EEFECT OF GENOTYPE BY ENVIRONMENT INTERACTION ON TEA (*CAMELLIA SINENSIS* L. (O.) KUNTZE) YIELD AND QUALITY IN SELECTED AREAS OF TANZANIA

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EXTENDED ABSTRACT

The study on response of thirty-one (31) improved tea (*Camellia sinensis* L. (O). Kuntze) genotypes to environment variation and drip irrigation levels were conducted for tea yield and yield components. In same study, five genotypes were assessed on stability and adaptability for tea quality. A Complete Randomized Block Design with 3-replicates was adopted. Yield responses to drip irrigation were evaluated using five drip-irrigations (I_0 to I_4) levels. High genetic × environment interaction was evident among tea genotypes for yield and shoot density traits, implied potential to choose genotypes for these traits. Thus, new developed or introduced improved tea genotypes should be evaluated at different environments for identification of genotype specific locations. In view of locations, Ngwazi was identified most potential for yield, while Ilenge was prospective for shoot density production. Genotypes TRIT 201/43 (4) and TRIT 201/55 (8) were promising for yield in high tea performing environments. TRFK 12/19 (2), TRIT 201/47 (6), TRFK 31/8 (20) and TRFK 6/8 (30) were suitable for low yield performing environments. The genotypes exhibited above average means ($x>\overline{x}$) with average response ($\beta i \approx 1.0$), were stable ($S^2d_i = 0$) with high reliability response ($R^2_i \geq 70\%$). Genotypes TRIT 201/43 (4), TRIT 201/73 (9) and TRFK 303/577 (19) were promising both for yield and shoot density at high and low performing environments. TRIT 201/16 expressed higher proportion of catechins components, while TRIT 201/43 (4) was stable and accumulated higher TC. Genotypes varied in response to drip irrigation levels, with TRFK 303/577 (19) presenting higher yield at higher drip irrigation (I_4 =100%) treatment. This can be commercialized in tea areas where water for irrigation is not a constraint. Similarly, due to higher yield performance at no-drip irrigation (I_0) treatment, TRIT 201/43 (4) and TRFK 303/259 (18) were considered promising under rain-fed tea depended areas. Higher shoot density and

yield were recorded during 2014/15 and 2015/16 respectively. Yield and shoot density expressed significantly positive correlations with WUE.

Key words: *Stability, adaptability, environments, Catechins, drip irrigation*.

DECLARATION

I, Solomon William Msomba, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any institution.

_____ _____

Solomon William Msomba Date

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The above declaration is confirmed by;

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Professor Shazia O. W. M Reuben Date

(Supervisor)

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Professor Cornel Rweyemamu Date

(Supervisor)

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DEDICATION

To our gifted daughters Tulinagwe and Ikupa, my blessed and committed wife, Dr Given,

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LIST OF ABBREVIATIONS AND SYMBOLS

$1 - \beta_i$	Deviation of Regression Coefficient from Unit
1.°C	Degrees Celsius
ACHAR	African Centre for Health of Aquatic Resources
AEO	Agriculture Extension Officer
AMMI	Additive main effects and multiplicative interaction
ANOVA	Analysis of Variance
ANR	Anthocyanidin reductase
ANS	Anthocyanidin reductase
AOM	Agriculture Operation Manager
A_{std}	Peak Area of the Standard
C	Catechin
CAFF	Caffeine
CRBD	Complete Randomized Block Design
C_{std}	Concentration of Standard
D.f	Degrees of freedom
DFR	Dihydroflavonol 4-reductace
DMRT	Duncan Multiple Range Test
$E_{1...3}$	Environments
ECG	Epicatechin gallate
EDTA	Ethylene diamine tetra acetic acid
EGC	Epigallate Catechin
EGCG	Epigallocatechin gallate
ET	Evapotranspiration

F3’5’H	Flavonoid 3’5’-hydroxylase
F3’H	Flavonoid 3’hydroxylase
GA	Gallic Acid
HPLC	High Performance Liquid Chromatograph
I	Irrigation
ISO	International Standards Organization
JRA	Joint Regression Analysis
KTC	Kibena Tea Company
MS	Mean square
MTRS	Marikitanda Tea Research Station
NTRS	Ngwazi Tea Research Station
OP	Open Pollinated
PAL	Phenylalanine Ammonia –Lyase
PCA	Principle Component Analysis
PPO	Polyphenol oxidase
R^2_i	Coefficient of Determination
RF	Response Factor
$\mathbf{S^2_{di}}$	Variance of deviation from regression
SHD	Shoot density
SUA	Sokoine University of Agriculture
SWD	Soil Water Deficit
TC	Total Catechin
TRFCA	Tea Research Foundation of Central Africa
TRFK	Tea Research Foundation of Kenya
TRIT	Tea Research Institute of Tanzania
WATCO	Wakulima Tea Company

Wg	Stomata Conductance
WUE	Water Use Efficiency
β_i	Regression Coefficient

CHAPTER ONE

1.0 INTRODUCTION

Tea (*Camellia sinensis* L. Kuntze) is an important non-alcoholic beverage crop that contributes substantial foreign income in all tea producing countries. In Tanzania, for example, tea generated 65 million USD during 2017/18. Tea crop employs over 50 000 households, especially the smallholders (Techno Serve, 2006) and it is ranked fifth among key cash crops in the country. Tea belongs to family *Theacea*, genus: *Camellia* and species: *sinensis.* The plant is diploid (2n = 30; x = 15), out-crossing and highly heterozygous. Wight (1962) recognized three cultivated tea types namely; *Camellia sinensis* var. *sinensis* or the 'China' type; *C. sinensis* var. *assamica* (Masters) or the 'Assam' type and *C. sinensis* var. *lasiocalyx* (Planch M.S) or the 'cambod' type.

Tea growers in Tanzania have long been depended on seedling tea planting materials from Kenya and Malawi for production of processed tea (Carr *et al.,* 1992). Until 2003 over 60% of the tea farms in Tanzania were predominantly growing seedling teas (Mizambwa, 2003). Seedling tea cultivars are genetically heterogeneous, low yielding with low response to most agro-inputs (Owour *et al.,* 2011). Such predominant seedling tea may have contributed to reported low tea performance in Tanzania (TRIT, 2000); especially during the 4^{th} or 5^{th} year after field establishment (Kivambe, A. Pers. comm.). Use of introduced tea genotypes without verification on their suitability in target environments is likely to be additional cause for reported yield decline during 4^{th} or 5^{th} year after establishment (Wachira *et al.,* 2002; Owour *et al.,* 2011).

The tea growing areas in Tanzania vary (Mlingano, 2008; Carr, 2012). The weather in the southern highlands particularly in Mufindi and Njombe districts is cool and dry. However,

Rungwe District experiences relatively an even weather throughout the year (high precipitation and temperature). At the northern (Usambara Mountains) and around Lake Victoria, on average the weather is wet throughout the year causing variation which affects tea growth, yield and quality (Carr, 2012). Stress such as drought is reported to affect tea productivity through restriction of shoot growth especially in the southern highlands. The yield loss of up to 25% made tea is reported (Mathews and Stephens, 1998). This necessitate for need to identify drought tolerant, high yielding and quality, stable and more adaptable tea cultivars (Wachira *et al.,* 2002). Also, water conserving irrigation techniques may be necessary to mitigate drought stress on tea crop (Kigalu *et al*., 2008). Such variations in growing conditions demands for the need to evaluate new locally developed or introduced tea genotypes in diverse environments to determine the effect of G × E interactions for tea productivity in the country.

1.1 Literature Review

1.1.1 Stability and adaptability of tea genotypes for yield in diverse environments

There are distinct differences in tea growing environments of Tanzania (Mlingano, 2008; Carr, 2012); causing variation in tea yield performance among locations. Such fluctuations are referred to genotype × environment interactions (GEI) (Kamunya *et al.*, 2013; Khan *et al.,* 2014). The GEI dictates the need to identify appropriate environmental conditions to recommend productive genotypes (Sing *et al.,* 1995). Gonçalves *et al.* (2003), defined GEI as the differential genotypic response to changing environmental conditions. GEI is described to complicate genotype selection process (Khan *et al.,* 2014), yet it provides the basis for selection of suitable genotypes for specific or wider adaptability (Kamunya *et al.*, 2013).

The presence of GEI determine the need to test new genotypes in multi-environment trials (METs) to identify stable and wide adaptable high yielding genotypes (Lúquez *et al.*,

2002). Suitable genotypes are associated with high yields and consistent performance in diverse environments (Gauch *et al.,* 2008). A genotype associated with high mean yields and consistent performance in diverse environments measures wider adaptability (Khan *et al.,* 2014); while, association of high mean yield, a unit regression coefficient (β_1 =1.0) and minimum variance of deviation from regression (S^2d_i = 0) define a stable genotype (Eberhart and Russell, 1966).

Significant shoot density and shoot mass × environment interactions are reported in clonal tea genotypes (Wachira *et al.,* 1990). Sing *et al.* (1995) reported significantly high genotype × environment interactions effect on clonal over seedling teas; therefore, implied existence of variations between clonal and seedling tea genotypes. Thus, there is necessity to evaluate in diverse environments. The significant genotype × environment interactions of seasons and genotypes underscore the need to evaluate clonal and seedling teas over seasons. Several stability procedures are proposed, but, the coefficient regression and joint regression analysis is most widely used (Rocha *et al.,* 2005).

In Tanzania, yield stability and adaptability on tea are reported from a regional study (Kamunya *et al*., 2013). Results indicated yields at each location were affected by within and between year fluctuations due to effect of weather factors. However, studies on effects of genotype × environment interaction on tea yield and yield components in Tanzania are very scanty. Therefore, these marks an appropriate time to confirm developed or introduced tea genotypes in selected varied environments to identify productive ones on yield and yield components, stability and wider adaptability attributes for growers' adoption.

1.1.2 Assessment of quality attributes for tea genotypes grown in diverse environments

Tea quality is a polygenically controlled trait; directly or indirectly influenced by various traits (Kamunya *et al.,* 2010) and environments (Babu *et al.*, 2004). Total polyphenol contents (TPC) are most important group compounds especially catechin contents (CC) in tea. The catechins are water-soluble, colourless substances which impart bitter and astringent characteristics of green tea quality (Bharadwaz and Bhattacharjee, 2012). The TPC and CC in harvested tea shoots are in the range of 27% to 30% and 3% to 30% (on the dry wt. basis), respectively (Cherotich *et al.,* 2013). The importance of TPC and CC is based on their health benefits, their ability to control diseases associated with reactive oxygen species including; Cancer, Cardiovascular, Neurodegenerative diseases and HIV (Cheruiyot, 2008; Anesini *et al.,* 2008).

Tea chemical compositions are influenced by factors such as; genetic make-up, climate and soils (Wright, 2005; Cherotich *et al.,* 2013); causing variations in tea qualities. The TPC is also reported to vary with geographical origin of leaf and type of soils (Owour *et al.,* 2011); catechins are reported to increase with altitude in dried leaf (Muthumuni *et al.,* 2013). Seasonal variations affect black tea quality, while cold seasons slow down shoot growth causing low made tea yield but high black tea quality (Wright, 2005; Owour *et al.*, 2011). Warm seasons impart faster tea growth which influence high made tea yield, but low black tea quality (Wright, 2005).

Proper cultivar evaluation is vital to quantify the TPC and CC and estimate quality of black tea in diverse environments. The quality of dried greenleaf is estimated using TPC and CC based on strongly and positive correlation with tea quality in diverse environments

(Liang *et al.,* 2003). The methods ferric thiocyanate (Anesini *et al.,* 2008) and spectrophotometer procedures (Maung, 2012) effectively quantifies TPC and CC in black tea. The TPC and CC quality correlation, ability to discriminate genotypes based on geographical origin and diversity facilitates selection of genotypes associated with black tea quality. Mutuku *et al.* (2016) noted some tea clones are more stable and less susceptible to variation in biomolecules composition due to differences in environmental conditions. The growing conditions are changing quite fast demanding the tea industry to improve tea quality productivity. Therefore, there is a need to evaluate newly developed or introduced tea genotypes in diverse environments over seasons to identify stable and wide adaptable genotypes on important biomolecules such as phenolics and Catechins for improved tea quality productivity.

1.1.3 Yield responses of tea genotypes to differential drip irrigation levels

Inadequate water availability for irrigation can limit tea growth and production. To increase and improve tea productivity; availability of water, particularly in areas with limited supplies has to be used effectively. Carr (2012) described the cause for uneven water distribution and wastage in tea to include; poor design, excessively wide sprinkler spacing and adverse effect of wind. Under limited water resource, Möller and Weatherhead (2007) tea growers have opted for centre-pivot or drip irrigation as one of the best alternatives.

The southern highland produces almost 70% of the annual made tea in the country. However, the area experiences 6 to 7 months of extended dry period which greatly affects tea production. Mathews and Stephens (1998) reported a loss of up to 25% made tea due to drought stress. This demands for drought tolerant, more adaptable cultivars (Wachira *et al.,* 2002) with high response to irrigation (Kigalu *et al.,* 2008; Carr, 2012). According to

Burgess (1992) in terms of yield different tea genotypes vary with irrigation levels. Carr (2012) summarized studies based on several line-source irrigations; Clone S15/10, a drought sensitive genotype has been identified under sprinkler water sources.

The critical potential SWD for annual yields for young and mature tea varied between 50mm and 200 – 300mm depending on age of the tea genotype. The value of drip irrigation on tea has been associated with higher yields with greater savings in water, energy and labour than overhead method (Kigalu *et al.,* 2008). Such benefits emphasize the importance to evaluate developed/outsourced tea genotypes and identify which may be responsive to drip irrigation. Identified superior tea genotypes may be recommended for adoption by large and small scale tea growers. The genotypes under study have yet to be evaluated using any of the two irrigation methods. The present study will evaluate 29 developed/outsourced genotypes to establish their responses to demanded differential drip irrigation among tea growers in the country.

1.2 Problem Statement and Justification

Until 1971, tea growers in Tanzania depended largely on seedling plants for processed tea. Besides, they imported planting materials from within East and Central African regions (Carr *et al.,* 1992). A large proportion of the introduced tea materials were adopted even without verifying for their location suitability (Wachira *et al.,* 2002; Owour *et al.,* 2011). Growers hoped that genotypes will maintain productivity irrespective of where it is grown. But, such assumption has not always yielded desired results (Wachira *et al.,* 2002; Owour *et al.,* 2011). Lack of initiatives to evaluate/re-evaluate new developed/imported genotypes led to adoption of potentially unproductive genotypes. Therefore, change in climate, use of genetically unverified genotypes in target areas and dependence on low performing

seedling planting materials may have contributed to reported low tea productivity in Tanzania (TRIT, 2000; Kivambe, A. personal communication, 2012).

In Tanzania, the effect of GEI on tea yield is reported from the East African regional trial (Kamunya *et al.,* 2013). However, there are inadequate comparable studies on tea yield and yield components for newly developed/imported genotypes in diverse representative environments in the country. This takes into account that tea is grown in diverse environments where conditions such as soil types and climate factors vary (Mlingano, 2008; Carr, 2012); causing significant variation in yield and black tea quality. Both yield and made tea quality are not well maximized through evaluation of new developed/imported tea genotypes that would lead to selection of stable cultivars for specific or wider adaptability.

Quality of black tea in Tanzania has frequently been judged as plain, thus fetching low price (Techno Serve, 2006). This has probably been due to more reliance on seedling teas and introduced but not verified genotypes which lead to lower yield performance (Carr *et al.,* 1992). This imparts severe effect to growers, especially to over 30 000 smallholders in Tanzania whom tea farming is their main stay. The changing environmental conditions, expansion of tea to new agro-ecologies coupled with use of unverified new tea cultivars in diverse environments; may have had an attribute to low tea performance. Therefore, it is vital to conduct rigorous studies on effect of the GEI on new developed/introduced genotypes to maximize yield and quality attributes to improve tea productivity. In view of this, the present studies will evaluate new developed/introduced genotypes to establish stability and adaptability for improved yield and quality attributes in diverse environments of Tanzania.

1.3 Objectives

1.3.1 Overall objective

To address the understanding on the stability and adaptability of developed or introduced tea genotypes for improved yield and quality productivity in selected environments of Tanzania.

1.3.2 Specific objectives

i. To assess improved tea genotypes to diverse environments for stability, adaptability of yield and yield components in Tanzania.
ii. To evaluate new developed or introduced tea genotypes on quality stability and adaptability.
iii. To determine the optimum irrigation regime on tea yield, shoot density and water use efficiency in drought prone areas of Tanzania.

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CHAPTER TWO

2.0 Genotype by Environment Interaction of Tea (*Camellia sinensis* (L.) O. Kuntze) Genotypes in Selected Growing Areas of Tanzania

2.1 Abstract

In Tanzania, tea (*Camellia sinensis* L. (O.) Kuntze) is grown in diverse environments ranging from different elevations, climatic and edaphic (i.e. physical, chemical, and biological soil properties) conditions. Such variation in growing conditions affects both yield and yield components such as shoot density. Thirty-one (31) improved tea genotypes were evaluated for two seasons at Ngwazi, Marikitanda and Ilenge locations. The objective was to assess tea genotypes to diverse environments on stability and adaptability of yield and yield components in Tanzania. Complete Randomized Block Design (CRBD) was adopted in 3 replicates. The G × L and L × S were significant for yield and change in genotypic ranks was evident during both seasons. The location main effect considerably influenced the expression of yield and shoot density traits. Higher yield and shoot density was recorded in 2014/15 and 2015/16 seasons respectively. Ngwazi and Ilenge locations were considered most potential for tea yield and shoot density respectively. The mean shoot density and β_i (r = 0.61**) was significantly positively associated, but significantly negatively correlated with 1 - β_i (r = 0.63**). The β_i and 1- β_i (r = -1.0**) had perfect significant negative association for yield, but expressed near-perfect significantly negative association (r = -0.99**) with shoot density. Positive correlation was evident among tested environments for both traits. Genotypes TRIT 201/43 (4) and TRIT 201/55 (8) were promising for high performing environments. Genotype TRFK 303/577 (19) was potential both for yield and shoot density traits. Due to

expression of high yield and shoot density potentiality with high stability, genotype TRIT 201/43 may be considered for commercialization especially in high tea yield performing environments.

Key words: *genotype × environment interaction, stability and adaptability parameters*.

2.2 Introduction

2.2.1 Background information

Tea (*Camellia sinensis*) economically is an important non-alcoholic beverage produced worldwide. In Tanzania tea is frequently ranked between 4th and 5th as an important cash crop after coffee, cotton, cashew-nuts and tobacco. The annual made tea production is estimated at 35.6 metric tons from a total of 22 924.8 hectares (Tea Board of Tanzania, 2015). The crop employs over 50 000 households mainly the smallholders' community. Directly or indirectly, over 2 million households' benefits from the tea industry (Techno Serve, 2006). The crop is practised by three growers' categories that includes the smallholders (over 30 000), imminent medium growers (23) and large estates (34-companies). Smallholder tea growers produces over 9.8-ton annual tea from 9 495 hectares; while, the imminent medium growers and large estates produce over 22-ton annual made tea from 12 868 hectares. In 2013, Tanzania produced a total of 32.0-ton annual made tea; which generated over 65 million USD (Tea Board of Tanzania, 2018). The tea growing environments in Tanzania vary. The weather in the Southern Highlands is prominently a uni-modal rainfall pattern followed by cool period (June - August) and a dry spell of up to six or seven months (May-November). This affects tea performance through restricted tea shoot growth rates and yield (Carr, 2012). The Northern part experiences a bimodal rainfall pattern with two short dry seasons i.e. hot (December - March) and cool dry (May or October) seasons. Short rains (*Vuli*) fall in November, while, the long rains (*Masika*) occur from April to May, averaging 1500mm (Mafuru *et al*., 1999).

