

Genetic Analysis of Cultivar Response to Dry Weather Induced Stress Conditions in Tea (*Camellia Sinensis* (L.) O. Kuntze)

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ABSTRACT

Variable responses to dry weather induced abiotic stress conditions were studied in a unique tea breeding stock derived from diverse parental material. Broad sense heritability of the response traits was estimated under stress conditions. Stress susceptibility index (SSI) and yield advantage of the breeding stock were determined based on highly heritable traits. Significant genotypic variance was observed in the average shoot density per plucking round and in the average active shoot fresh weight and dry weight. Broad sense heritability estimates were substantially high for the traits and was in the range of 0.59 to 0.64. Highly heritable traits identified herein, can be utilized as reliable selection criteria to identify genotypes superior in yield under stress conditions. Active shoot dry weight measurements under favorable and stress conditions revealed four distinct cultivar responses. Stable progeny lines that produced high active shoot dry weights even under stress conditions and those that demonstrated seasonal effects comparative to the standard cultivar TRI 2025 were identified based on the results. None of the progeny lines were found to have yield advantage over standard cultivar (TRI 2025) under the stress conditions based either on active shoot dry weight or on average shoot density per plucking round. The information is highly useful in developing resistance to dry weather induced stress conditions in tea cultivars *via* recurrent breeding programs in future.

Keywords: Tea (*Camellia sinensis* (L.) O. Kuntze), broad sense heritability, stress susceptibility, yield advantage

INTRODUCTION

Sri Lanka markets over 300 million kg of tea (*Camellia sinensis* (L.) O. Kuntze) annually and is among the largest tea exporters in the world. Earning 15% of the national agricultural GDP tea industry continues as an economically important, vibrant local industry. Abiotic stress, especially drought is identified as a major environmental factor that curtails crop

production across the globe. Tea being a rain-fed crop, the yield is greatly influenced by environment effects. Drought inflicts irreparable losses in tea in the form of yield loss, bush debilitation and death imposing restrictions on productivity and sustainability of the tea plantations (Stephans and Carr, 1989; Barua, 1989; Wijeratne *et al.*, 2007).

Tea yield is a complex multi-component character, determined by simultaneous action of the shoot population density, shoot weight and growth rate. Shoot density accounts for 80% of the yield variability in tea whereas shoot weight accounts for more than 22% - 27% (Wijeratne, 1996). All those parameters are strongly weather related (Stephans and Carr 1989, Stephens and Carr 1990, Fordham, 1970, Fordham and Palmer-Jones, 1977, Tanton, 1992; Stephens and Carr, 1994; Wijeratne, 1996). Physiological response of drought stress in tea has been previously studied in two of the commercial cultivars, TRI 2025, which is known to be a drought tolerant and TRI 2023, a drought susceptible cultivar (Wijeratne, 1996). The author did not observe any cultivar variation but seasonal variation in the yield components. Similar observations have been made in the Kenyan germplasm (Magambo and Waithika, 1983; Kanayama and Wachira, 2004).

Genetic improvement of crops especially for quantitative traits requires reliable estimates on magnitude, type of genetic variability and heritability of corresponding traits to develop economically feasible, effective breeding schemes and selection criteria. Heritability determines the extent to which improvement is possible through selection (Falconer and Whyatt, 1981). High heritability of traits indicates high probability of inheritance of superior phenotypes from parents to offspring and less influence of the external environment on the phenotypes. Importantly such traits can be subjected to early selection in hybrid breeding programs. Information on highly heritable traits can be utilized in all three stages of crop improvement *viz.* (1) assembly or creation of pool of variable germplasm, (2) selection of superior individuals from the pool, and (3) utilization of the selected individuals to create a superior variety. However, the estimates apply specifically to the germplasm pool and the environments sampled. Heritability estimates as high as 0.93 for shoot dry weight has been reported in a previous study (Pool, 1982). The same author has observed relatively low estimates, 0.17 and 0.34, for heritability of yield and shoots density.

This paper describes studies conducted to identify performance of a selected tea breeding stock under dry weather induced abiotic stress conditions and the heritability of such response traits.

