACTERS

a. Growth habit

1. Erect
2. Prostrate

b. Plant height at flowering, in cm

1. Less than 30
2. 30-45
3. 46-60
4. More than 60

c. Branching index

1. No branches
2. Few branches, all near the base of the stem
3. Many branches, all near the base of the stem
4. Branches all among the stem

d. Stem pubescence

0. None
3. Low
7. Conspicuous

e. Stem pigmentation

1. Green
2. Purple or pink

f. Spines in the leaf axile

0. Absent
+. Present

g. Leaf length(measured in cm on 6^{th} or 8^{th} leaf)

1. Less than 5
3. 5-10

5. 11 and above

h. Leaf width(measured in cm on 6th or 8th leaf)

1. Less than 5

3. 5-10

6. 11-16

i. Leaf pubescence

0. None

3. Low

5. Conspicuous

j. Leaf pigmentation

1. Entire lamina purple or pink
2. Basal area pigmented
3. Central spot
4. Two stripes(v- shaped)
5. One stripe(v- shaped)
6. Margin and vein pigmented
7. One pale green or chlorotic stripe on normal green
8. Normal green
9. Dark green
10. Other(specify)

k. Leaf shape

1. Lanceolate
2. Elliptical
3. Cuneate
4. Obovate
5. Ovatainate
6. Rhombic
7. Oval
8. Other(specify)

l. Leaf margin

1. Entire

2. Crenate
3. Undulated
4. Other(specify)

m. Prominence of leaf veins

1. Smooth
2. Rugose (veins prominent)

n. Petiole pigmentation

1. Green
2. Dark green
3. Purple
4. Dark purple

o. Root type

1. Tap root
2. Fleshy root

2. INFLORESCENCE CHARACTERS

a. Presence of axillary inflorescence

0. Absent
+. Present

b. Inflorescence colour

1. Yellow
2. Green
3. Pink
4. Red
5. Other(specify)

3. SEED CHARACTERS

a. Seed colour

1. Pale colour
2. Pink

3. Red
4. Brown
5. Black

b. Seed coat type

1. Translucent
2. Opaque

c. **Seed shape**

1. Round
2. Ellipsoid or Ovoid

4. PRELIMINARY YIELD EVALUATION

a. Germination rate

1. Rapid(less than 2 days)
2. Slow(2-7 days)
3. Very slow(more than 7 days)
4. Irregular

b. Days to 50% bolting

1. 30-45 days
2. 46-60 days
3. 61-75 days