The Lake Victoria basin (LVB), experiences bimodal rainfall pattern with short rains (*vuli*) (October-December) and long rains (*Masika*) (March-April). The dry season is expected from June to September. To the northern and Lake Victoria Basin, the rainfall pattern is of variable intensity and duration, limiting tea yields (Carr *et al.*, 1988). Soils are described as very deep, well drained and acidic (pH: 4.0 – 5.5) (Carr *et al.*, 1988). This causes interaction between the grown tea genotypes and environments in which they are practised affecting tea growth and yield (Carr, 2012; Makola, 2013) and quality (Owour *et al.*, 2011).

The interaction i.e. genotype × environment (GEI) is defined as the differential phenotypic response of genotypes to changes in environmental conditions (Tolessa *et al.*, 2013). Due to this interaction, there is a need to better understand the way genotypes interact across the tea growing areas in Tanzania. This may be through determination of yield stability and genotype response patterns (adaptability) across environments. The way superior tea genotypes are selected and recommended in selected new target environments also needs to be improved.

Several statistical methods are adopted to determine stability and adaptability of crop genotypes (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Pinthus, 1978). Due to its simplicity and easy applicability of information on adaptive response to locations, the joint regression analysis (JRA) is adopted as most popular method for stability analysis (Rea and Veira, 2002).

The previous regional studies on Genotype × Environmental Interaction (GEI) trials, reported significant ($p \leq 0.05$) differences among Tanzanian tea growing environments,

indicating different genotypes perform differently in diverse sites (Ngwazi, Katoke and Maruku) (Kamunya *et al*., 2011). With regards to yield variations attributable to sites, Ngwazi and Ilenge locations were reported the most suitable for tea growing environments in Tanzania (Kamunya *et al*., 2011).

On average, the realized *versus* expected tea yield in Tanzania stands at 1.5t/ha to 2.2t/ha for smallholders (TBT, 2015). Such a gap is probably caused by multiple factors including diversity of tea growing environments (GEI) (Carr, 2012). Such environmental variations are explained to greatly affect tea yield and quality (Wachira *et al.,* 2002; Kamunya *et al.,* 2012; Makola, 2013). Therefore, efforts are needed to develop improved high yielding, stable and widely adaptable tea genotypes to suit Tanzania tea growing environment.

The future tea productivity is likely to suffer due to climate change effect. According to Kamau (2008), areas once considered potential for tea production are gradually turning into unsuitable for tea production. More specifically on tea crop, less evenly distributed rainfall with prolonged dry periods are expected. Rainfall which is likely to damage tea bushes and erode top soils may be on the increase. Frost is increasingly becoming problematic especially in higher tea growing area. Across Tanzania, high variability in rainfall pattern is predicted. Predictions reveals the expected decrease of 5 – 15% and increase of 5 – 45% of rainfall in areas under uni-modal and bimodal patterns respectively (Mattee *et al.*, 2015). Occurrence of such extreme conditions is likely to affect crop productivity. To sustain tea growers, it is suggested to develop effective agronomic adaptation measures including accessibility to stable and widely adaptable tea cultivars.

In the Tanzanian tea industry, there has been inadequate studies on tea genetic stability and adaptability with respect to yield and yield components such as shoot density.

Therefore, the objective of the study was to examine newly developed tea genotypes over a range of environments and assess yield, stability and adaptability under diverse environments in the country.

2.3 Objectives

To address the understanding on the stability and adaptability of developed or introduced tea genotypes for improved yield and quality productivity in selected environments of Tanzania.

2.3.1 Specific objective

To assess improved tea genotypes to diverse environments for stability, adaptability of yield and yield components in Tanzania.

2.4 Materials and Methods

2.4.1 Description of the study area

The experiments were set up at three tea representative growing areas in Tanzania (Figure 2.1), namely; the Marikitanda Tea Research Station (MTRS: Latitude: 05º08´S, 38º35´E and altitude: 970 m a.s.l); Ilenge Site (Latitude: 09° 12´ 23" S, 33° 34´ 37'E and altitude 1 426m a.s.l) and Ngwazi Tea Research Station (NTRS: latitude 08º32´S, 35º10´E and altitude 1 840 m a.s.l) (Fig 2.1). The locations varied in factors such as soils pH, soil types and soil fertility (Table 2.2) altitude, weather (temperature (°C), annual precipitations (mm), (Fig.2.2).

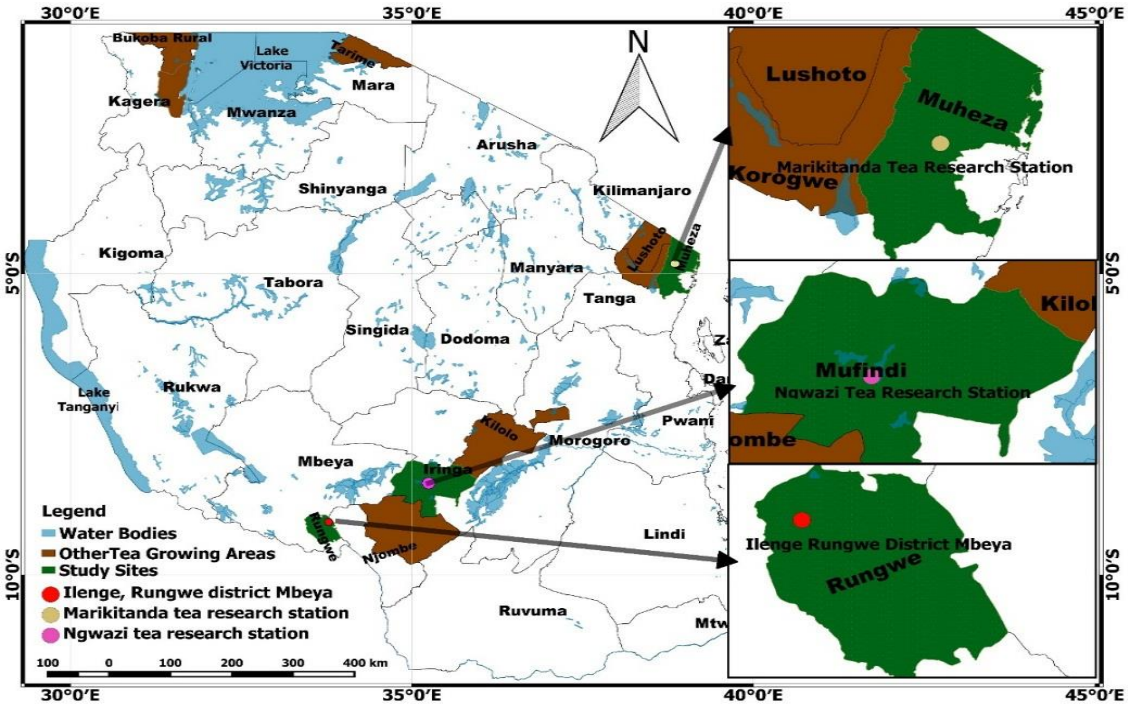

Figure 2.1: Map of Tanzania showing location of field experimentation.

2.4.2 Description of Tea Genotypes

Thirty-one (31) improved tea genotypes of commercialized diverse agronomic features were evaluated at three experimental sites as presented in Figure 2.1. Ten (10) and nineteen (19) of the tested tea genotypes originated from Tanzania and Kenya respectively. Due to its popularity across many tea growing areas in Tanzania, a commercial tea clone SFS150 from Malawi, was used as yield check. Tea genotypes used in the study and their agronomic characteristics for each tested genotype are presented in Table 2.1.

Table 2.1: List of 31-tea genotypes evaluated at three growing environments in Tanzania during 2014-16.

Serial No.	Genotype	Source of origin	Varietal type
1	TRFK 11/4	Kenya local selection	Assam
2	TRFK 12/19	Kenya local selection	Assam
3	TRIT 201/16	Tanzania local selection	Assam/Chinery hybrid
4	TRIT 201/43	Tanzania local selection	Assam
5	TRIT 201/44	Tanzania local selection	Assam
6	TRIT 201/47	Tanzania local selection	Assam/Chinery hybrid
7	TRIT 201/50	Tanzania local selection	Assam
8	TRIT 201/55	Tanzania local selection	Assam/Chinery hybrid
9	TRIT 201/73	Tanzania local selection	Assam/Chinery hybrid
10	TRIT 201/75	Tanzania local selection	Assam/Chinery hybrid
11	TRIT 201/82	Tanzania local selection	Assam/Chinery hybrid
12	TRFK 301/4	Kenya local selection	Cambod
13	TRFK 301/5	Kenya local selection	Cambod
14	TRFK 301/6	Kenya	Cambod
15	TRFK 303/1199	OP progeny TRFK 6/8	Assam/Chinery hybrid
16	TRFK 303/178	OP progeny TRFK 6/8	Assam
17	TRFK 303/216	OP progeny TRFK 6/8	Assam
18	TRFK 303/259	OP Progeny TRFK 6/8	Assam
19	TRFK 303/577	OP progeny TRFK 6/8	Assam/Chinery hybrid
20	TRFK 31/8	Kenya	Assam
21	TRFK 371/2	Kenya	Assam
22	TRFK 371/3	OP progeny AHP S15/10	Assam
23	TRFK 371/6	OP progeny AHP S15/10 in Kenya.	Assam
24	TRFK 371/8	OP progeny AHP S15/10	Assam
25	TRFK 381/5	BB35 × BB2	Assam
26	TRFK 400/10	Kenya	Assam
27	TRFK 400/4	OP progeny AHP S15/10	Assam
28	TRFK430/63	TRFC × EPK TN 14/3	Assam/Chinery hybrid
29	TRFK 430/7	TRFCA SFS 150× EPKTN14/3	Assam/Chinery hybrid
30	TRFK 6/8	Kenya local selection	Assam
31	SFS150 (Ck-2)	Malawi local selection	Assam

With permission from Makola (2013).

Table 2.2: Soil Physico-Chemical characteristics of three tea experimental sites in Tanzania during 2014-2015

Location	Chemical Properties							Physical Properties			
		CEC	Total	Available			OM	Sand	Silt	Clay	Textural
	$P^H(H_2O)$	Cmol(+)kg	N (%)				(%)	(%)	(%)	(%)	Class*
				K^+	P	Mg^{2+}					
				Cmol kg^{-1}	(ppm)	Cmol kg^{-1}					
NTRS (A)	4.3	14.76	0.18	0.69	15.37	0.91	2.39	46.2	18.3	35.5	Sandy clay loam
MTRS (B)	3.9	14.43	0.21	0.12	12.81	0.36	3.34	46.9	18.3	34.8	Sandy clay loam
Ilenge (C)	4.4	19.91	0.34	0.75	7.26	1.11	6.36	67.5	21.7	10.8	Sandy loam
Interpretation*	Low	Medium	Low to medium	Medium	Medium	Low to medium	Medium to high				

*= interpretation according to Landon (1991).

2.4.3 Soil Samples

Soil samples (≈500 g) per experimental site were collected to include soil surface (0 – 30 cm), subsoil (30 – 60 cm) and (60 – 90 cm depth). The soil samples were analyzed for chemical and physical properties (Table 2.2). Across locations, the soil pH (H_2O) and available P was analyzed using the Bray No. 1 Extract method (Bray and Kurtz, 1945). The total nitrogen, Potassium (K^+), the caution exchange capacity CEC and the available magnesium (Mg^{2+}) each was determined using the Ammonium Acetate method (Schollenberger and Simon, 1945). The Walkley-Black titration method (Walkley and Black, 1934) was adopted to analyse the organic matter (OM). The soil textural was determined based on Beretta *et al*. (2014). The soil texture ranged from sandy loam at Ilenge site to sandy loam clay soils at Ngwazi and Marikitanda sites. All soils analytical work was conducted at the Tea Research Institute of Tanzania (TRIT) Leaf and Soil laboratory. The interpretation was carried out according to Landon (1991). Table 2.2 summarizes the soil analysis results.

2.4.4 Weather data

The meteorological data were recorded at the weather stations installed close to the experimental sites of Ngwazi Tea Research Station (NTRS), Marikitanda Tea Research Station (MTRS) and Wakulima Tea Company (WATCO) (Ilenge) (Fig. 2.2 A and 2.2 B). The data were adopted to explain differential genotypic responses in the tea crop. The weather data including daily rainfall (mm) was determined using the standard rain gauge. Using thermometer, data on daily minimum and maximum air temperature (°C) were collected from June 2014 to May 2015 (First season) and June 2015 to May 2016 (Second season) (Section 2.3.4). The weather stations were installed at each of the study sites viz.; Ngwazi Tea Research Station, Ilenge and Marikitanda Tea Research Station. The recorded

maximum and minimum temperature (°C) and rainfall (mm) are presented in Fig. 2.2: A, B, C and D and Appendices 2.2, 2.3 and 2.4.

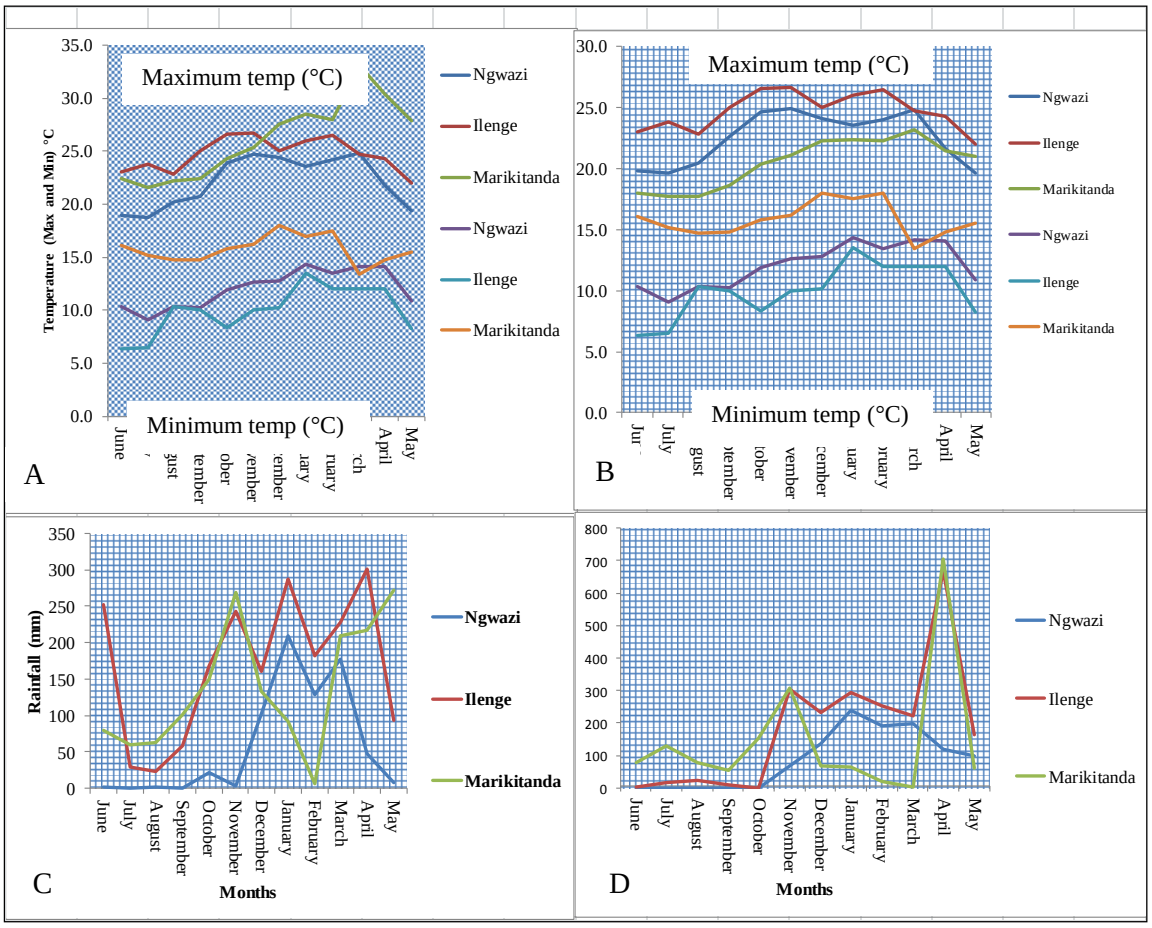

Figure 2.2: A & B: Top left clockwise represents temperature (°C) (Maximum and minimum 2014-15), maximum and minimum 2015-16. Bottom: C & D represents rainfall (mm) during 2014-15 and 2015-16.

2.4.5 Experiment layout and design

A total of 31 improved tea genotypes of diverse agronomic characteristics were evaluated under field conditions during two seasons (2014/15 and 2015/16). Field experiments were set in the previously established (March, 2005) commercial tea farms at Ngwazi, Ilenge and Marikitanda sites. Of the 31-genotypes, 10 were locally developed in Tanzania and 19

were introduced from Kenya through the tea crop germplasm exchange program (section 2.3.2). Genotype SFS150 was included as yield check. The experimental units were arranged in a complete randomized block design (CRBD) with three (3) replicates at each site and during the two seasons. Tea bushes were spaced at 0.6 m (within rows) × 1.2 m (between rows) giving a plant population of 13 888 per hectare. The plot size (Gross Area) was 3m × 7.2m with 7.0 rows. The test environments were represented by E1 (2014/15-Ngwazi), E2 (2014/115-Marikitanda), E3 (2014/15-Ilenge), E4 (2015/16-Ngwazi), E5 (2015/16-Marikitanda) and E6 (2015/16-Ilenge). The experimental plots were maintained weed-free using herbicide [(i.e. Glyphosate (*N*-(phosphonomethyl) glycine) and 2, 4-Dichlorophenoxyacetic acid)] at 2.5 lt/ha and hand-as weed control methods. Compound fertilizer in form of N.P.K 25: 5: 5 was applied at 250 kg N $ha^{-1}year^{-1}$ in single application to all 3-experimental plots i.e. NTRS, MTRS and Ilenge sites at the commencement of wet season (Nov-Dec).

2.5 Data Collection

Data were recorded from the net plot area of 3.0 m (within rows) × 2.4 m (between rows). The gross area comprised of 7 rows, while the net area each plot consisted of 3 rows.

2.5.1 Green leaf yields (kg mt ha^{-1})

Greenleaf yields were determined from 31 tea test genotypes at all three sites during the two seasons i.e. 2014/15 and 2015/16. The green leaf shoots were hand harvested (Standard: 2 leaves + a bud) at 7 to 14 day intervals depending on leaf availability. Weight for green leaf from each plot was recorded (g or kg per plot) from November 2014 at all three sites during the beginning of wet season. Harvested and weighed green leaf for yields (kg/plot) was converted to annual made tea (kg mt ha^{-1}) by multiplying by an

outturn factor of 0.225 (Makola, 2013). Obtained tea yields were expressed as kilogram made tea per hectare per year (kg mtha^{-1}year^{-1}).

2.5.2 Shoot density (shoots m^{-2})

Data on shoot density was collected from December 2014 at MTRS and Ilenge and from January 2015 at Ngwazi (NTRS) sites. The shoot density was determined according to Nyabundi *et al.* (2016). Average number of shoots per plot was counted and shoot density was determined from counted shoots according to Makola (2013) and Nyabundi *et al.* (2016). Leaf harvesting involving fully expanded shoots (2 tender leaves + a bud) was carried out throughout wet and dry seasons at 7 to 14 days interval (Carr, 2012) using the same pluckers. Except during the cool dry season, harvesting was extended from 14 to 21 days interval. Shoot count was carried out a day before harvesting green leaf for yield determination. Shoots were counted using a 0.2 m^2 wooden grid after randomly thrown over the plucking table at a frequency of five grids per plot. The total fresh mass of the shoots from each plot was counted at each harvest and converted into number of shoots per m^2 (Makola, 2013; Nyabundi *et al.*, 2016) and as indicated below:

$$\text{Shoot density } (m^{-2}) = \frac{\text{Number of shoots}}{\text{Land area } (m^2)} \quad \ldots\ldots (1)$$

2.5.3 Statistical analysis

Tea yields (kg mt ha^{-1}) and yield components (shoots m^{-2}) from the three multi-environmental trials (METs) were analyzed statistically for each environment using

Genestat software version 15.0 VSN International (2012) and analysis of variance (ANOVA) procedure. The error variance was tested for their homogeneity using the Bartlett's test (Gomez and Gomez, 1984). The treatment differences were separated using

the Duncan Multiple Range Test (DMRT). The statistical model for analysis was as follows:

$Y_{ijkl} = \mu + G_i + L_j + S_k + (G*L_{ij}) + (G*S_{ik}) + (L*S_{jk}) + (G*L*S_{ijk}) + \varepsilon_{ijkl}$..... (2)

Where;

μ= the general mean.