MATERIALS AND METHODS

Yield components of tea were studied in progenies developed by crossing highly diverse parents. The parental sources included introductions (ASM 4/10), estate selections (TRI 777, CY 9; N 2, TC 10) and high potential commercial tea cultivars of the TRI 2000 series including TRI 2024, TRI 2023, TRI 2025, and TRI 2026 capturing range of different parental sources available for hybridization programs. Fifty five different progeny lines were studied. The study was conducted from June to December 2008 at St. Coombs, Talawakele (Lat. 6° 54' N, Long. 80° 42' E, 1382 m amsl; average rainfall 144.5 mm, average number of sunshine hours 4.9, mean air temperature 24.3 °C). Data gathered during August (Rainfall 79 mm, sunshine hrs 4.2, mean air temperature 22.4 °C) and November (Rainfall 161 mm, sunshine hrs 4.7, mean air temperature 24.2 °C) were used in the analysis. Those two months were later confirmed as the prominent lean and rush crop periods respectively referring to the yield records of St. Coombs Estate.

Existing cultivar evaluation trials in the plant breeding program, TRISL were utilized for the purpose. The trials were laid out in complete randomized design with 2 replicates. Vegetatively propagated material was used in replications. Each progeny line/ genotype was represented by 24 vegetatively propagated bushes planted at recommended spacing. The experimental design was a 2 factor factorial having progeny lines (55 levels) and environmental conditions (2 levels), stressed and non-stressed or favorable. Average values of the yield components per plucking round during August and November were studied by two-way analysis of variance (ANOVA) using PROC GLM of SAS (SAS Inst., Inc., N.C.).

Ten out performing individual bushes were plucked regularly at weekly intervals per each of the 55 different progeny lines. Center of the plucking surface of the bushes was plucked by laying out a quadrant (30 cm x 30 cm). Yield components including total shoot counts, active shoot counts, dormant (Banji) shoot counts, were collected. Fresh and dry weights of the total shoots, active shoots and banji shoots were recorded separately. The monthly averages of all the yield components were calculated.

Broad sense heritability of yield components was estimated under stress conditions (August). The experimental model was $y_{ij} = \mu + \tau_i + \varepsilon_{ij}$ where $i = 1, 2, 3, \dots, 12$, and $j = 1, 2, 3, \dots, n$. Y_{ij} is the phenotypic value of individuals, τ_i is the variability due to the effect of genotype (between genotype variability) and ε_{ij} is the random error (variability within genotypes or among the vegetatively propagated material). n is the number of different progeny lines. Broad sense heritability (h^2) of the yield components was estimated as

the ratio of variance between genotypes (σ_b^2) to variance between genotypes (σ_b^2) plus variance among the vegetatively propagated material (σ_w^2); $h^2 = (\sigma_b^2) / (\sigma_b^2 + \sigma_w^2)$.

Stress susceptibility index (SSI) of the different genotypes were determined based on measurements made in August and November

$$SSI = \{1 - (DW_s/DW_{ns})\} / (1 - D)$$

Where DW_s = mean yield component of the progeny lines under stress/August, DW_{ns} = mean yield component of the progeny lines under non stress/November, and D is the ratio of the overall mean of all cultivars under stress to the overall mean of all cultivars under non-stress conditions. Highly heritable traits were further studied to determine hybrid performance or yield advantage over the standard cultivar, TRI 2025, under stress and non stress conditions.

RESULTS AND DISCUSSION

Monthly average values of the different yield components are given in Table 1. The analysis of variance revealed statistically significant seasonal ($p \leq 0.0001$, CV = 32.81) and genotypic ($p = 0.05$, CV = 32.81) variability in the average shoot density per plucking round. No statistically significant variation was observed among the genotypes in the active and banji shoot production. However, acute decrease in the average active and banji shoot fresh weights and dry weights occurred during August dry period among the genotypes. No genotypic variability was noted in either banji shoot fresh weight ($p = 0.74$, CV = 17.20) or in dry weight ($p = 0.80$, CV = 21.37). However the seasonal effect was statistically significant on both parameters (fresh weight: $p \leq 0.001$, CV = 17.20; dry weight: $p \leq 0.001$, CV = 21.37). The genotypic and the seasonal effects on active shoot fresh weight (genotypic: $p = 0.01$, CV = 22.53 and seasonal: $p = 0.008$, CV = 22.53) and dry weights (genotypic $p = 0.002$, CV = 26.28 and seasonal $p \leq 0.001$, CV = 26.28) were statistically significant. The genotypic seasonal interaction effect was also significantly high for active shoot fresh weight ($p \leq 0.02$, CV = 22.53) and dry weight ($p = 0.008$, CV = 26.28).

The variance between genotypes reached a highly significant level compared to the between replicate (clonal material) variance in the yield components shoot density, active shoot fresh weights and dry weights. The phenotypic and genotypic variance components and the broad sense heritability estimates for the traits are presented in Table 2. Broad sense heritability estimates were substantially high for all the 3 traits and was in the range of 0.59 to 0.64.

Table 1. Average per pluck yield components of the 18 different families

Family	August							November					
	% Active shoots	% Banji shoots	At. sh. fresh wt (g)	At. sh. dry wt (g)	B. sh. fresh wt(g)	B. sh. dry wt (g)	% Active shoots	% Banji shoots	At. sh. fresh wt (g)	At. sh. dry wt (g)	B. sh. fresh wt(g)	B. sh. dry wt (g)	
2025 CY9	15.08	84.92	0.57	0.10	0.62	0.15	15.96	84.04	0.58	0.13	0.81	0.20	
2026 2023	15.09	84.91	0.70	0.14	0.70	0.15	10.70	89.30	0.43	0.11	0.83	0.19	
2024 N2	15.24	84.76	0.63	0.13	0.72	0.15	23.91	76.09	0.85	0.20	0.92	0.24	
TC9	2024	19.33	80.67	0.82	0.09	0.66	0.19	41.67	58.33	0.73	0.16	0.80	0.19
N2	2024	19.55	80.45	0.64	0.11	0.60	0.13	33.44	66.56	0.79	0.18	0.85	0.19
CY9	ASM	21.00	79.00	0.76	0.17	0.67	0.14	19.14	80.86	0.81	0.16	0.87	0.19
N2	2026	21.32	78.68	0.64	0.13	0.63	0.13	27.63	72.37	0.68	0.15	0.78	0.18
CY9	2025	23.02	76.98	0.64	0.13	0.61	0.14	33.27	66.73	0.77	0.18	0.84	0.19
777	2026	23.43	76.57	0.65	0.13	0.67	0.12	21.35	78.65	0.75	0.17	0.83	0.19
2023	2026	24.38	75.62	0.70	0.14	0.74	0.22	24.86	75.14	0.65	0.15	0.82	0.19
2026	777	25.30	74.70	0.74	0.16	0.65	0.11	29.73	70.27	0.71	0.16	0.80	0.19
2020	2025	26.71	73.29	0.69	0.15	0.64	0.14	30.72	69.28	0.91	0.20	0.97	0.22
777	CY9	29.72	70.28	0.69	0.15	0.67	0.16	40.42	59.58	0.66	0.15	0.83	0.19
N2	N2	32.32	67.68	0.56	0.13	0.66	0.13	26.87	73.13	0.62	0.14	0.84	0.19
ASM													
4/10	2024	37.54	62.46	0.66	0.14	0.66	0.15	33.57	66.43	0.85	0.21	0.89	0.21
ASM													
2026	4/10	39.71	60.29	0.57	0.13	0.72	0.15	29.16	70.84	0.82	0.19	0.79	0.21
Average		24.30	75.70	0.67	0.13	0.67	0.15	27.65	72.35	0.73	0.16	0.84	0.20

At. sh. fresh wt: active shoot fresh weight

At. sh. dry wt : active shoot dry weight

B. sh. fresh wt: banji shoot fresh weight

B. sh. dry wt: banji shoot dry weight

Table 2. Broad sense heritability of shoot density, active shoot fresh weight and dry weight estimates under stress condition

Trait	Genotypic variability	Total variability	Broad sense heritability
Shoot density	0.64	1.06	0.59
Active shoot fresh weight	0.04	0.07	0.62
Active shoot dry weight	0.01	0.01	0.64

Four distinct patterns of cultivar response curves could be identified (Figure 1) viz. (1) highly stable progeny lines that have comparatively high active shoot dry weight represented by TRI 4027 and TRI 4038; (2) highly stable progeny lines that have comparatively low active shoot dry weight represented by TRI 4023, TRI 4069, and TRI 4088 (3) progeny lines that show seasonal variation comparative to TRI 2025 represented by effect TRI 4004, TRI 4052, TRI 4063, TRI 4047, TRI 4077 and TRI 4056 and (4) the remaining progeny lines that show substantially high level of seasonal variation compared to TRI 2025.