Y_{ijkl} = Mean yield of *i*th genotype in jth location and in the kth season and lth plot.

G_i and L_j, and S_k represent the effect of ith genotype, jth location and kth Season, respectively.

Three terms of $G*L_{ij}$, $G*S_{ik}$ and $L*S_{jk}$ are the respective first order interactions.

$G*L*S_{ijk}$ represent the second order interaction.

ε_{ijkl} = Error associated with ith genotype, jth location, kth season and lth plot.

The tea genotype stability across environments (genotype × location) was determined based on the regression coefficient (β_i) and linearity deviations (S^2_{di}) (Eberhart and Russell, 1966). The deviation of regression coefficient from unity 1 - β_i which determines whether a genotype responds on average as environmental conditions change was adopted according to Paroda and Hayes (1970). The coefficient of determination (R^2_i) measured the amount of overall variance due to linear and non-linear effects for each genotype (Pinthus, 1978). The adaptability of each test genotype was determined according to Finlay and Wilkinson (1963).

2.6 Results

2.6.1 Yield

Statistical significant effects were observed for genotypes (G), locations (L), seasons (S), genotypes (G) × locations (L) and locations (L) × seasons (S) interactions for made tea

yield trait (Appendix 2.1). The location main effects (L), location (L) × season (S) interactions and season (S) accounted for 76.3%, 13.3% and 4.3% of the total variation (mean square MS). The genotype (G) × location (L), Genotype (G) and genotype × season × Location interactions accounted only marginally being 2.0%, 1.9% and 0.5%, respectively. The location main effect was 38.2 times higher than the genotype × location interaction and almost 40.0 times than the genotype main effect.

2.6.2 Shoot density

Based on combined analysis (Appendix 2.1), 31-evaluated tea genotypes differed significantly with respect to shoot density trait for genotype (G), location (L), genotype (G) × location (L), genotype (G) × season (S) and genotype (G) × location (L) × season (S) interactions. The highest contribution to the mean square (MS) were for location (L) main effects which accounted for 85.8%, followed by location (L) × Season (S) interactions effects (12.5%). About 0.8% of the total mean variance was contributed by genotype main effects. Other relatively marginal variances of 0.2%, 0.1% and 0.1 were accounted for by genotype (G) × location (L) and genotype (G) × season (S) and genotype (G) × season (S) × location (L) interactions, respectively. The magnitude of the variance contributed by the location (L) was almost 429-times greater than what was contributed by the genotype (G) × location (L) interaction effect.

2.7 Main Effects

2.7.1 Main effects of genotypes

2.7.1.1Yield

The yield means ranged from 2 245 to 3 271 kg mt ha^{-1} with overall mean of 2 787 $kgmtha^{-1}$ (Table 2.3; Appendix 2.5). Genotype TRFK 430/63 gave highest mean yield of 3

271 kg mt ha^{-1}. The genotype TRFK 430/63 significantly out-yielded the check SFS150 (2 818kgmtha^{-1}) and the overall mean (2 787kgmtha^{-1}) by 13.8% and 14.8% respectively. Genotype TRFK 303/577 (3 210kgmtha^{-1}), also had high mean yield which was not significantly different from the best genotype TRFK 430/63. The genotype excelled the check and environmental mean by 12.2% and 13.2%, respectively. The other three genotypes TRFK 301/6 (3 196 kgmtha^{-1}), TRIT 201/16 (3 032 kg mt ha^{-1}) and TRFK 381/5 (3 003 kg mt ha^{-1}), also expressed high mean yields which did not significantly differ from the best genotype TRFK 303/577. The three genotypes TRFK 301/6, TRIT 201/16 and TRFK 381/5 excelled over the control SFS150 (2 818kgmtha^{-1}) by 11.8%, 7.1% and 6.2%, respectively. On the other hand, significant least mean yield of 2 245 kg mt ha^{-1} was recorded for genotype TRFK 371/6. The genotype TRFK 371/6 under-performed below the entire tested genotypes and the control by 20.3%.

Seven tea genotypes including TRIT 201/55 (8), TRIT 201/73(9), TRFK 301/5 (13), TRFK 303/178 (16), TRFK 371/8 (24), TRFK 400/4 (27), TRFK 303/259 (18) excelled the overall genotypic mean by the range from 0.9% to 5.6%. The other fifteen tea genotypes had mean yields significantly below the overall genotypic mean.

2.7.1.2 Shoot density (shoots m^{-2})

Results of means of genotypes for shoot density are given in Table 3 and Appendix 2.6. The shoot density ranged from 202 to 305 shoots m^{-2}, with mean of 242 shoots m^{-2}. The least produced mean of 202 shoots m^{-2} was recorded in genotype TRFK 400/4 (27). Genotype TRFK 303/577 (19) gave significantly highest mean of 305 shoots m^{-2}, exceeding both the control genotype SFS150 (31) and environmental mean by 21.5% and 26% respectively. Seven tea genotypes; TRIT 201/55 (8), TRIT 201/16 (3), TRIT 201/44

(5), TRIT 201/82 (11), TRFK 301/6 (14), TRFK 430/7 (29) and TRIT 201/47 (6) had high shoot densities, but significantly less than the best genotype TRFK 303/577 (19). The genotypes produced shoot densities of 285, 273, 268, 264, 262, 258 and 254 in that order, exceeding the check SFS150 (251shoots m^{-2}) by 13.5%, 8.8%, 6.8%, 5.2%, 4.3%, 2.8% and 1.2%, respectively. Other genotypes viz. TRFK 301/4 (12) and TRFK 303/216 (17) had similar shoot density of 247shoots m^{-2}, the TRFK 400/10 (26) and TRFK 301/5 (13) each produced shoot density of 213 shoots m^{-2}, while the TRFK 371/2 (21) and TRFK 371/3 (22) also each had shoot density of 229 shoots m^{-2}.

Table 2.3: Means of tea genotypes for yield and shoot density variables

Serial No.	Genotype	Yield (kg mt ha^{-1})	Rank	Shoot density (shoots m^{-2})	Rank
1	TRFK 11/4	2 554g-h	25	238h-k	16
2	TRFK 12/19	2 687d-i	22	243g-k	14
3	TRIT 201/16	3 032a-c	4	273b-c	3
4	TRIT 201/43	2 813c-h	15	244f-k	13
5	TRIT 201/44	2 629f-i	23	268cd	4
6	TRIT 201/47	2 547f-j	26	254d-h	8
7	TRIT 201/50	2 609e-i	24	246f-k	12
8	TRIT 201/55	2 952b-f	6	285b	2
9	TRIT 201/73	2 861b-f	13	242g-k	15
10	TRIT 201/75	2 771e-i	16	268cd	4
11	TRIT 201/82	2 396i-k	28	264c-e	5
12	TRFK 301/4	2 737f-j	17	247e-j	11
13	TRFK 301/5	2 951b-f	7	213m-o	20
14	TRFK 301/6	3 196ab	3	262c-e	6
15	TRFK 303/1199	2 388k	29	248c-f	10
16	TRFK 303/178	2 923f-j	9	235i-j	16
17	TRFK 303/216	2 722c-g	18	247e-j	11
18	TRFK 303/259	2 878b-c	12	207no	23
19	TRFK 303/577	3 210a	2	305a	1
20	TRFK 31/8	2 714b-f	20	221l-n	19
21	TRFK 371/2	2 719c-h	19	229k-m	18
22	TRFK 371/3	2 907h-k	10	229k-m	18
23	TRFK 371/6	2 245h-k	31	209no	22
24	TRFK 371/8	2 950a-c	8	210no	21
25	TRFK 381/5	3 003a-c	5	206no	24
26	TRFK 400/10	2 365jk	30	213m-o	20
27	TRFK 400/4	2 895c-g	11	202o	25
28	TRFK 430/63	3 271a	1	243g-k	14
29	TRFK 430/7	2 700f-j	21	258c-g	7
30	TRFK 6/8	2 421h-k	27	233j-l	17
31	SFS150 (Ck)	2 818b-f	14	251d-i	9
Mean ($\bar{x}$)		2 787		242.0	
S.e.d (n=29)		156.8		8.3	
CV (%)		5.6		3.4	

S.e.d = standard error of differences of means; CV (%) = coefficient of variation; Means followed by the same letter are not significantly different at $p \leq 0.05$ by DMRT.

Fourteen tea genotypes; TRFK 303/577 (19), TRIT 201/55(8), TRIT 201/16 (3), TRIT 201/44 (5), TRIT 201/82 (11), TRFK 301/6 (14), TRFK 430/7 (29), TRIT 201/47(6), TRFK 12/19 (2), TRIT 201/43 (4), TRIT 201/50 (7), TRFK 301/4 (12), TRFK 303/1199 (15) and TRFK 303/216 (17) produced higher shoot densities than the overall genotypes mean ranging from 243 for TRFK 12/19 (2) to 305 shoots m^{-2} for TRFK 303/577. The

shoots were higher over the environmental mean by 0.41% (TRFK 12/19) and (TRFK 430/63) to 26% for TRFK 303/577. Genotype TRIT 201/73 (242 shoots m^{-2}) exhibited comparable shoot density to the overall genotypic mean. The other fourteen tea genotypes produced below the overall genotypes mean shoot density.

2.7.2 Main locations effect

The mean yield (kg mt ha^{-1}) and shoot density (shoots m^{-2}) values of made tea of 31-genotypes for separate locations and overall means for the three locations are presented in Table 2.4. Results of means of locations (main effects) for yield trait ranged from 2 409 to 3 358 kg mt ha^{-1}, with mean yield of 2 882 kg mt ha^{-1}. The highest mean yield of 3 358 kg mt ha^{-1} was recorded at Ngwazi location and closely followed by mean yield at Marikitanda (2 878 kg mt ha^{-1}).

Table 2.4: Main effects of locations for the studied variables

Location	**Yield (kg mt ha^{-1})**	**Rank**	**Shoot density (shoots m^{-2})**	**Rank**
Ngwazi	3 358	1	153	3
Marikitanda	2 878	2	268	2
Ilenge	2 409	3	304	1
Mean **($\bar{x}$)**	2 882		242.0	
S.e.d (n=29)	48.8		2.6	
LSD ($p<0.05$)	95.9		5.1	
CV (%)	1.7		1.2	

S.e.d = standard error of differences of means; LSD = Least significant differences; CV (%) = coefficient of variation.

The least mean yield of 2 409 kg mt ha^{-1} was recorded at Ilenge location. The mean yields at Marikitanda and Ilenge locations were significantly lower than the yield at Ngwazi site. The mean yields at the two locations also were lower than the overall location mean by 0.14% and 16.4%, respectively. The shoot density (shoots m^{-2}) ranged from the lowest of

153 shoots m^{-2} at Ngwazi location to the highest of 304 shoots m^{-2} at Ilenge location, with average of 242 shoots m^{-2}.

2.7.3 Main effects of seasons

The mean effects of seasons are indicated in Table 2.5. The lower mean tea yield of 2 615 kg mt ha^{-1} and higher mean tea yield of 2 944 kg mt ha^{-1} were recorded during the second season (2015/16) and the first season (2014/15), respectively. The average mean yield across the two seasons (2014/15 and 2015/16) was 2 778 kg mt ha^{-1}. With respect to shoot density, the mean for two seasons did not differ significantly, being 241 shoots m^{-2} (2014/15) and 242 shoots m^{-2} (2015/16) with overall mean of 242 shoots m^{-2}.

Table 2.5: Main effects of seasons for the studied variables

Season	**Yield (kg mt ha^{-1})**	**Rank**	**Shoot density (shoots m^{-2})**	**Rank**
2014-15	2 944	1	241	2
2015-16	2 615	2	242	1
Mean **(**$\bar{x}$±39.8**)**	2 778		242	
S.e.d (n=29)	39.2		1.9	
LSD ($p<0.05$)	77.1		3.8	
CV (%)	5.6		3.1	

S.e.d = standard error of differences of means; LSD = Least significant differences; CV (%) = coefficient of variation.

2.8 Interaction of Factors

2.8.1 Season (S) × location (L) interaction

Results for the combination of season × location interaction on yield are presented in Table 2.6. Significantly highest yield of 3 397 kg mt ha^{-1} was recorded at Ngwazi location during the first season (2014/15). This was followed by a mean yield of 3 152 kg mt ha^{-1}

obtained at Marikitanda location, also during the 2014/15 season. On the other hand, significantly lowest yield of 2 291 kg mt ha^{-1} was observed at Ilenge site during the first season (2014/15).

Table 2.6: Combination of season (S) × location (L) interaction on tea yield (kg mt ha^{-1})

Season × Location	Yield (kg mt ha^{-1})
2014/15: Ngwazi	3 397
2014/15: Marikitanda	3 152
2014/15: Ilenge	2 291
2015/16: Ngwazi	2 600
2015/16: Marikitanda	2 603
2015/16: Ilenge	2 641
Mean ($\bar{x}$ ±48.8)	2 882
S.e.d (n=29)	69.0
LSD (p<0.05)	135.7
CV (%)	16.3

S.e.d = standard error of differences of means; LSD = Least significant differences; CV (%) = coefficient of variation.

2.8.2 Genotype × season interaction -Shoot density

Combination means for genotype × season interaction for shoot density (shoots m^{-2}) are presented in Table 2.7. The mean shoot density varied considerably during 2014/15 and 2015/16 seasons. Based on combined data on means for genotype (G) × season (S) interactions, there were differential genotypic rankings during the two seasons. The significantly highest shoot density (shoots m^{-2}) was recorded for genotype TRFK 303/577 (320 shoots m^{-2}) during 2014/15. The least mean shoot density was 191shoots m^{-2} for genotype TRFK 381/5 (25) during 2014/15 season. The genotype TRFK 303/577 (19) more or less maintained its ranking during the two seasons. Combinations that had statistically lowest shoot densities were TRFK 400/10 (26), TRFK 371/8 (24), TRFK

371/6 (23), TRFK 303/259 (18), TRFK 301/5 (13) during 2014/15, whereas TRFK 303/259 (18), TRFK 371/6 (23), TRFK 371/8 (24) and TRFK 400/4 (27) during 2015/16.

Table 2.7: Genotype (G) × season (S) interaction for shoot density (shoots m^{-2}) during 2014/15 and 2015/16 seasons at three locations

		Seasons					
Serial No.	**Genotype**	**2014/15**	**Rank**	**2015/16**	**Rank**	**Mean**	**Rank**
1	TRFK 11/4	232g-l	17	245f-j	12	239h-l	16
2	TRFK 12/19	244e-i	15	242g-k	14	243f-l	14
3	TRIT 201/16	297b	2	249e-j	10	273bc	3
4	TRIT 201/43	249e-h	12	240g-k	15	245e-k	13
5	TRIT 201/44	269c-e	5	267b-f	6	268cd	4
6	TRIT 201/47	256e-h	8	252d-h	9	254d-h	8
7	TRIT 201/50	244e-j	15	247e-j	11	246e-k	12
8	TRIT 201/55	281b-d	4	290ab	2	286b	2
9	TRIT 201/73	245e-h	14	239g-k	16	242g-l	15
10	TRIT 201/75	261c-f	6	275a-d	4	268cd	4
11	TRIT 201/82	257d-g	7	271a-e	5	264c-e	5
12	TRFK 301/4	245e-h	14	294a	1	247e-j	11
13	TRFK 301/5	197mn	23	229j-n	19	213no	22
14	TRFK 301/6	246e-h	13	278a-c	3	262c-f	6
15	TRFK 303/1199	250e-h	11	245f-j	12	248e-j	10
16	TRFK 303/178	218i-m	20	253e-j	8	235j-m	19
17	TRFK 303/216	252e-h	10	243f-k	13	248e-k	10
18	TRFK 303/259	210k-n	21	203n	26	207o	24
19	TRFK 303/577	320a	1	290ab	2	305a	1
20	TRFK 31/8	229h-l	19	213l-n	22	221i-n	21
21	TRFK 371/2	231g-l	18	229i-n	19	229j-m	19
22	TRFK 371/3	231g-l	18	239i-n	16	228j-m	20
23	TRFK 371/6	210k-n	21	209l-n	24	210m-o	23
24	TRFK 371/8	210k-n	21	210k-n	23	210m-o	23
25	TRFK 381/5	191n	24	222k-n	20	207o	24
26	TRFK 400/10	207i-n	22	219k-n	21	213m-o	22
27	TRFK 400/4	197mn	23	206i-n	25	202o	25
28	TRFK 430/63	229h-l	19	256c-g	7	243g-l	14
29	TRFK 430/7	284bc	3	233g-l	17	259c-g	7
30	TRFK 6/8	236f-k	16	230h-m	18	233i-l	18
31	SFS150 (Ck)	253e-h	9	249e-i	10	251d-i	9
Mean (**$\bar{x}$** ±8.3)		241		242		242	
CV (%)				4.2			

CV (%) = coefficient of variation; Means followed by the same letter are not significantly different at p≤0.05 by DMRT.

2.8.3 Combination means for genotype × location interactions

2.7.3.1 Yield

Table 2.8: Genotype (G) × location (L) interaction for yield (kg mt ha^{-1}) at three locations

		Location							
Serial No.	**Genotype**	**Ngwazi**	**Rank**	**Marikitanda**	**Rank**	**Ilenge**	**Rank**	**Mean**	**Rank**
1	TRFK 11/4	3 124e-j	20	2 600b-e	28	1 888f-i	28	2 523f-h	28
2	TRFK 12/19	2 808i-k	28	2 993a-d	10	2 692b-d	8	2 846d-h	17
3	TRIT 201/16	3 704b-e	9	2 992a-d	12	3 003 ab	3	3 229a-d	5
4	TRIT 201/43	3 030g-j	22	3 207a-c	7	2 36c-g8	15	2 853a-g	16
5	TRIT 201/44	2 795i-k	29	3 009a-d	11	2 519b-e	11	2 782d-h	22
6	TRIT 201/47	3 357c-i	16	2 885a-e	25	2 405b-g	15	2 842a-g	18
7	TRIT 201/50	2 855i-k	25	3 455a	5	2 341c-g	18	2 834a-g	19
8	TRIT 201/55	3 482b-g	14	3 076a-d	2	2 263c-h	22	3 053a-d	9
9	TRIT 201/73	3 194d-j	19	2 841a-e	16	2 691b-d	9	2 920a-f	12
10	TRIT 201/75	2 827i-k	26	3 032a-d	3	2 355c-g	16	2 827a-g	20
11	TRIT 201/82	3 106f-j	21	2 885a-e	22	1 716hi	30	2 539f-h	27
12	TRFK 301/4	3 755b-d	7	2 850a-e	21	1 834g-i	29	2 800a-g	21
13	TRFK 301/5	3 779b-d	6	2 464c-e	19	2 512b-e	12	3 038a-d	10
14	TRFK 301/6	3 533b-g	13	3 297ab	1	2 827bc	4	3 298a-d	3
15	TRFK 303/119	3 807bc	4	2 180e	31	1 591i	31	2 363h	31
16	TRFK 303/178	3 874bc	3	2 221e	15	2 710b-d	6	3 179a-d	7
17	TRFK 303/216	3 342c-i	17	2 609b-e	23	2 201c-h	23	2 747b-h	23
18	TRFK 303/259	3 621b-f	11	2 710a-e	24	2 321c-h	19	2 873a-f	13
19	TRFK 303/577	4 871a	1	2 820a-e	14	2 462b-f	13	3 384a	2
20	TRFK 31/8	2 682jk	30	2 824a-e	17	2 29b-d	10	2 689b-h	24
21	TRFK 371/2	3 318c-i	18	3 163a-d	6	2 752b-d	5	3 087a-d	8
22	TRFK 371/3	3 688b-f	10	3 351ab	18	2 052e-i	25	2 860a-g	15
23	TRFK 371/6	2 894h-k	24	2 760a-e	29	2 290c-h	20	2 554f-h	26
24	TRFK 371/8	3 608b-g	12	3 196a-c	4	2 705b-d	7	3 189a-d	6
25	TRFK 381/5	3 711b-e	8	2 409c-e	27	3 385a	1	3 237a-e	4
26	TRFK 400/10	2 823i-k	27	2 401de	30	2 193d-h	24	2 412gh	30
27	TRFK 400/4	3 454b-h	15	3 122a-d	13	2 040e-i	26	2 873a-f	14
28	TRFK 430/63	4 038b	2	2 740a-e	9	3 383a	2	3 387a	1
29	TRFK 430/7	2 903h-k	23	3 142a-d	8	2 002e-i	27	2 686b-h	25
30	TRFK 6/8	2 405k	31	3 122a-d	26	2 347c-g	17	2 456h	29
31	SFS150 (Ck)	3 784b-d	5	2 876a-d	20	2 290c-h	21	2 984a-g	11
Mean ($\bar{x}$±48.8)		3 360		2 878		2 409		2 882	
CV (%)					9.4				

CV (%) = coefficient of variation; Means followed by the same letter are not significantly different at p≤0.05 by DMRT.