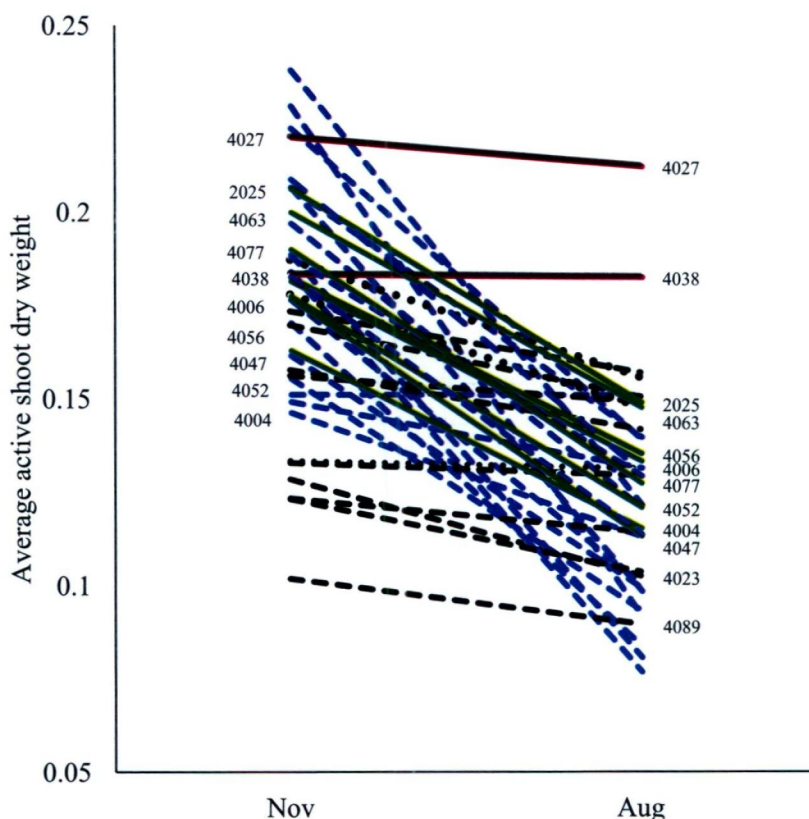


Figure 1. Cultivar response during favourable (November) and stress (August) conditions. The 4 cultivar response patterns are indicated as: (1) red solid line - stable progeny lines having high active shoot dry weights; (2) dark dotted lines - stable progeny lines having low active active shoot dry weights; (3) green solid lines - progeny lines that demonstrate seasonal variation comparative to the standard cultivar TRI 2025 and (4) dotted blue lines - progeny lines that demonstrate substantially high seasonal variation compared to the standard cultivar TRI 2025

SSI estimates based on active shoot dry weights are illustrated in the Figure 2. Notably low SSI values obtained for TRI 4027 and TRI 4038 was an interesting finding and probably a result of the stable response of the progeny lines throughout the seasons producing active shoots with high dry weights. The results revealed 3 progeny lines, TRI 4057, TRI 4012 and TRI 4086 having negative estimate of SSI. The average active shoot dry weight of those progeny lines was increased during August compared to November.