There were differential genotype rankings at different locations on yield of tea (Table 2.8). The highest mean yield of 4871 kg mt ha^{-1} was recorded for genotype TRFK 303/577 (19) at Ngwazi site. On the other hand, the lowest mean yield of 1 591 kg mt ha^{-1} as recorded for TRFK 303/1199 (15) at Ilenge location. Also, genotype TRIT 201/82 gave significantly lowest mean yield similar to genotype TRFK 303/1199 (15) also at Ilenge site.

Across the three locations, the mean yield varied from the lowest (1 591 kg mt ha^{-1}) to the highest (4 871 kg mt ha^{-1}) at Ilenge and Ngwazi sites respectively; with an overall environmental mean yield of 2 882 kg mt ha^{-1}. Two genotypes TRFK 11/4 (1) and TRFK 303/216 (17) expressed relatively minimum rank change in low mean tea yield performance; while, TRFK 430/63 (28) had minimum rank change in high tea yield performance. Also, TRIT 201/82 (11) and TRFK 11/4 (1), TRFK 301/4 (12), TRFK 303/1199 (15), TRFK 371/3 (22), TRFK 400/4 (27) and TRFK 430/7 (29) gave statistically significantly low mean yield (1 716 kg mt ha^{-1}) similar to TRFK 303/1199 (1 591 kg mt ha^{-1}) at Ilenge site.

2.8.3.2 Shoot density

Table 2.9: Genotype (G) × location (L) interaction for shoot density (shoots m^{-2}) at three locations

		Location							
Serial No.	**Genotype**	**Ngwazi**	**Rank**	**Marikitanda**	**Rank**	**Ilenge**	**Rank**	**Mean**	**Rank**
1	TRFK 11/4	140i-m	18	255g-k	16	320b-d	5	238	16
2	TRFK 12/19	161c-g	6	253g-k	17	314b-e	8	243	14
3	TRIT 201/16	154e-k	10	309cd	6	355a	2	273	3
4	TRIT 201/43	142h-m	17	278e-h	10	312b-e	9	244	13
5	TRIT 201/44	156d-j	9	298c-f	8	349ab	3	268	4
6	TRIT 201/47	163c-l	5	280d-g	9	319b-d	6	254	8
7	TRIT 201/50	143g-m	16	278e-h	10	316b-e	7	246	12
8	TRIT 201/55	181b	2	363a	1	311b-f	10	285	2
9	TRIT201/73	154e-k	10	269f-I	14	302c-g	13	242	15
10	TRIT 201/75	146f-l	14	346ab	4	312b-f	9	268	4
11	TRIT 201/82	173b-d	4	307c-e	7	312b-f	9	264	5
12	TRFK 301/4	160c-h	7	277e-h	11	304c-g	12	247	11
13	TRFK 301/5	152e-l	11	214mn	27	273f-i	22	213	22
14	TRFK 301/6	136k-m	20	347ab	3	302c-g	13	262	6
15	TRFK 303/1199	173b-d	4	275f-h	12	296c-i	15	248	10
16	TRFK 303/178	149e-l	13	241i-m	19	316b-e	7	235	17
17	TRFK 303/216	175bc	3	275f-h	12	292c-i	17	247	11
18	TRFK 303/259	152e-l	11	209n	28	258i	25	207	25
19	TRFK 303/577	210a	1	350a	2	356a	1	305	1
20	TRFK 31/8	143f-m	16	225k-n	22	295c-i	16	221	21
21	TRFK 371/2	146f-l	14	229j-n	21	312b-f	9	229	19
22	TRFK 371/3	150e-l	12	257g-j	15	279e-i	21	228	20
23	TRFK 371/6	126m	22	220l-n	24	281d-i	20	209	24
24	TRFK 371/8	144f-m	15	221l-n	23	266g-i	23	210	23
25	TRFK 381/5	135lm	21	203n	29	282d-i	19	206	26
26	TRFK 400/10	138j-m	19	215mn	26	287d-i	18	213	22
27	TRFK 400/4	126j-m	22	218l-n	25	261hi	24	202	27
28	TRFK 430/63	161c-h	6	240i-m	20	327a-c	4	243	14
29	TRFK 430/7	157c-i	8	320bc	5	297c-h	14	258	7
30	TRFK 6/8	146f-l	14	248h-l	18	305c-f	11	233	18
31	SFS150 (Ck)	166b-e	6	274f-h	13	314b-e	8	251	9
Mean $\bar{x}$±3.4**)**		153		268		304		242	
CV (%)				7.8					

CV (%)= Coefficient of variation; Means followed by the same letter are not significantly different at p≤0.05 by DMRT.

The mean shoot density ranged from the lowest of 126 shoots m^{-2} (lowest) for TRFK 371/6 (23) and TRFK 400/4 at Ngwazi location to 363 shoots m^{-2} (highest) for TRIT 201/55 (8) at Marikitanda location (Table 2.9). Genotype TRFK 303/577 (19) maintained consistently higher shoot density across the three locations. Combinations which were statistically similar to highest mean shoot density included; TRIT 201/16 (3), TRIT 201/44 (5), TRFK 303/577 (19) at Ilenge and TRIT 201/55 (8), TRIT 201/75 (10), TRFK 301/6 (14), TRFK 303/577 (19) at Marikitanda site. Fourteen, genotypes viz. TRFK 11/4 (1), TRIT 201/43 (4), TRIT 201/50 (7), TRIT 201/75 (10), TRFK 31/8 (20), TRFK 371/3 (22), TRFK 371/8 (24), TRFK 301/5 (13), TRFK 301/6 (23), TRFK 371/6 (23), TRFK 303/259 (18), TRFK 371/2 21), TRFK 381/5 (25), TRFK 400/10 (26), TRFK 6/8 (30) and TRFK 400/4 (27), had significantly lowest mean shoot densities (126 to 152 shoots m^{-2}) all at Ngwazi location. Among the evaluated 31-tea genotypes, TRFK 303/577 (19) relatively maintained the minimum genotypic rank change with high mean across locations followed by TRIT 201/55 (8). The genotype TRFK 303/577 (19) ranked 1st at Ngwazi, Ilenge and across locations and 2nd at Marikitanda location. Genotype TRIT 201/55 (8) also ranked 1st at Marikitanda but 2nd at Ngwazi and Ilenge sites. Other genotypes were variously fluctuating from location to location on shoot density trait.

2.9 Effects of Environmental Index on Tea Yield and Shoot Density

The environmental indices for shoot density and yield traits were calculated as the difference between the location mean and the mean of overall test locations (Soliman, 2006). Environments with high environmental index (Ij) values were considered to exhibit high genotypic selectivity, thus suitable for detecting and making choice of good performing genotypes (Isik and Kleinschmit, 2005). According to Hassan *et al.* (2011), environmental index (Ij) designates favourable or unfavourable environment for

productivity of a specific crop. Arunkumar *et al.* (2014), pointed out that favourable environment should express high mean and positive environmental index (Ij) and vice versa. The environmental indices for tea yield and shoot density are presented in Table 2.10. The environmental mean yield ranged from 2 290 to 3 397 kg mt ha^{-1} for environments E3 (Ilenge: 2014/15) and E1 (Ngwazi: 2014/15). For tea yield trait, the environmental indices (Ij) ranged from Ij = - 496 to 602 also for environments E3 (Ilenge: 2014/15) and E1 (Ngwazi: 2014/15). On the basis of combinations of environmental mean and environmental index (Ij), environments E1 (Ngwazi: 2014/15) and E2 (Marikitanda: 2014/15) revealed significantly highest mean yields with positive environmental indices. During 2014/15 Ngwazi (E1) had 3 397kgmtha^{-1} yield with positive environmental index Ij of 602, while during 2014/15 Marikitanda (E2) produced yield of 3 152 kg mt ha^{-1} with positive environmental index (Ij) of 365.

For shoot density, the environmental mean ranged from 127 to 310 shoots m^{-2} for environments E4 (Ngwazi: 2015/16) and E3 (Ilenge: 2014/15). The environmental indices (Ij) ranged from -114 to 69 at environments E4 (Ngwazi: 2015/16) and E3 (Ilenge: 2014/15), respectively.

Table 2.10: Mean effects of environments for yield and shoot density variables 2014-2016.

	Variable					
Environment	**Yield (kg mt ha^{-1})**	**Rank***	**Environmental index (Ij)**	**Shoot density (shoots m^{-2})**	**Rank****	**Environmental index (Ij)**
E1 (Ngwazi 2014/15)	3 397	1	602	179	5	-62
E2 (Marikitanda 2014/15)	3 152	2	365	234	4	-9
E3 (Ilenge 2014/15)	2 290	6	-496	310	1	69
E4 (Ngwazi 2015/16)	2 600	5	-188	127	6	-114
E5 (Marikitanda 2015/16)	2 603	4	-184	301	2	59
E6 (Ilenge 2015/16)	2 641	3	-145.9	298	3	56
Mean ($\bar{x}$)	2 781			242		
S.e.d (n=4)	218.2			18.7		
LSD (0.05)	743.2			36.8		
CV (%)	7.8			7.7		

*=Ranking based on yield and environmental index (Ij); **= Ranking based on shoot density and environmental index (Ij); S.e.d = Standard error of the differences means LSD=Least significant differences; CV (%) coefficient of variation.

2.9.1 Estimate of stability parameters

2.9.1.1 Yield

The estimated stability parameters of individual genotypes for yield are presented in Table 11 and Appendices 2.7 and 2.8. For yield trait, genotypes TRFK 371/6 (23), TRFK 303/577 (19) and TRFK 430/63 (28) recorded significantly higher mean yields. The TRFK 371/2 (21) was the only genotype with $\beta_i = 1.0$ and non-significant S^2d_i. Genotypes TRIT 201/43 (4), TRIT 201/55 (8), TRIT 201/82 (11), TRFK 301/4 (12), TRFK 371/3 (22), TRFK 371/8 (24), TRFK 400/4 (27), TRFK 430/7 (29) and SFS150 (31) expressed $\beta_i > 1.0$ with non-significant S^2d_i.

Other genotypes TRIT 201/73 (9), TRFK 303/259 (18), TRFK 371/6 (23) and TRFK 6/8 (30) had $\beta_i < 1.0$ and non-significant S^2d_i. Genotypes viz. TRFK 11/4 (1), TRIT 201/73 (9), TRIT 201/82 (11), TRFK 301/4 (12), TRFK 303/216 (17), TRFK 371/3 (22), TRFK 371/6 (23), TRFK 371/8 (24), TRFK 400/4 (27) and TRFK 430/7 (29) expressed non-significant S^2d_i with high predictability ($R^2_i \geq 70\%$) values.

Table 2.11: Estimates of stability parameters on mean yield of 31 tea genotypes grown at six environments during 2014/15 to 2015/16

Serial No.	Genotype	Mean Yield	β_i	$\beta_i - 0$	$1-\beta_i$	S^2_{di}	R^2_i
1	TRFK 11/4	2 554	0.94±0.024	0.94*	0.06*	-16209.1	0.75
2	TRFK 12/19	2 687	0.97±0.003	0.97*	0.03*	-64709.7	0.58
3	TRIT 201/16	3 032	1.04±0.004	1.04*	-0.04*	65675.5	0.61
4	TRIT 201/43	2 813	1.15±0.010	1.15*	-0.15*	13326.8	0.75
5	TRIT 201/44	2 629	0.39±0.004	0.39	0.61*	56799.6*	0.19
6	TRIT 201/47	2 547	0.95±0.004	0.95*	0.05*	-52594.5	0.88
7	TRIT 201/50	2 609	1.04±0.003	1.04*	-0.04*	160809.8*	0.49
8	TRIT 201/55	2 952	1.22±0.013	1.22*	-0.22*	9486.8	0.78
9	TRIT 201/73	2 861	0.69±0.002	0.69	0.31*	-61646.3	0.85
10	TRIT 201/75	2 771	0.68±0.008	0.68	0.32*	175743.2*	0.28
11	TRIT 201/82	2 396	1.33±0.012	1.33*	-0.33*	30064.7	0.77
12	TRFK 301/4	2 737	1.37±0.030	1.37*	-0.37*	-2103.2	0.84
13	TRFK 301/5	2 951	0.60±0.003	0.60	0.4*	53526.5*	0.37
14	TRFK 301/6	3 196	1.32±0.003	1.32*	-0.32*	180900.1*	0.59
15	TRFK 303/1199	2 388	1.69±0.002	1.69*	-0.69*	553935.3***	0.49
16	TRFK 303/178	2 923	0.97±0.002	0.97*	0.03*	190759.9**	0.42
17	TRFK 303/216	2 722	0.96±0.015	0.96*	0.04*	4382.5	0.70
18	TRFK 303/259	2 878	0.62±0.002	0.62	0.38*	107012.4	0.30
19	TRFK 303/577	3 696	1.71±0.004	1.71*	-0.71*	208748.6**	0.68
20	TRFK 31/8	2 714	0.56±0.002	0.56	0.44*	-4581.3*	0.47
21	TRFK 371/2	2 819	0.99±0.012	0.99*	0.01ns	83517.1	0.56
22	TRFK 371/3	2 907	1.51±0.018	1.51*	-0.51*	-6772.5	0.87
23	TRFK 371/6	2 445	0.81±0.005	0.81*	0.19*	-28403.1	0.73
24	TRFK 371/8	2 950	1.32±0.018	1.32*	-0.32*	-5319.9	0.83
25	TRFK 381/5	3 003	0.74±0.001	0.74	0.26*	329895.4***	0.22
26	TRFK 400/10	2 365	0.45±0.012	0.45	0.55*	-1475.8*	0.36
27	TRFK 400/4	2 895	1.32±0.007	1.32*	-0.32*	-39291.8	0.90
28	TRFK 430/63	3 271	0.43±0.001	0.43	0.57*	235163.2*	0.11
29	TRFK 430/7	2 700	1.23±0.002	1.23*	-0.23*	34795.6	0.73
30	TRFK 6/8	2 421	0.64±0.020	0.64	0.36*	-1794.3	0.52
31	SFS150 (Ck)	2 818	1.38±0.015	1.38*	-0.38*	100177.7	0.69
	Mean ($\bar{x}$):	2 787					
	CV (%)	5.6					

*= Significant at $P \leq 0.05$; ** Significant at $P \leq 0.01$; ***Significant at $P \leq 0.001$. Ck represent yield check. Means followed by the same letter are not significantly different at P≤0.05 by DMRT; CV (%) Coefficient of variation.

2.9.1.2 Shoot density

The estimated stability parameters for individual genotypes on shoot density are presented in Table 2.12; Appendices 2.9 and 2.10. The mean shoot density ranged from 202 for TRFK 400/4 (27) to 305 for TRFK 303/577 (19). Genotypes with shoot density above overall mean were sixteen namely TRFK 12/19 (2), TRIT 201/16 (3), TRIT 201/43 (4), TRIT 201/44 (5), TRIT 201/47 (6), TRIT 201/50 (7), TRIT 201/55 (8), TRIT 201/75 (10), TRIT 201/82 (11), TRFK 301/4 (12), TRFK 301/6 (14), TRFK 303/1199 (15), TRFK 303/216 (17) and 303/577 (19), 430/63 (29) and SFS150 (31). The regression coefficient β_i values ranged from 0.67 for TRFK 303/259 (18) to 1.3 for TRIT 201/16 (3). Genotypes TRFK 12/19 (2) and TRIT 201/82 (11), recorded above average mean shoot density and $\beta_i \approx 1.0$. Genotype and $\beta_i \approx 1.0$ with non-significant S^2d_i were TRFK 12/19 (2) and TRFK 6/8 (30).

Genotypes that expressed $\beta_i > 1.0$ with non-significant S^2d_i were TRIT 201/43 (4), TRIT 201/44 (5), TRIT 201/50 (7), and TRFK 301/6 (14). Other genotypes TRFK 303/216 (17), TRFK 31/8 (20) and TRFK 371/3 (22) had $\beta_i < 1.0$ with non-significant S^2d_i. Genotypes that had non-significant S^2d_i with high predictability ($R^2i > 70\%$) were TRFK 12/19 (2), TRIT 201/43 (4), TRIT 201/44 (5), TRIT 201/50 (7), TRIT 201/73 (9), TRIT 201/82 (11), TRFK 301/4 (12), TRFK 301/6 (14), TRFK 303/178 (16), TRFK 303/216 (17), TRFK 303/577 (19), TRFK 31/8 (20), TRFK 371/2 (21), TRFK 371/3 (22), TRFK 371/6 (23), TRFK 381/5 (25), TRFK 430/7(29), TRFK 6/8 (30) and SFS150 (31). Almost all genotypes had higher predictability values of $R^2_i \geq 70\%$.