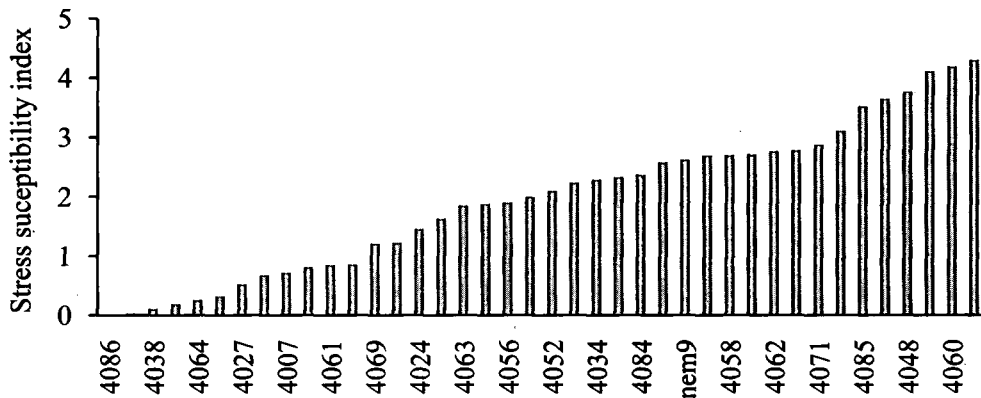


Figure 2. Stress susceptibility indices of the test accessions

None of the progeny lines was found to express significant yield advantage over TRI 2025 under stress conditions ($P = 0.09$, $CV = 28.44$) based on either active shoot dry weights or on average shoot density.

The observations made available herein on a wider germplasm of different origins are in evidence for the acute effect of drought stress on the yield components. The significant level of genetic variation and heritability of the traits verified in the breeding stock warrants direct selection of the material to incorporate in clonal breeding programs for further improvements. It was evident from the results that the traits shoot density, active shoot fresh weights and dry weight were highly heritable in the germplasm the studied, providing prospects to select and manipulate the traits in crop improvement programs. The traits shoot density, and active shoot dry weights which have direct and strong correlation with tea yield and productivity (Wijeratne, 1996), were also noticed to be acutely influenced by stress conditions. Positive plant response of the traits under stress conditions would therefore increase bush performance despite the presence of stress conditions. Since the traits can also be easily measured with relatively high precision there are high prospects to utilize them as reliable selection criteria to identify genotypes superior in yield under stress conditions.

Since the marketable product of tea is in the form of dried leaves dry matter production is an important aspect in tea cultivar development. Cultivar that give high economic yields produce higher amounts of dry matter than low yielders and have highest shoot/root and leaf/root ratios (Ng'etich and Stephens, 2001; Magambo and Waithika, 1983). Thus progeny lines capable of producing more dry matter under stress conditions would out-perform those that have genetically less capacity to do so. Presence of heritable diversity of the traits and the high magnitude of heritability estimates is a strong basis and motivation to develop practical breeding schemes and selection criteria for crop improvement purposes.

TRI 2025 is a genetically stable cultivar (Wickramaratne, 1981) which is known to be tolerant to drought (Wijeratne, 1996). A unique cluster of progeny lines were identified which were less susceptible or having tolerance to drought/ abiotic stress compared to TRI 2025. The findings need verification and further evaluation on the resistance mechanisms. Yet the material is of high value to be utilized in resistance breeding programs and to develop further knowledge on drought resistance and response in the tea plant.

Abiotic stress conditions especially drought is a complex phenomenon governed by several pseudo-climatic phenomenon acting simultaneously. Therefore, performance evaluations under different drought stress conditions vary to large extents. Screening for drought resistance need long term and multi-environment selection. However, regular addition of known drought resistance traits into the breeding stock during breeding programs can have benefits by eventually building up of resistance. Similar efforts have been successfully implemented in several plantation tree crops including coffee, coconut and Eucalyptus through intense recurrent breeding schemes (Baudouin et al., 1997). The observations recorded herein are of significant practical importance and emanates future research prospects to develop abiotic stress resistance in tea.

CONCLUSIONS

Out of six traits studied, broad sense heritability estimates were substantially high for shoot density, fresh and dry weights of active shoots revealing high prospects in utilizing them as reliable selection criteria to identify genotypes superior in yield under stress conditions. Measurements of dry weights of active shoots during favorable and stress conditions revealed four distinct cultivar responses. Two of the progeny lines TRI 4027 and TRI 4038 demonstrated high active shoot dry weights compared to the standard cultivar TRI 2025, that remained stable even under stress conditions. None of the progeny lines were found to have yield advantage over the known standard cultivar (TRI 2025)

under stress conditions based either on active shoot dry weight or on average shoot density per plucking round.

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