Table 2.12: Estimates of stability and adaptability for shoot density for 31 tea genotypes grown at three environments during 2014/15 to 2015/16

Serial No.	Genotype	Mean Shoots	β_i	β_i -0	1-β_i	S^2_{di}	R^2_i
1	TRFK 11/4	238	1.15±0.060	1.15*	-0.15*	438.2*	0.93
2	TRFK 12/19	243	0.99±0.050	0.99*	0.01ns	20.3	0.96
3	TRIT 201/16	273	1.30±0.002	1.30*	-0.3*	806.5**	0.92
4	TRIT 201/43	244	1.11±0.017	1.11*	-0.11*	-65.1	0.98
5	TRIT 201/44	268	1.23±0.013	1.23*	-0.23*	-94.2	0.99
6	TRIT 201/47	254	0.99±0.008	0.99*	0.01*	-125.8	0.98
7	TRIT 201/50	246	1.15±0.006	1.15*	-0.15*	-206.1	0.99
8	TRIT 201/55	285	1.07±0.001	1.07*	-0.07ns	2102.4***	0.77
9	TRIT 201/73	242	1.01±0.005	1.01*	-0.01*	-210.8	0.99
10	TRIT 201/75	268	1.26±0.001	1.26*	-0.26*	1578.4***	0.86
11	TRIT 201/82	264	0.99±0.006	0.99*	0.01ns	156.8	0.95
12	TRFK 301/4	247	0.98±0.006	0.98*	0.02*	165.1	0.94
13	TRFK 301/5	213	0.79±0.001	0.79*	0.21*	623.2**	0.84
14	TRFK 301/6	262	1.25±0.004	1.25*	-0.25*	278.4	0.80
15	TRFK 303/1199	248	0.90±0.004	0.90*	0.1*	971.4***	0.92
16	TRFK 303/178	235	1.09±0.013	1.09*	-0.09*	-84.5	0.87
17	TRFK 303/216	247	0.82±0.019	0.82*	0.18*	88.5	0.97
18	TRFK 303/259	207	0.67±0.001	0.67*	0.33*	448.0*	0.90
19	TRFK 303/577	305	1.05±0.003	1.05*	-0.05*	339.6	0.92
20	TRFK 31/8	221	0.89±0.003	0.89*	0.11*	317.2	0.90
21	TRFK 371/2	229	1.01±0.005	1.01*	-0.01ns	-184.2	0.93
22	TRFK 371/3	228	0.87±0.029	0.87*	0.13*	-29.7	0.99
23	TRFK 371/6	209	0.95±0.005	0.95*	0.05*	-179.3	0.97
24	TRFK 371/8	210	0.78±0.029	0.78*	0.22*	842.6**	0.98
25	TRFK 381/5	206	0.95±0.005	0.95*	0.05*	200.1	0.85
26	TRFK 400/10	213	0.90±0.009	0.90*	0.1*	-100.0	0.93
27	TRFK 400/4	202	0.85±0.004	0.85*	0.15*	2013.5***	0.97
28	TRFK 430/63	240	1.16±0.005	1.16*	-0.16*	2394.4***	0.81
29	TRFK 430/7	258	0.93±0.004	0.93*	0.07*	-225.3	0.70
30	TRFK 6/8	233	0.98±0.023	0.98*	0.02ns	-42.3	0.97
31	SFS150 (Ck)	251	0.93±0.007	0.93*	0.07*	-129.3	0.98
	Mean ($\bar{x}$):	242.0					
	CV (%)	3.4					

*= Significant at $P \leq 0.05$; ** Significant at $P \leq 0.01$; ***Significant at $P \leq 0.001$. Ck represent yield check. Means followed by the same letter are not significantly different at P≤0.05 by DMRT; CV (%) Coefficient of variation.

2.9.2 Relationships of regression coefficient β_i with means of yield and shoot density

2.9.2.1 Regression coefficient β_i with means of yield (kg mt ha^{-1})

Results for relationship of regression coefficient with means of yield are presented in Figure 2.3. A genotype with β_i =1.0 and above average yield is considered to respond on average with change in environment (Eberhart and Russell, 1966). Among the 31 evaluated genotypes, TRFK 430/63 (28) expressed above average mean yield values, below unity β_i (β_i <1.0). Genotype TRIT 201/16 (3) was considered to have above average mean yield with average β_i value (β_i =1.0). Genotypes with below average means and average response (β_i =1.0) were TRIT 201/47 (6), TRFK 371/6 (23), TRFK 6/8 (30) and TRIT 201/82 (11).

Genotypes with above average means of β_i values significantly deviating from unity were TRFK 303/577 (19) and TRFK 430/63 (28). Genotypes with average yield and β_i values around unit (average response) were TRIT 201/43 (4), TRIT 201/73 (9), TRIT 201/75 (10), TRFK 301/4 (12), TRFK 303/259 (18), TRFK 400/4 (27), TRFK 430/7 (29) and control SFS150 (31). Genotypes TRFK 400/10 (26) recorded both below average mean and unity β_i value.

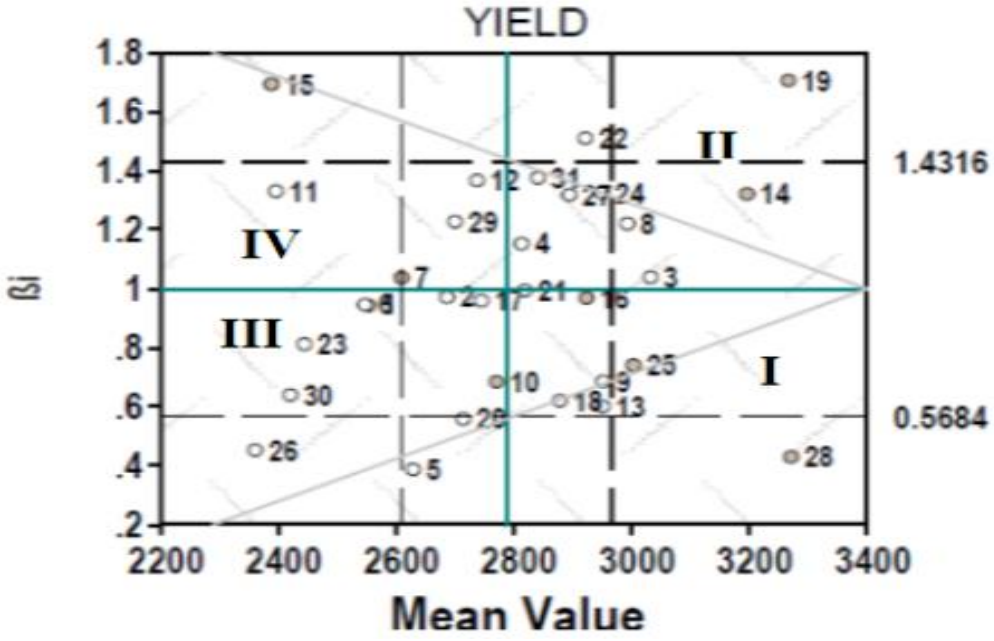

Figure 2.3: Regression coefficient β_i against mean yield (kgmtha^{-1}) for 31 tea genotypes at three locations and two seasons. o = represents tested tea genotypes.

2.9.2.2 Regression coefficient β_i with means of shoot density (shoots m^{-2})

The relationships of regression coefficient (β_i) with means of shoot density are presented in Fig. 2.4. The genotypes with above average mean shoot density and approximate unity β_i values ($x > \bar{x}$; $\beta_i \approx 1.0$) were TRIT 201/47 (6), TRIT 201/55 (8), TRIT 201/82 (11), TRFK 301/4 (12), TRFK 303/577(19) and TRFK 430/7 (29). Genotypes with above average mean shoot density and greater than unity β_i values ($x > \bar{x}$; $\beta_i > 1.0$) were TRIT 201/16 (3), TRIT 201/44 (5), TRIT 201/75 (10) and TRFK 301/6 (14). On the other hand, genotypes TRFK 11/4 (1), TRFK 12/19 (2), TRIT 201/43 (4), TRIT 201/73(9), TRFK 301/4 (12), TRFK 303/1199 (15), TRFK 303/178 (16), TRFK 371/2 (21), TRFK 6/8 (30) and SFS150 (31) exhibited average mean shoot densities with approximate unity β_i values ($x = \bar{x}$; $\beta_i \approx 1.0$).

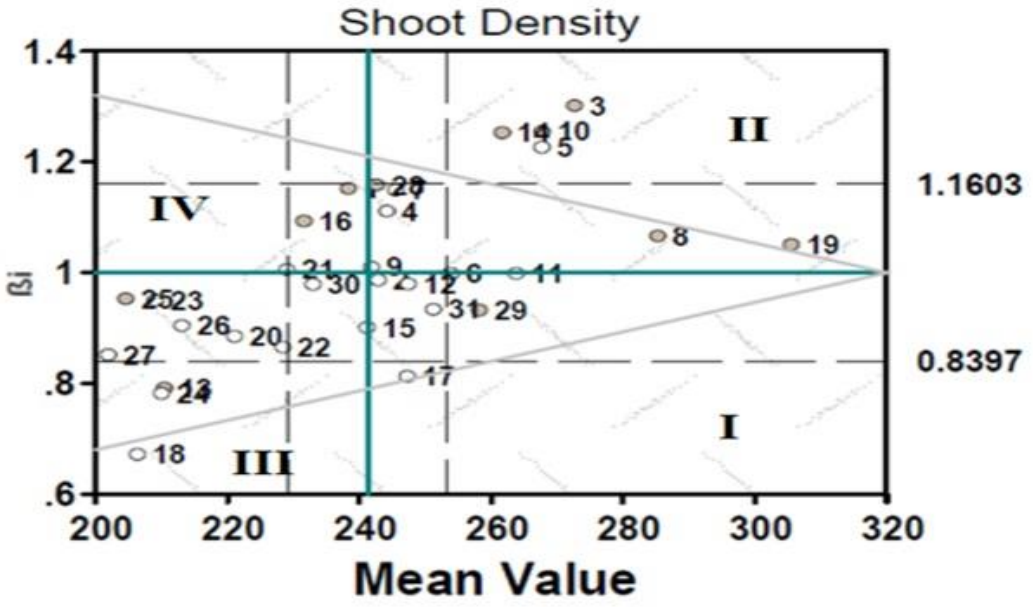

Figure 2.4: Regression coefficient β_i against mean shoots (shoots m^{-2}) for 31 tea genotypes at three locations and two seasons. o = represents tested tea genotypes.

Genotypes that registered below average mean shoot densities and less than unity β_i values ($x < \bar{x}$; $\beta_i < 1.0$) were TRFK 301/5 (13), TRFK 303/259 (18) and TRFK 371/8 (24). The other genotypes viz. TRFK 31/8 (20), TRFK 371/6 (23), TRFK 381/5 (25), TRFK 400/10 (26) and TRFK 400/4 (27) expressed below average mean shoot density and average βi values ($x > \bar{x}$; $\beta_i \approx 1.0$).

2.9.2.3 Relationships of S^2d_i and β_i with means of yield (kg mt ha^{-1})

S^2d_i and β_i with means of yield (kg mt ha^{-1})

A genotype with lower deviation from regression coefficient ($S^2d_i = 0$) and regression coefficient ($\beta_i = 1.0$) is being treated as stable (Finlay and Wilkinson, 1963). Results for relationship of variance of deviation from regression coefficient (S^2d_i) with regression coefficient (β_i) are presented in Figure 2.5. Results indicated genotypes viz. TRIT 201/16 (3), TRIT 201/43 (4), TRIT 201/50 (7), TRFK 301/6 (14), TRFK 303/577 (19), TRFK

371/3 (22), TRFK 371/8 (24), TRFK 400/4 (27) and SFS150 (31) were adapted to high performing environments with high stability (Quadrant I). Genotype TRFK 303/1199 (15) was adapting to high performing environments, but with low stability (Quadrant II).

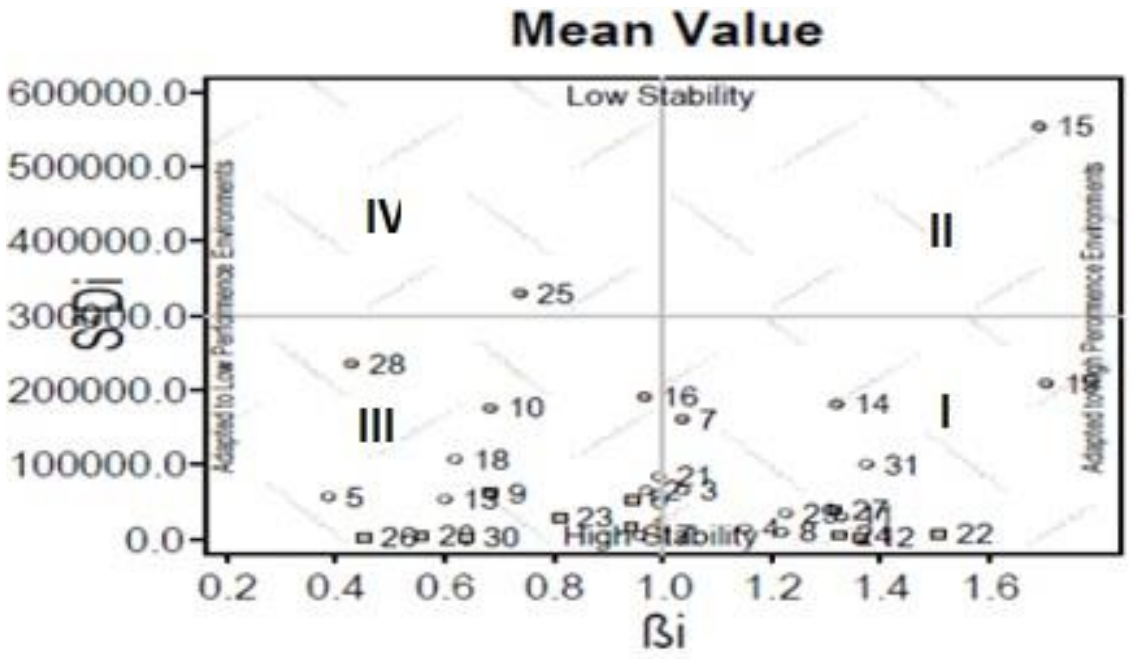

Figure 2.5: Relationships between regression coefficient (β_i) against variance of deviation from regression coefficient (S^2d_i) for yield of 31 tea genotypes at three locations and two seasons. o = represents tested tea genotypes.

On the other hand, genotypes that were adapted to low performing environments, with high stability were TRIT 201/44 (5), TRIT 201/73 (9), TRIT 201/75 (10), TRFK 303/259 (18), TRFK 31/8 (20), TRFK 400/10 (26), TRFK 430/63 (28) and TRFK 6/8 (30) (Quadrant III). The only genotype that was adapting to low performing environments with low stability was TRFK 381/5 (25) (Quadrant IV).

2.9.2.4 Relationships of S^2d_i and β_i with means of shoot density (shoots m^{-2})

Results for relationships of the deviation from regression S^2d_i and regression coefficient β_i for shoot density are given in Figure 2.6.

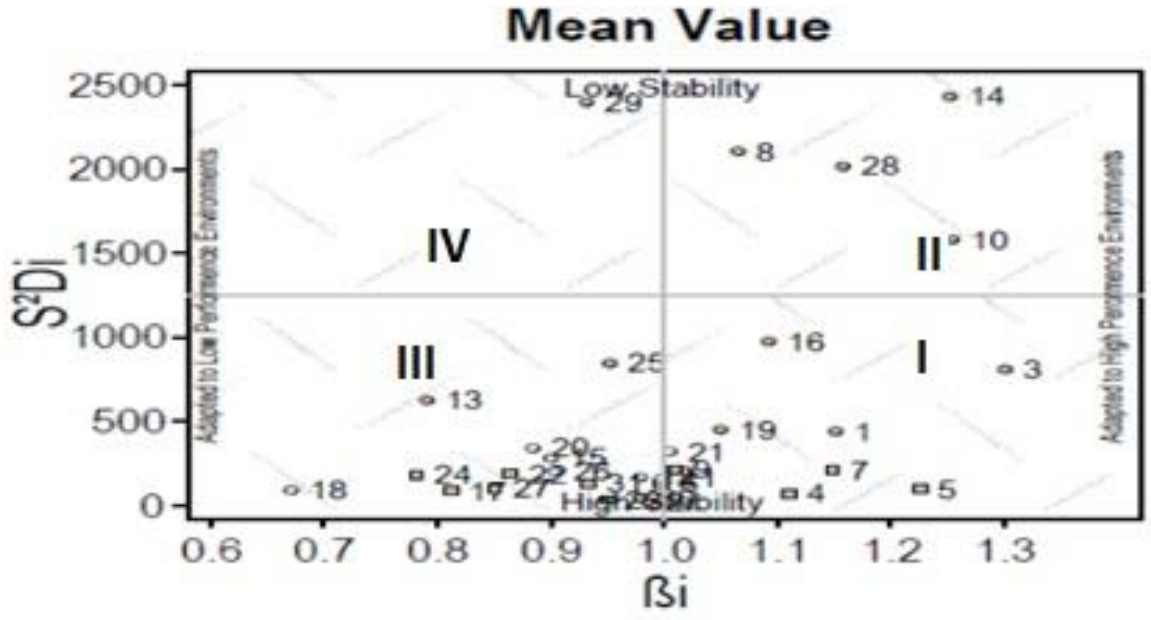

Figure 2.6: Relationships between variance from regression (S^2d_i) and regression coefficients (β_i) for shoot density of 31 tea genotypes at three locations and two seasons. o = represents tested tea genotypes.

Nine genotypes viz. TRFK 11/4 (1), TRIT 201/16 (3), TRIT 201/43 (4), TRIT 201/44 (5), TRIT 201/50 (7), TRIT 201/73 (9), TRFK 303/178 (16), TRFK 303/577 (19) and TRFK 371/2 (21) were adapted to high performing environments with high stability (Quadrant I). The four other genotypes viz. TRIT 201/55 (8), TRIT 201/75 (10), TRFK 301/6 (14) and TRFK 430/63 (28), were adapted to high performing environments with low stability (Quadrant II).

On the other hand, genotypes TRIT 201/82 (11), TRFK 303/1199 (15), TRFK 301/5 (13), TRFK 303/259 (18), TRFK 31/8 (20), TRFK 371/3 (22), TRFK 381/5 (25), TRFK 400/10 (26) and TRFK 400/4 (27) exhibited high stability and were adapting to low performing environments (Quadrant III). Genotype TRFK 430/7 (29) was adapted to low performing environments and with low stability (Quadrant IV).

2.10 Additive Main Effects and Multiplicative Interaction (AMMI) Biplot Analysis of

2.10.1 Shoot Density (shoots m^{-2})

The additive main effects and multiplicative interaction (AMMI) biplot relationship for shoot density (shoots m^{-2}) (Y) variable at six environments is presented in Figures 2.7. The model summarized patterns and relationships of 31 genotypes (o) and six environments (▫) (combined 3-locations and 2-seasons). In the AMMI model (Figure 2.6), the PCA1 score appears on the vertical axis and the mean yield on the horizontal axis.

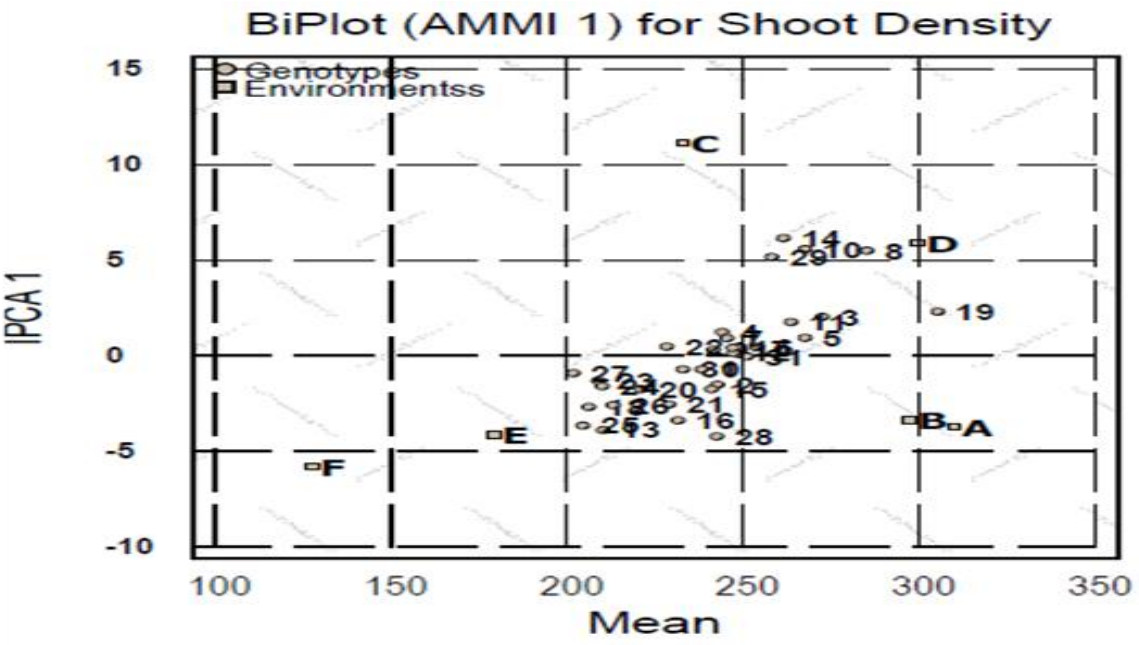

Figure 2.7: AMMI 1 biplot for shoot density (shoots m^{-2}) of 31 tea genotypes and six-environments (A-F) using genotypic and environmental IPCA scores at 3 environments and 2 seasons.

Although genotypes pattern is not quite clear in the presented figure 2.7, yet five genotypes TRFK 11/4 (1), TRFK 12/19 (2), TRIT 201/44 (5), TRFK 303/1199 (15), TRFK 301/4 (12) were aligned together almost along the vertical line (Mean shoot density = 250 shoots m^{-2}). Four genotypes TRIT 201/47 (6), TRFK 301/4 (12), TRFK 371/3 (22) and SFS150 (31) showed to align together on the horizontal axis (IPCA 1= 0).

With respect to environments, according to AMMI method, environments A, B and D that position almost on a perpendicular axis (Mean shoot density = 300 shoots m^{-2}), indicate similar mean performance. But, those which were aligned on a horizontal axis presented similar interaction patterns. Therefore, two environments B (Marikitanda: 2014/15) and D (Ngwazi: 2015/16) were aligned on the same perpendicular line (along Mean=300 shoots m^{-2}). In contrast, two environments E (Marikitanda: 2015/16) and F (Ilenge: 2015/16) appeared to be almost aligned along the same horizontal axis (along the IPCA 1= -5).

Genotypes that grouped together close to each other expressed similar performance, and genotypes that appeared close to specific environment, indicated better adaptation to that particular environment (Ayalneh *et al.,* 2013). Four genotypes TRIT 201/75 (10), TRFK 430/7 (29), TRIT 201/55 (8) and TRFK 301/6 (14) positioned close to environment D (Ngwazi 2015/16) (mean = 300 shoots m^{-2}).

In AMMI 1 biplot, genotypes or environments aligned on the right side of the midpoint of the perpendicular axis (mean = 250 shoots $^{-2}$) were expressing higher potential means unlike genotypes or environments positioned to the left side of the same vertical axis (Ayalney *et al.,* 2013). Thus, genotype TRFK 400/4 (27) was aligned to the extreme left part of the mid-perpendicular axis (Mean = 250 shoots $^{-2}$). In contrast, genotype TRFK 303/577 (19) was positioned to the extreme right side of the midpoint of the perpendicular axis (Mean = 250 shoots m^{-2}). Similarly, environments E and F were positioned far from the left side (unfavourable environments), while environments A, B, and D are positioned to the right side of the mid-perpendicular axis (Mean = 250 shoots $^{-2}$) (most favourable environments) (Fig. 2.7).

2.11 Biplot Analysis for Mean Shoot Density (shoots m^{-2})

The first two PCA (principle component analysis) axes (IPCA 1and 2) were plotted against one another to determine the G × E interactions pattern of each evaluated genotype (Figure 2.8). The AMMI Biplot analysis graphic of 31 tea genotypes in six environments over two seasons is presented in Fig. 2.8.

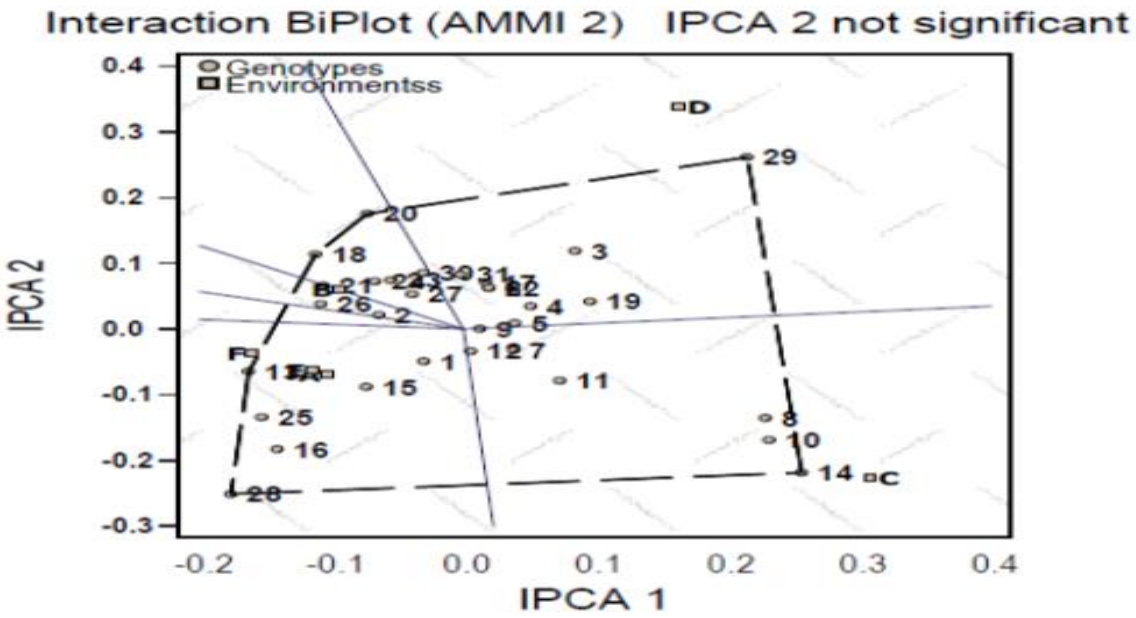

Figure 2.8: Biplot for IPCA 1 versus IPCA 2 for mean shoot density (shoots m^{-2}) of 31 tea genotypes at six environments (3 locations x 2 seaons).

Based on the AMMI model, genotypes TRFK 11/4 (1), TRFK 12/19 (2), TRIT 201/43 (4), TRIT 201/44 (5), TRIT 201/50 (7), TRIT 201/73 (9) and TRFK 301/4 (12) were positioned very close to the centre of the IPCA plot (Near zero value). In contrast, genotypes TRFK 301/6 (14), TRFK 303/259 (18), TRFK 31/8 (20), TRFK 430/63 (28) and TRFK 430/7 (29) were kept far from the centre of the IPCA plot. This implies that the genotypes were contributing to the interaction effect.

Genotypes or environments with large PCA1 score, either negative or positive will indicate large interaction. Therefore, genotypes TRIT 201/55 (8) and TRIT 201/75 (10)

and environment C scored relatively high PCA1 of positive (0. 25). On the other hand, genotype 430/63 (28) and environment F scored large negative PCA1 score of -0.25.

Three genotypes placed together within vicinity to environment B viz. TRFK 303/259 (18), TRFK 371/2 (21) and TRFK 400/10 (26). Genotype TRFK 303/259 (18), TRFK 371/2 (21) and TRFK 400/10 (26), were adapting better to environment B. Genotypes that were clustered near environment C included TRIT 201/55 (8), TRIT 201/75 (10) and TRFK 301/6 (14). Whereas, genotype TRFK 430/7 (29) was the only genotype appeared to place very close to environment D. Four other genotypes TRFK 301/5 (13), TRFK 303/1199 (15), TRFK 303/178 (16) and TRFK 381/5 (25) were grouped together around three environments A, E and F. Among the six environments, three environments A, E and F were grouped together in the IPCA plot. Clustered together the three environments A, E and F indicated had similar yield performance.

2.12 Correlation of Yield and Shoots Density with other Four Stabilities parameters

2.12.1 Yield

Results of correlation of yield with other stability parameters are given in Table 2.13.

Table 2.13: Correlations of yield and shoot density with four stability parameters

	Yield (kg mt ha^{-1})[a]						Shoot Density (shoots m^{-2})[b]				
	Mean	**β_i**	**1 - β_i**	**S^2_{di}**	**R^2_i**		**Mean**	**β_i**	**1 - β_i**	**S^2_{di}**	**R^2_i**
Mean	-					Mean	-				
β_i	0.02	-				β_i	0.61**	-			
1 - β_i	-0.02	-1.0**	-			1 - β_i	-0.63**	-0.99**	-		
S^2_{di}	0.18	0.20	-0.02	-		S^2_{di}	0.03	0.12	-0.14	-	
R^2_i	0.18	0.58**	-0.59**	-0.54**	-	R^2_i	-0.17	-0.14	0.17	-0.38*	-

KEY: Yield (kg mt ha^{-1}); β_i = Regression coefficient; 1-β_i = Deviation of regression coefficient from unity; S^2_{di} =Deviation of regression coefficient; R^2_i = Coefficient of determination; *= significantly different at p< 0.05; **= significantly different at p<0.01; SHD = Shoot density. Table 13a =Yield (kgmtha^{-1})[a]; Table 13b = Shoot Density (shoots m^{-2})[b].

For yield, the correlations among stability parameters and mean yield varied from -0.59 to 0.58. Perfect significant negative association was obtained between the regression coefficient β_i and the deviation of regression coefficient from unit 1 - β_i; r = -1.0** ($p \leq 0.01$). In contrast, the regression coefficient β_i expressed significant positive association with the coefficient of determination R^2_i; r = 0.58*($p \leq 0.01$).

The deviation of regression coefficient from unit 1 - β_i displayed significant and negative correlation r = -0.59* ($p \leq 0.01$) with the coefficient of determination (R^2_i). On the other hand, the deviation from regression coefficient S^2d_i exhibited significant negative correlation r = -0.54**($p < 0.01$) with the coefficient of determination R^2_i.

2.12.2 Shoot density

Results for correlation of shoot density with other evaluated stability parameters are given in Table 2.13. The correlation for mean shoot density varied from -0.99 to 0.61. The mean shoot density $\bar{x}$ exhibited significant positive correlation r = 0.61** ($p \leq 0.01$) with the coefficient of regression β_i. On the other hand, mean shoot density significantly correlated negatively r = -0.63** ($p \leq 0.01$) with the deviation of regression from unit 1 - β_i. The regression coefficient showed significant negative (near perfect) correlation r = -0.99** ($p \leq 0.01$) with the deviation of regression coefficient from unit 1 - β_i. The variance of deviation from mean regression S^2d_i and coefficient of determination R^2_i were significantly and negatively correlated r = -0.38* ($p \leq 0.05$).

2.13 Correlations of Test-environments with Yield and Shoot Density Variables

2.13.1 Yield

The association among test environments in yield trait using 31 evaluated tea genotypes is showed in Table 2.14.

Table 2.14: Correlation coefficients between environments (Combination of locations and seasons) for yield (a) and shoot density (b) traits

	Yield (a)						Shoot Density (b)					
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**
E2	-0.19	-					0.50*	-				
E3	0.36*	-0.04	-				0.56*	0.50*	-			
E4	0.63**	-0.19	0.14	-			0.59*	0.28	0.27	-		
E5	0.10	0.44*	0.47*	0.10	-		0.50*	0.63**	0.47*	0.39*	-	
E6	0.14	0.26	0.82**	-0.03	0.63**	-	0.43*	0.39*	0.60**	0.04	0.60**	-

Key: E1= Ngwazi 2014 -15, E2 = Marikitanda 2014-15, E3=Ilenge 2014-15, E4 = Ngwazi 2015-16, E5 = Marikitanda 2015-16, E6 = Ilenge 2015-16. *, ** significant at $p \leq 0.05$ and 0.01, respectively.

The environment E1 (Ngwazi: 2014/15) significantly and positively correlated r = 0.36*(p≤ 0.05) with E3 (Ilenge: 2014/15) and E4 (Ngwazi: 2015/16) r = 0.63** (p≤ 0.01). Significant positive correlation of r = 0.44*(p≤ 0.05), was observed from the same Marikitanda location in different seasons of 2014/15 and 2015/16.

The environment E3 (Ilenge: 2014/15) with E5 (Marikitanda: 2015/16) r = 0.47* (p≤ 0.05) and E6 (Ilenge: 2015/16) r = 0.82**(p≤ 0.01) expressed significant positive correlations. Environments E5 (Marikitanda: 2015/16) and E6 (Ilenge: 2015/16) indicated highly significant and positive correlation r = 0.63** (p≤ 0.01) between the two.

2.13.2 Shoot density

Results for correlations among environments on shoot density are given in Table 14. For shoot density, environment E1 had significant positive correlations with E2 (r = 0.50*), E3 (r = 0.56*), E4 (r = 0.59*), E5 (r = 0.50*) and E6 (r = 0.43*). Environment E2 also correlated significantly positive with E3 (r = 0.50*), E6 (r = 0.39*), E5 (r = 0.63**). Similarly, E4 and E5 correlated significantly positive (p≥ 0.05) and E5 with E6 (r = 0.63**).

2.14 Correlations of Yield with Shoot Density at Different Environments

Table 2.15 presents the relationships (r-value) between shoot density and yield at each of the location – season combination.

Table 2.15: Relationships between yields (kg mt ha^{-1}) and shoot density (shoots m^{-2}) at different environments (location-season)

Environment	Correlation (r)*
E1 (Ngwazi 2014/15)	0.214
E2 (Marikitanda 2014/15)	0.128
E3 (Ilenge 2014/15)	-0.289
E4 (Ngwazi 2015/16)	0.089
E5 (Marikitanda 2015/16)	-0.054
E6 (Ilenge 2015/16)	-0.200

*Degrees of freedom n-2 = 29; r = 0.355 ($p \leq 0.05$); r = 0.456 ($p \leq 0.01$); E1 – E6 = Environment 1 to 6.

Analysis was conducted to determine the relationship between yields and shoot density at varied geographical locations. The results indicated that yield exhibited non-significant correlations with shoot density at each of the environments.

2.15 Summarized Performance for Yield and Shoot Density Traits

2.15.1 Yield

The summarized performance and stability parameters for yield trait are presented in Table 2.16. Genotypes that had mean yield consistently greater than the overall mean at each location and during all seasons were viz. TRIT 201/16 (3), TRFK 301/6 (14), TRFK 303/577 (19) and TRFK 371/8 (24) (Table 2.16). Genotypes TRIT 201/44 (5), TRIT 201/55 (8), TRFK 301/5 (13), TRFK 381/5 (25), TRFK 400/10 (26) and TRFK 400/4 (27) showed consistently greater than the overall mean yield during both seasons. Other genotypes were variously detected by stability parameters on the yield trait.

Table 2.16: Summarized performance for yield trait

Serial No.	Genotype	$\bar{x}$ consistently > overall mean at each location	$\bar{x}$ consistently > overall mean during each season
1	TRFK 11/4	X	X
2	TRFK 12/19	X	X
3	TRIT 201/16	+	+
4	TRIT 201/43	X	X
5	TRIT 201/44	X	+
6	TRIT 201/47	X	X
7	TRIT 201/50	X	X
8	TRIT 201/55	X	+
9	TRIT 201/73	X	X
10	TRIT 201/75	X	X
11	TRIT 201/82	X	X
12	TRFK 301/4	X	X
13	TRFK 301/5	X	+
14	TRFK 301/6	+	+
15	TRFK 303/1199	X	X
16	TRFK 303/178	X	X
17	TRFK 303/216	X	X
18	TRFK 303/259	X	X
19	TRFK 303/577	+	+
20	TRFK 31/8	X	X
21	TRFK 371/2	X	X
22	TRFK 371/3	X	X
23	TRFK 371/6	X	X
24	TRFK 371/8	+	+
25	TRFK 381/5	X	+
26	TRFK 400/10	X	+
27	TRFK 400/4	X	+
28	TRFK 430/63	X	X
29	TRFK 430/7	X	X
30	TRFK 6/8	X	X
31	SFS150 (Ck)	X	X

+ = Outperformed the overall yield means at each locations or seasons; x = not excelled the overall yield means at each location or season; Ck= Check variety.

2.16.2 Shoot density

On shoot density trait, eleven genotypes viz. 201/16 (3), TRIT 201/44 (5), TRIT 201/47 (6), TRIT 201/55 (8), TRIT 201/82 (11), TRFK 301/4 (12), TRFK 301/6 (14), TRFK 303/1199 (15), TRFK 303/216 (17), TRFK 303/577 (19) and SFS150 (31) performed consistently above average both at all locations and during the two seasons (Table 2.17). Results also indicated genotype TRFK 430/7 (29) had consistent higher shoot density performance at all locations, while TRFK 12/19 (2), TRIT 201/50 (7) and TRIT 201/75 (10) presented similar results during all seasons. The other genotypes did not express consistent high shoot density above average either at all locations or during both seasons.

Table 2.17: Summarized performance and stabilities for shoot density trait

Serial No.	Genotype	$\bar{x}$ consistently > overall mean at each location	$\bar{x}$ consistently > overall mean during each season
1	TRFK 11/4	x	X
2	TRFK 12/19	x	+
3	TRIT 201/16	+	+
4	TRIT 201/43	x	X
5	TRIT 201/44	+	+
6	TRIT 201/47	+	+
7	TRIT 201/50	x	+
8	TRIT 201/55	+	+
9	TRIT 201/73	x	X
10	TRIT 201/75	x	+
11	TRIT 201/82	+	+
12	TRFK 301/4	+	+
13	TRFK 301/5	x	X
14	TRFK 301/6	+	+
15	TRFK 303/1199	+	+
16	TRFK 303/178	x	X
17	TRFK 303/216	+	+
18	TRFK 303/259	x	X
19	TRFK 303/577	+	+
20	TRFK 31/8	x	X
21	TRFK 371/2	x	X
22	TRFK 371/3	x	X
23	TRFK 371/6	x	X
24	TRFK 371/8	x	X
25	TRFK 381/5	x	X
26	TRFK 400/10	x	X
27	TRFK 400/4	x	X
28	TRFK 430/63	x	X
29	TRFK 430/7	+	X
30	TRFK 6/8	x	X
31	SFS150 (Ck)	+	+

+ = Outperformed the overall shoot density means at each locations or seasons; x = not excelled the overall shoot density means at each location or season, Ck=Check variety.

2.17 Summarized Performance at High, Low Environments and Stabilities for Yield Trait

2.17.1 Yield

The summarized results on performance of genotypes in high performing environments is shown in Appendix 2.7. Genotypes TRIT 201/43 (4) and TRIT 201/55 (8) were optimally detected by all stability parameters in high performing environments. These were stable ($S^2d_i = 0$), had average response ($\beta i \approx 1.0$) and expressed high coefficient of determination (R^2_i) for yield of tea. All stability parameters except for reliability in response ($R^2_i \geq 70\%$) were favourable for genotypes TRIT 201/16 (3), TRFK 301/6 (14), TRFK 371/2 (21) and TRFK 371/8 (24). All stability parameters except for average response ($\beta i \neq 1.0$) favoured only genotype TRFK 400/4 (27).

Genotypes TRFK 12/19 (2), TRIT 201/47 (6), TRFK 31/8 (20) and TRFK 6/8 (30) were identified by all stability parameters at low performing environments for yield (Appendix 2.8). Genotype TRFK 400/10 (26) was detected by all stability parameters at low performing environments except for the average response ($\beta i \neq 1.0$) in yield of tea.

2.17.2 Shoot density

Results on shoot density at high and low performing environments are shown in Appendices 2.9 and 2.10. Four genotypes viz. TRIT 201/43 (4), TRIT 201/73 (9) and TRFK 303/577 (19) were preferably detected by all stability parameters at high performing environments for shoot density trait (Appendix 2.9). Two genotypes TRIT 201/16 (3) and TRIT 201/44 (5), also were detected by all stability parameters for shoot density at high performing environments except for the average response ($\beta i \neq 1.0$). Similarly, all stability parameters favoured genotypes TRIT 201/55 (8) and TRFK 303/1199 (15) for high performing environments except for the stability ($S^2d_i > 0$).

On the other hand, genotypes TRFK 303/1199 (15) and TRFK 303/216 (17) were identified by all stability parameters at low shoot density performing environments (Appendix 2.10). The TRFK 381/5 (25) was detected by all stability parameters except for the average response ($\beta_i \neq 1$); while TRFK 430/7 (29) also was detected by all stability parameters except for the stability ($S^2d_i \neq 0$) all at low shoot density performing environments.

2.18 Discussions

2.18.1 Performance of 31 tea genotypes at 3 test locations during 2 seasons (2014/15 and 2015/16).

Change in ranks performance among 31genotypes was evident during the present study, indicating existence of genotype × location interaction for shoot density on the tea crop (Nyabundi *et al.*, 2016). The genotype × location interaction on yield was significant, indicating that the expression of genotypes depends on location. Therefore, selecting superior genotypes for yield could be a challenge on tea crop. The best option should be to select a group of genotypes instead of single genotype for each location (Arshad, 2003). However, each genotype should show statistically similar performance at each location.

The genotype (G), location (L) and season (S) main effects were highly significant for yield. Similarly, the first order interaction of location (L) × season (S) was significant, indicating that genotypes were highly influenced by seasons and locations (Ackgoz *et al.*, 2009). This suggests that, evaluation of genotypes for yield over several seasons and locations should be a strategy while selecting for superior tea genotypes. Significant genotype × location, indicated that both genotypes and locations had effects on the expression of tea yield and that specific combinations of these factors can provide good

expressions. For yield combination of genotypes × seasons that significantly gave higher yields in both seasons was TRFK 303/577 (19). For combination of genotypes × location for yield, genotype TRFK 303/577 (19) only at Ngwazi location gave significantly the highest yields only at Ngwazi location.

The location (L) mean effects accounted for 76.3% of total variation in yield and 85.8% in shoot density. The location (L) × season (S) interaction effects accounted for 13.3% of the total mean squares in yield and 12.5% in shoot density, suggesting that the location main effects influenced the expression of both traits though more for shoot density than yield (Satoto *et al.,* 2016). Shoot density is one of the major tea yield components (Wijeratne, 2003, Nyabundi *et al.*, 2016) and thus in order to improve tea yield, Wijeratne (2003) suggested improvement of shoot density.

The genotype (G) × location (L) interaction was significant on both shoot density and yield, suggesting the performance of genotypes depends on location. Therefore, selecting superior genotypes for shoot density and yield based on overall locations scenario may be difficult. The best alternative should be to select a group of genotypes instead of a single genotype for each location (Arshad, 2003). Thus, specific combinations of genotype (G) × location (L) for high shoot density were TRIT 201/55 (8), TRIT 201/75 (10), TRFK 301/6 (14), and TRFK 303/577 (19) at Marikitanda; and TRIT 201/16 (3), TRIT 201/44 (5), and TRFK 303/577 (19) at Ilenge site.

The location (L) main effects for shoot density accounted for 85.8% of the total mean squares (TMS), indicating significant influence of location on shoot density expression among genotypes. In this case, Ilenge site could be considered the most suitable environment for shoot density production.

The genotype × season and second order interactions (G × S × L), also were significant, each accounting for 0.1% of the total mean squares. Thus, for genotype × season combination, genotype TRFK 303/577 (19) specifically performed well during both seasons in shoot density. The observed location variations were attributed to agro-ecological conditions (Venkatesan *et al.*, 2004; Carter, 2007). For instance, during the two seasons, Ngwazi recorded lower precipitation of 873.6mm with average temperature of 22.3°C. Marikitanda received average rainfall of 1687.6mm with relatively low maximum temperature of 20.9°C. Ilenge received a relatively higher precipitation of 2103.8 mm and higher mean maximum temperature of 24.7°C. To a large extent, the Marikitanda conditions fall within the optimal conditions for tea production. Kamau (2008) described optimal tea growing conditions that include warm humid tropical climate with fairly well distributed rainfall of at least 1 000 mm annually. A wide range of soils but loamy soils or red clays of volcanic origin are more desirable.

Air temperature affects tea yield mainly through the rate of photosynthesis (Tanton, 1982), change in plant mesophyll activities (Barbora, 1994) and respiration which controls growth (Bhagat *et al*., 2010). Also, both Ngwazi and Marikitanda locations, had sandy clay loam soil texture which allows good soil drainage yet retaining required moisture for normal tea growth. However, the soils at Ilenge were sandy loam textured which does not retain enough moisture after drainage.

The highest recorded mean yield at Ngwazi followed by Marikitanda locations could be influenced both by climate and edaphic conditions (Satoto *et al.*, 2016). Both locations received moderate mean precipitation of 873.5 and 1687mm, respectively with optimal minimum and maximum temperatures of 12-13 °C and 21.0 - 22.0°C) and sandy clay loam

soil texture which provides good drainage for tea bush (Makweta pers. Comm, 2017). Good drainage is reported to improve tea yields by 30% to 55 % over a period of time (Bhagat, 2010).

Tea grows well within optimal maximum temperature range of 18 - 25 ^{o}C; below 13^{o}C and above 30 ^{o}C reduces shoot growth (Carr, 2012). Good shoot density performance at Ilenge could mainly be attributed to optimal temperature (24.3 ^{o}C) and relatively higher well distributed rainfall (>2 000 mm) throughout the year in the sandy loam textural soils. Such conditions favoured higher shoot density production within the tea canopy. However, this could have caused shoot density intra-plant competitions affecting shoot weight through reduced rate of photosynthesis and consequently yield (De Costa *et al.*, 2007).

2.18.2 Main effects

The main effects for genotypes indicated genotypes TRFK 430/63 (28) gave significantly highest mean yield exceeding the control SFS150 (31) and overall mean by 13.8% and 14.8% respectively (Table 3). TRFK 303/577 (19) had significantly highest shoot density. It excelled above the control SFS150 (31) and the overall mean by 17.7% and 20.4% respectively for shoot density trait. Results on yield and shoot density potential at Ngwazi and Ilenge respectively were in agreement with Kamunya *et al.* (2011) report especially for Ngwazi, but it contradicted on Ilenge site. With respect to season main effects, higher yield was recorded during the first season (2014/15), while shoot density did not show significant differences between the two seasons. The variation of genotypes, locations and seasons on yield (Wachira *et al*., 2002; Kamunya *et al*., 2011; 2012; Makola, 2013; Nyabundi *et al*., 2016) and shoot density (Makola, 2013) is widely reported. Thus, for

optimal tea production, there is a possibility to evaluate new locally developed/introduced genotypes and select for superior genotypes, suitable locations and seasons.

2.18.3 Interactions effects

The significant genotype and season interaction (G*S) effect on shoot density. could be attributed to good precipitation distribution especially during 2014/15 (June 2014 to May 2015) almost at all locations. As a result, genotype TRFK 303/577 (19) recorded highest mean shoot density during 2014/15. Poor precipitation distribution was evident at Ngwazi location during 2015/16 (June 2015 to May 2016, this may have contributed to low shoot density during the season. Makola (2013) reported significantly higher shoot density at Kipkebe (Sotik) location where precipitation was relatively higher.

The significant genotype and location interaction (G*L) effect for yield indicated genotype TRFK 303/577 (19) gave highest yield at Ngwazi location. This implies that Ngwazi location was the most potential for tea yield production. At regional tea trial, Kamunya *et al.* (2011) also reported similar results in Tanzania. The variation among genotypes on yield performance across locations was due to genetic composition as influenced by ability to exploit the existing environmental resources (De Costa *et al*., 2007). Thus, selection for high tea yielding genotypes at specific locations is possible. The results were in agreement with those of Nyabundi *et al.* (2016) who also identified genotype TRFK 303/577 (19) as outstanding for tea yield across three locations in Kenya.

Genotype TRIT 201/55 (8) recorded the highest mean shoot density at Marikitanda location. The superior shoot density performance at Marikitanda was favoured by relatively high and well distributed precipitation in 2014/15 (November – April) and

during 2015/16 (March - May) and favourable mean min. and max. temperatures of 13.3ºC and 20.9ºC. Carr (2012) reported the optimal temperature for shoot density growth of between 13.0ºC and 25ºC. Nyabundi *et al.* (2016) reported variations among tea clonal genotypes on shoot density due to location effects in Kenya. Makola (2013), also had similar results on tea genotype TRIT 201/55 (8) at two varied locations in Kenya.

2.18.3 Environmental index for shoot density and yield

On the basis of high or low mean tea yield with positive or negative environmental index values, Ngwazi (3 397kg mt ha^{-1}; Ij = 602) was the most favourable site for tea yield during 2014/15. During this season, Ngwazi received minimum temperature of 12.0ºC, slightly lower than the minimum base temperature (13.0ºC) by 1.0ºC and maximum temperature of 22.1ºC within optimal range. Such conditions could have favoured both normal shoot growth rate and the gain in shoot weight which positively influenced tea yield.

In contrast, Ilenge - 2014/15 (2 290 kg mt ha^{-1}; Ij = - 496) site was considered poor environment for yield. The results agreed with those of Kamunya *et al.* (2011) who cited Ngwazi as one of the potential location for tea yield production. Ilenge -2014/15 (310 shoots m^{-2}; Ij = 69) was considered the most productive site for shoot density due to high maximum temperature i.e. 24.9ºC and precipitation 2 025 mm. The conditions favoured fast shoot density formation creating intra-competition within the tea canopy, thus, reducing shoot weight and yield (De Costa, 2007).

Conversely, Ngwazi which recorded relatively low shoot density (127 shoots m^{-2}) and negative Ij = -114 was considered poor environment for shoot density. Such performance

could be due to relatively low minimum temperature (12.0^{o}C) which was lower by 1^{o}C below the critical base temperature (13.0^{o}C), maximum (22.1^{o}C) temperature with precipitation of 701.1 mm. Ngwazi and Ilenge locations could be suitable for evaluation and selection of promising tea genotypes on yield and shoot density respectively.

2.18.4 Correlations of yield and shoot density with four stability parameters

The perfect significant negative correlation of β_i with 1 - β_i both for yield and shoot density traits suggested that, as an increment is made on β_i value, it causes reduction in 1 - β_i by a similar proportion. Results implies that highly responsive tea genotypes to environmental changes for yield or shoot density are associated with low deviation of regression from unit (1 - β_i) (Paroda and Hayes, 1970). Therefore, selecting genotypes using β_i and 1 - β_i parameters could identify more responsive tea genotypes with low deviation from average response on either yield or shoot density traits or both (Temesgen *et al.*, 2015). Such genotypes can be recommended where agricultural-inputs may not be a limiting factor.

The significant negative correlation 1 - β_i with R^2_i stability parameters both in tea yield and shoot density traits implied that genotypes with low 1 - β_i values had high predictability (R^2_i) in their response, results to a more responsive genotype. Such genotypes tend to be less stable due to high S^2d_i. Thus, selecting for low 1 - β_i also leads to selecting for high S^2d_i and less stable genotypes.

The significant negative relationship of S^2d_i with R^2_i on tea yield and shoot density traits suggested that, genotypes with high stability, were associated with higher predictability. Therefore, selecting genotypes of low S^2d_i can result to genotype with high predictability

in response i.e. high R_i^2 value. The results agreed well with KiliÇ (2012) on bread wheat (*Triticum aestivum* L.) and Kaya and Ozer (2014) on *Triticale* (×*Triticosecale* Wittmack).

The association of 1 - β_i with S^2d_i was negative and significant for shoot density suggesting that, in tea crop low 1 - β_i associated with high S^2d_i, indicates genotype is more responsive to environmental changes. Such genotype tends to be less stable i.e. high S^2d_i. Therefore, selecting tea genotype for low 1 - β_i also selects for high S^2d_i, hence less stable. Thus, selecting tea genotype for low 1 - β_i also selects for high S^2d_i and less stable.

The positive and significant association between β_i with mean tea shoot density, implied that, genotypes with high β_i values respond more to changing environments. Thus, the two stability parameters can be used as criteria to identify and select tea genotypes responsive to favourable environments for higher shoot density performance (Djuroviæ *et al.*, 2014; Temesgen *et al.*, 2015).

The negative significant correlation between mean shoot density with 1 - β_i values, indicated that genotypes with high 1 - β_i values will be associated with low mean shoot density ($\bar{x}$). Such genotypes will demonstrate low response to favourable conditions, hence, low mean shoot density performance (Temesgen *et al.*, 2015) especially when inputs are provided.

2.18.5 Relationships between means with β_i, S^2d_i and R^2 on yield and shoot density traits

2.18.5.1 Yield

An ideal genotype is one with high mean performance, a unit regression coefficient (β_i =1.0) and low deviation from mean regression (S^2d_i = 0) (Eberhart and Russell, 1966).

Genotypes TRIT 201/43 (4) and TRIT 201/55 (8) which expressed average response (β_i = 1.0), high stability (S^2d_i = 0) and high predictability ($R^2_i \geq 70\%$) values, in high yield performing environments. may be considered for production in high performing environments with certainty.

Genotype TRFK 303/577 (19) also had above average mean yield and β_i value greater than unit ($\beta_i > 1.0$), low S^2d_i = 0 with high predictability ($R^2_i \geq 70\%$) value, indicating higher sensitivity to environmental change and greater adaptability to high tea yield performing environments.

The genotypes TRFK 12/19 (2), TRIT 201/47 (6), TRFK 31/8 (20) and TRFK 6/8 (30) which had $\bar{x}$ < overall mean, $\beta_i \approx 1.0$), low mean square for deviation from regression (S^2d_i = 0) and high predictability ($R^2_i \geq 70\%$), were adapting better to low tea growing environments. Such genotypes can be considered for low tea growing environments where tea yield response may be low due to average response to agricultural inputs.

2.18.5.2 Shoot density

Genotypes including TRIT 201/43 (4), TRIT 201/73 (9) and TRFK 303/577 (19) showed $\bar{x}$ greater than mean shoot density performance, high stability (S^2d_i = 0) and high predictability ($R^2_i \geq 70\%$) values in high shoot density performing environments, suggested better adaption to high tea shoot density performing environments. Similarly, genotypes TRFK 303/1199 (15) and TRFK 303/216 (17), TRIT 201/73 (9) expressed $\bar{x}$ greater than average shoot density performance, with approximate unity β_i value ($\beta_i \approx 1.0$), high stability and high predictability ($R^2_i \geq 70\%$) values, suggested that, the genotypes may be suitable in high tea shoot density performing environments. Interestingly, genotype TRIT 201/43 (4)

revealed $\bar{x}$ greater than mean performance, $\beta_i > 1.0$ high stability ($S^2d_i = 0$) and high predictability ($R^2_i \geq 70\%$) values in high tea performing environments both for yield and shoot density traits. The genotype can be recommended for production and improvement for tea yield in high tea performing environments.

2.18.5.3 Biplot analysis for mean shoot density (shoots m^{-2})

Due to placement near the origin of the AMMI centre, genotypes TRFK 11/4 (1), TRFK 12/19 (2), TRIT 201/43 (4), TRIT 201/44 (5), TRIT 201/50 (7), TRIT 201/73 (9) and TRFK 301/4 (12) indicated less responsiveness to environmental changes. According to Miranda *et al.* (2009) and Kadhem and Baktash (2016), the genotypes were contributing less to genotype × environment interaction (GEI). In contrast, genotypes TRFK 301/6 (14), TRFK 303/259 (18), TRFK 31/8 (20), TRFK 430/63 (28) and TRFK 430/7 (29) which were placed far from centre of origin contributed most to G × E interaction. Such genotypes revealed inconsistence in shoot density performance; thus, specific environments should be suitable for them. Kadhem and Baktash (2016) had similar results in wheat bread crop.

Placement of tea genotypes close to specific environment indicated better adaptation to specific environment (Ilker *et al*., 2009). Therefore, two genotypes TRFK 303/259 (18) and TRFK 371/2 (21) were better adapting to environment B, while TRIT 201/55 (8) and TRIT 201/75 (10) to environment C and TRFK 301/5 (13) and TRFK 381/5 (25) to Ngwazi (A), Marikitanda (E) and Ilenge (F) environments. Two genotypes TRFK 303/178 (16) and TRFK 381/5 (25) were better adapted to environments Ngwazi (A) and Marikitanda (E) (Figure 6). Such differential but same rankings of tea genotypes across environments indicated possible existence of both crossover and non-crossover GEI. This emphasizes that field technical personnel should take on board the specific

recommendations to maximize utilization of the genotypes. İlker *et al.* (2009) had similar results in maize (*Zea mays* L.). Genotypes TRFK 303/1199 (15) and TRFK 303/216 (17) indicated similarity in presenting $\bar{x}$ greater than mean shoot density performance, high stability ($S^2d_i = 0$) and high predictability ($R^2_i \geq 70\%$) values in low tea shoot density performing environments.

2.18.6.4 Correlations between environments (Combination of locations and seasons) for yield and Shoot density traits

The association of Ngwazi with Marikitanda and Ngwazi with Ilenge locations was significant and positive. This indicates that Ngwazi location contributes similar responses on tea yields and shoot density with Marikitanda and Ilenge locations, respectively. Therefore, testing developed improved tea materials to identify superior genotypes for yield and shoot density traits may be possible using either of the locations (Wachira *et al.*, 2002).

The similarity between Ngwazi and Marikitanda environments could be attributed to similar soil texture i.e. sandy clay loam and mean maximum temperatures of 22.3^{o}C and 24.4^{o}C within tea growth optimal temperatures range of 18^{o}C -25^{o}C (Carr, 2012).

The significant positive association for Ngwazi to different seasons, were reflected in similar tea yields response at each of the tested seasons. Such response could be attributed to same environment or location and minimal fluctuations of seasonal conditions. Therefore, the expected variation such as climate and precipitation was minimal. For instance, during 2014/15, Ngwazi received a total precipitation of 701.1mm, which was less by 345 mm compared to 2015/16. The mean min. and max. temperatures were 12.0^{o}C and 22.1^{o}C during 2014/15 and 12.0^{o}C and 22.5^{o}C during 2015/16 (1 045.9 mm). The

seasonal differences in terms of temperature was evident only in minimum temperature. Similar association was observed at Marikitanda location. During the two seasons, Marikitanda received precipitation amounting to 1649.9 mm and 1 725.3 mm during 2014/15 and 2015/16, respectively, a difference of 75.4 mm. The mean min and max temperatures were 12.9^{o}C and 21.4^{o}C during 2014/15 and 13.6^{o}C and 20.5^{o}C during 2015/16, presented only marginal variations of 0.7^{o}C and 0.9^{o}C. At Ilenge location, the mean min and max. temperatures differed by 0.4^{o}C and 158.2 mm for maximum temperature and precipitation, respectively, but, the mean min temperature did not vary between the seasons.

The association between E2 (Marikitanda: 2014/15) with E5 (Marikitanda: 2015/16) was positive and significant for yield and shoot density. Comparable relationship was evident between E2 (Marikitanda 2014/15) with E3 (Ilenge 2014/15) for yield and shoot density, indicating that during diverse or parallel seasons, Marikitanda location presents similar response for yield and shoot density traits.

When environment E4 (Ngwazi 2015/16) was evaluated with E5 (Marikitanda 2015/16) on shoot density, they displayed significant positive association. This indicated that Ngwazi and Marikitanda expressed similar shoot density performance on tea crop. Significant positive correlation was also observed between E1(Ngwazi 2014/15) with E5 (Marikitanda 2015/16) and E1(Ngwazi 2014/15) with E6 (Ilenge 2015/16). This implies that, Ngwazi location expressed similar responses on shoot density when evaluated with Marikitanda and Ilenge locations during different seasons.

2.18.6.5 Relationship between environments for yields and shoot density

The significant positive correlation between E1 (Ngwazi 2014/15) with E3 (Ilenge 2014/15) and E4 (Ngwazi 2015/16); E2 (Marikitanda 2014/15) with E5 (Marikitanda

2015/16); E3 (Ilenge 2014/15) with E5 (Marikitanda 2015/16) and E6 (Ilenge 2015/16); E5 (Marikitanda 2015/16) with E6 (Ilenge 2015/16) on tea yield; suggested the pair of environments varied in a similar pattern for yield of tea. Thus, they have similar tea growing conditions for yield. With respect to shoot density, the significant and positive association of environments E2 (Marikitanda 2014/15) with E3 (Ilenge 2014/15); E5 (Marikitanda 2015/16) with E6 (Ilenge 2015/16); E3 (Ilenge 2014/15) with E5 (Marikitanda 2015/16), E4 (Ngwazi 2015/16) with E5 (Marikitanda 2015/16) and E5 (Marikitanda 2015/16) with E6 (Ilenge 2015/16), suggested that most pairs of environments varied in a similar way. Therefore, similar conditions exist among environments for shoot density development.

2.18.6.6 Relationship between yields and shoot density at different environments

The yield and shoot density at different environments had varied associations. Considering all locations separately, yield and shoot density were not significantly associated. This suggested that there is opportunity to improve either of the traits without adversely affecting the other. Neranjana *et al.* (2014) also reported low direct and indirect correlation both for tea shoot density and yield traits due to environmental influence.

2.19 Summarized Performance at High and Low Performing Environments and Stabilities for Yield Trait

2.19.1 Yield

Genotypes TRIT 201/43 (4) and TRIT 201/55 (8) were optimally detected by all stability parameters, suggesting that the genotypes were adapting to high yield performing environments. They expressed average response ($\beta_i \approx 1.0$), higher stability ($S^2d_i = 0$) and predictability ($R^2_i \geq 70\%$) for yield trait. Thus, they could be considered for

commercialization in high tea yield performing environments. Genotypes TRIT 201/16 (3), TRFK 301/6 (14), TRFK 371/2 (21) and TRFK 371/8 (24) were detected by all stability parameters except for reliable response ($R^2_i \geq 70\%$). Such genotypes may be incorporated in tea breeding programmes through crossing with either of the genotypes TRIT 201/43 (4) and TRIT 201/55 (8) to gain well predictable response background.

All of the stability parameters except for average response ($\beta_i \neq 1.0$) favoured only genotype TRFK 400/4 (27), thus, in order to gain the average response background, TRFK 400/4 could be crossed with TRIT 201/43 (4) and TRIT 201/55 (8).

Genotypes TRFK 12/19 (2), TRIT 201/47 (6), TRFK 31/8 (20) and TRFK 6/8 (30) were optimally identified by all stability parameters in low performing environments for yield. The genotypes may be considered for production in low tea performing environments where sometimes tea suffers from stresses such as nutritional deficiencies. Similar findings are widely reported in clonal tea crop (Wachira *et al.*, 2002; Kamunya *et al.*, 2012, Makola, 2013). Genotype TRFK 400/10 (26) was also detected by all stability parameters at low performing environments except the average response ($\beta_i \neq 1.0$) for yield. Therefore, crossings could be designed using genotypes such as TRFK 12/19 (2), TRIT 201/47 (6), TRFK 31/8 (20) and TRFK 6/8 (30) to incorporate desirable stability traits in the same background.

2.19. 2 Shoot density

Results on shoot density at high and low performing environments are shown in. In tea crop shoot density is the key yield components. Three genotypes; TRIT 201/43 (4), TRIT 201/73 (9) and TRFK 303/577 (19) were detected by all stability parameters in high performing environments for shoot density.; thus the genotypes may be recommended for

high tea performing environments indirectly through shoot density for high yield production. In an experiment on irrigation × fertilizer interaction, Carr (1988) reported improved tea yield through improved shoot density. Two genotypes TRIT 201/16 (3) and TRIT 201/44 (5) also were detected by all stability parameters for shoot density in high performing environments except for the average response ($\beta_i \neq 1.0$). Similarly, all stability parameters favoured genotypes TRIT 201/55 (8) and TRFK 303/1199 (15) for high performing environments except for the stability ($S^2d_i > 0$).

On the other hand, genotypes TRFK 303/1199 (15) and TRFK 303/216 (17) were identified by all stability parameters in low shoot density performing environments. These genotypes could be considered in low tea shoot density performing environments. The TRFK 381/5 (25) was detected by all stability parameters except for the means ($x < \bar{x}$), while TRFK 430/7 (29) also was detected by all stability parameters except for stability ($S^2d_i \neq 0$) in low shoot density performing environments. Thus, crosses could be designed to complement the genetic backgrounds so as to have desirable stability parameters in the same background.

2.19 Summarized Performance at High, Low Performing Environments and Stability Parameters

2.19.1 Yield

The consistent high mean yields of above average at all locations and during all seasons of genotypes TRIT 201/16 (3), TRFK 301/6 (14), TRFK 303/577 (19) and TRFK 371/8 (24) indicated wide adaptability across locations and during all seasons of these genotypes for yield trait.

2.19.2 Shoot density

The expression of high performance greater than overall means across locations and seasons for shoot density trait of genotypes TRIT 201/44 (5), TRIT 201/47 (6), TRIT 201/55 (8), TRIT 201/82 (11), TRFK 301/4 (12), TRFK 303/1199 (15), TRFK 303/216 (17) and control SFS150 expressed high performance greater than overall means across locations and seasons for shoot density trait. This suggested that the genotypes are widely adapted for shoot density production, thus can be considered for commercialization in these areas.

2.20 Conclusion and Recommendations

2.20.1 Conclusion

The present study demonstrated that varying environments significantly affected grown different improved developed or introduced tea genotypes for yield and shoot density traits. Thus, indicating sufficient genetic differences among tested genotypes. Such genetic differences may be exploited in tea breeding programmes. The significant genotype × location interaction for both traits, suggests the importance of assessing tea genotypes in multi-location.

For yield, significant location × season interaction, implied location performance was dependent on seasons. The location main effect was most important in expression of both traits. Among genotypes, TRFK 303/577 (19) was the most promising for yield and shoot density traits, while Ngwazi and Ilenge were most potential for yield and shoot density respectively. Highest yield was recorded in 2014/15, while for shoot density during 2015/16 though not significantly so.

For shoot density, the genotype × season interaction presented highest (320 shoots m^{-2}) shoot density for TRFK 303/577 (19) during 2014/15. Significantly highest yield was for TRFK 303/577 (19) at Ngwazi and Ilenge sites. Due to higher mean yield and positive environmental index (Ij), Ilenge was favourable during 2014/15 season.

For both traits, β_i was perfectly and significantly negatively associated with $1 - \beta_i$, thus selecting improved genotypes for β_i leads to reduction in $1- \beta_i$. The significantly positive correlation of mean shoot density with β_i, but significantly negative with$1 - \beta_i$ implied that high tea shoot performing genotypes will be more responsive, but reduced $1 - \beta_i$ for same trait. Significant positive correlations of environmental indices for yield and shoot density, suggested most pairs of environments varied in a similar way.

Due to consistent higher means for both traits at all locations and during both seasons, TRIT 201/16 (3), TRFK 301/6 (14) and TRFK 303/577 (19) demonstrated wide adaptability. Genotypes TRIT 201/43 (4) and TRIT 201/55 (8) were stable for high tea yield performing environments, while TRFK 12/19 (2), TRIT 201/47 (6), TRFK 31/8 (20) and TRFK 6/8 (30) for low yield performing environments.

2.20.2 Recommendations

i. Genotypes TRFK 12/19 (2), TRIT 201/47 (6), TRFK 31/8 (20) and TRFK 6/8 (30) should be grown in low tea yield performing environments i.e. non-optimal conditions.
ii. Genotypes TRIT 201/43 (4) and TRIT 201/55 (8) should be grown in high tea yield performing environments i.e. under optimal growing conditions.
iii. Genotypes should be inter-crossed to complement for mean and stability parameters for shoot density and yield of tea.

iv. Ngwazi location should be earmarked for yield of tea, while Ilenge for shoot density.

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CHAPTER THREE

3.0 Effect of stability and adaptability on tea quality in diverse growing environments of Tanzania

3.1 Abstract

Experiments were set to study the effect of genotype × environment interaction on tea quality; at Ngwazi, Ilenge and Marikitanda locations. A Complete Randomized Block Design (CRBD) with 3-replicates was applied during 2016 wet and dry seasons. Thirty-one genotypes and 2-standards were evaluated. The ISO 14502-2: 2005 procedure was adopted using High Performance Liquid Chromatography (HPLC) equipment to determine quality. The ANOVA showed significant ($p \leq 0.05$) variation among phenolics and catechin levels. Genotypes varied response to quality among locations and between seasons. EGCG was the most abundant catechin. TRIT 201/16 (1), TRIT 201/43 (4) and TRFK 303/577 (3) accumulated significantly higher TC. Genotype TRIT 201/43 (2) excelled on EGC, CAFF, ECG and TC, while TRIT 201/16 (1) on GA. Main location effects indicated significantly higher EGC, ECG, EGCG and TC accumulation at Ilenge. The genotype (G) × location (L) presented higher EGCG and TC for TRIT 201/43 at Ilenge. TRIT 201/16 excelled for CAFF and ECG at Marikitanda. The genotype (G) × season (S) indicated highest effect on EGCG and TC for TRIT 201/16 during wet season. The location (L) × season (S) had highest EGCG and TC at Ilenge during wet season. TRIT 201/16 (1) presented all desirable stability parameters for GA at Ngwazi. TRIT 201/43 (2) excelled on EGCG and TC at Ilenge location. The TRFK 303/577 (3) and SFS150 (5) met all stability requirements for EGC and ECG, while TRIT 201/43 (2) for TC. Due to accumulation of tea higher Catechin content and meeting all stability parameters, TRIT 201/16 and TRIT 201/43 can be commercialized at Ilenge and other related growing conditions in Tanzania during wet season.

Key words: *Catechins, season, genotypes, response, correlation.*

3.2 Introduction

Commercially, tea (*Camellia sinensis* (O.) L. Kuntze), is an important crop in most of the tea growing areas worldwide. Tea is a popular non-alcoholic beverage second only to water and is consumed either as black, green, white or Oolong tea (Gunathilaka and Tularam, 2016). Of recent tea consumption is gaining interest due to associated health benefits (El Sheikh *et al.,* 2015). In Tanzania, until 2017/18 the crop contributed over 65 000 USD (Tea Board of Tanzania, 2018). Directly or indirectly over 30 000 households are actively involved in tea production and rely on it for their livelihood. Based on the estate workers and smallholder tea growers; the sector supports over 50 000 families (Tea Board of Tanzania, 2014).

The harvestable green leaf (GL) for processing tea beverage is obtained from the tender shoots (2 leaves + a bud). The quality of made tea is highly dependent on the chemical constituents of the tea leaf plus its fibrous content which in turn varies with the growth and maturity of the shoots (Wijeratne, 2003; Owour *et al.,* 2011). The environments in which tea is grown vary, affecting both yield and quality of crop (Owour *et al.,* 2011; Makola *et al.,* 2013). Kamau (2008) described the optimal tea growing conditions to include; warm humid tropical climate with fairly well distributed rainfall at least 1000 mm annually; a wide range of soils with loamy or red clays soils of volcanic origin considered more desirable.

In Tanzania, tea is grown from low altitude i.e. 790 m above sea level at the Usambara mountains, Northern part of Tanzania to over 22 000 m above sea level, at Dansland, in Njombe district, Southern Highlands part of Tanzania. The weather in the Northern Tanzania is mainly a bimodal rainfall with hot- (December-March) and cool dry (May or

October) seasons (Carr, 2010). The short rains (*Vuli*) occur in November, while the long rains (*Masika*) from April-May, averaging 1500mm. Such environment influences fast tea growth, a condition that gives high yields, but low black tea quality (Owour *et al.,* 2011).

The weather in Southern Tanzania is a uni-modal rainfall pattern from Nov. to April/May. This is followed by cool - from May/June to August and warm dry- from Sept. to Nov./ Dec. conditions (Carr, 2012). Under such higher altitude tea crop grows slowly leading to low yields due to restricted shoots growth (Carr, 2012) but of better black tea quality (Owour *et al.,* 2011). This may support the findings that tea grown at higher altitudes is of superior quality unlike that at low altitude (Makola, 2013). The interaction of tea grown genotypes with the environments significantly affects yields, chemical composition and the overall quality of tea (Owour *et al.,* 2011).

According to Cherotich *et al.* (2013), green tea leaf (2-3leaves + a bud) contains 30 - 42% polyphenols on a dry weight basis. Catechin is the main polyphenol component which is derived from phenylpropanoid and flavonoid biosynthetic pathways. Studies showed that different tea cultivars differ in the types and quantity of catechins (Cherotich *et al.,* 2013). Catechins concentration also declines with aging of the leaves. Higher in young tender leaves and low in older leaves (Thea *et al.,* 2012). The most abundant active catechins components which are related to tea quality are epigallocatechin gallate (EGCG), epigallocatechin (EGC) and catechins (C) which constitute over 70% of the total catechin content. Other important catechins include; epicatechins (EC), (-) -epicatechin gallate (ECG) (Turkmen *et al.,* 2009). Among the processed tea, green tea is the most abundant with catechin contents led by epigallocatechin gallate (EGCG).

Polyphenols in fresh tea leaves also vary with factors such as; leaf handling, season variation, geographical location, leaf age, harvest method and tea leaf variety (Turkmen *et al.,* 2009). Cherotich *et al.* (2013), noted non-significant catechins content variation with seasons, but lower and high caffeine content variations during wet- and dry seasons, respectively. The content and distribution of catechins in fresh tea leaves also vary with harvesting season. Higher levels of EGCG and ECG, are reported during warmer months with higher EGC during the cooler months (Turkmen *et al.,* 2009).

The climate change effect is predicted to affect future tea production. Due to increasingly erratic rainfall, temperatures and incidence of hails, the potentially used high producing tea areas are turning into less productive (FAOSTAT, 2014). There is prediction which indicates stressed tea plants will produce more secondary metabolites leading to improved tea flavour (Andrei, 2014; Ahmed, 2015).

The Tanzanian tea is judged as plain or of low quality at most of international markets (Anonymous, 2012) thus, fetching low price at the auction markets. Reliance on seedling propagated teas (>85%) owned mainly by large tea Estates could be the main course. Adoption of improved/ acquired clonal cultivars without verification for site suitability at target environments partly contributes to poor tea performance verification (Wachira *et al.*, 2002; Owour *et al.*, 2011). The performance of cultivars relative to each other varies with environment, such that, a superior genotype at one environment may not necessarily replicate (Wachira *et al.*, 2002; Kamunya *et al.*, 2012; Cherotich *et al*., 2013). Thus, this demands appropriate knowledge on stability and adaptability of developed tea genotypes on quality prior to recommending to tea growers. Therefore, the objective of the present study was to evaluate new developed or introduced tea genotypes on quality stability and adaptability.

3.3 Materials and Methods

3.3.1 Chemicals and reagents

Chemicals used in this study were purchased from various sources through the Tea Research Institute of Tanzania (TRIT). The standards including gallic acid (GA, 98%), purchased from sd Fine Chem Ltd, Maharashtra, India) (-)-Epigallate Catechin (EGC, 95%), (+)-Catechin (C, 98%), Caffeine (CAFF, 99%), (-)-Epigallocatechin gallate (EGCG, 98%) and (-)-Epicatechin gallate (ECG, 98%), all were procured from Sigma-Aldrich (China). Chemical reagents Acetonitrile (C_2H_3N; MUMBAI 400-002, India), Methanol (CH_3OH), Gallic acid ($C_6H_2(OH)_3COOH$; sd Fine Chem Ltd, Maharashtra, India), EDTA ($C_{10}H_{16}N_2O_8$; Avon Chem LTD), Ascorbic Acid ($C_6H_8O_6$; Carlo ERBA, SA), Acetic Acid (CH_3COOH; Jenway Chemicals, England), Water (H_2O; Rankem, RFCL LTD, India) all were of HPLC grade unless otherwise stated.

3.3.2 Leaf sample collection and preparation

After leaf shoot collection (at age of 12 years after field establishment) from three (3) tea growing environments in the country during the peak of wet and dry seasons (Appendix 1), approximately 500g of fresh harvested tea shoots (2 leaves + a bud) sample was immediately dried to deactivate oxidizing enzyme polyphenol oxidase (PPO) using domestic microwave (RISING, China) at 90°C for 3 min. Then, leaf samples were dried in Oven (European Union, Poleko - Aparatura SP. J) overnight in the laboratory at 85°C. Dried leaf samples were finely ground using electrical grinding machine (MIIS, Germany, IKA WERKER & Comp.). Prior to analysis prepared leaf samples were kept in aluminium laminated Manila paper bags in the dark room (at room temperature) in the Tea Research Institute Leaf and Soils Laboratory (TRIT) prior to analysis.

3.3.3 Samples Extraction

The method described by the International Organization for Standardization (ISO) 14502-2 was adopted (2005). Briefly, 0.200± 0.001 g each of dried tea powder sample was weighed in the extraction tube using electronic weighing balance. About 5 mL of 70% methanol at 70°C was added. The extract was thorough mixed, heated at 70°C and vortexed for 10 min. The heated sample was allowed to cool at room temperature. The extract approximate 200g was centrifuged at 3500rpm for 10min. Obtained supernatant was decanted into 10 mL volumetric flask. The extraction step was repeated twice. Both extracts were pooled and the volume adjusted to 10mL and diluted with cold 70% methanol. The extract was diluted 5 times (1: 4 ratio) with stabilizing agent prepared from the EDTA (500 µg mL^{-1}), ascorbic acid (500 µg mL^{-1}) and acetonitrile (25% v/v) in water.

3.3.4 Sample Analysis with High Performance Liquid Chromatography (HPLC)

The HPLC (Shimadzu 20AD) fitted with an auto sampler and a SPA UV detector at 278 nm was used for analysis in the African Center for Health of Aquatic Resources (ACHAR), at Sokoine University of Agriculture, Tanzania. A reversed-phase supelco C-18 column (150 x 4.60 mm and particle size of 5 µm) was used for separation with the column temperature set at 35 °C. The sample injection volume was 1.0µL and flow rate of 1.0mL/min; mobile phase A: 2% Glacial acetic acid, 9% acetonitrile, 20g/ml EDTA and 89% water; mobile phase B: 80% acetonitrile, 20.0g/ml, Glacial Acetic Acid (GAA) and 18% water (Dionized). The chromatographic peaks were identified and estimated by external standard method from the response factor (RF) (Kumara and Amarakoon, 2006);

Response Factor (RF) = C_{std}/A_{std}…… (1)

Where, RF = Standard Response Factor

C_{std} = The concentration of standard

A_{std}= Peak area of the standard

The concentration of individual components was estimated using the formula

$$\text{Individual components (\%)} = \frac{A_{std} \times RF \times V \times d}{M \times 1000} \quad \ldots\ldots (2)$$

Where,

A_{std} = The peak area of test sample

RF= Response factor of individual component

V= Sample extracted volume

d= Dilution factor

M = Mass in g of the test sample

3.3.5 Statistical analysis

The samples were drawn from 5-improved tea genotypes in 3-replicates at 3-locations making a total of 45 samples. The content of caffeine (CAF), catechin (C), epicatechin gallate (ECG), epigallocatechin (EGC) and epigallocatechin gallate (EGCG). Total catechins was calibrated based on the summation of the individual catechins above. were determined.

The data were subjected to analysis of variance (ANOVA) and Duncan's multiple range tests using the Genestat statistical program version 15.0. The significance level of $P \leq 0.05$ was considered in the analysis. The Stability was estimated according to Eberhart and Russell (1966).

3.4 Description of Tea Genotypes

Table 3.1: List of 5-tea genotypes evaluated at three selected tea growing varied environments in Tanzania during 2015/16.

Serial No.	Genotype[§]	Source of origin	Varietal Type
1	TRIT 201/16	Tanzania local selection	Assam/Chinery hybrid
2	TRIT 201/43	Tanzania local selection	Assam, local selection
3	TRFK 303/577	OP progeny TRFK 6/8	Assam/Chinery hybrid
4	TRFK 6/8 (Ck-1)	Kenya local selection	Assam, local selection
5	SFS150 (Ck-2)	Malawi local selection	Assam

[§]Ck-1 and Ck-2 = Check for good and poor tea Quality, respectively.

The three test tea genotypes were randomly selected. Genotype TRFK 6/8 was included as local check for excellent tea quality, while genotype SFS 150 also was included as local check for poor tea quality. Any of the three tea test genotypes were compared with the two local checks in terms of concentration of tea catechins.

3.5 Soil Physico-and Chemical Characteristics

Table 3.2: Soil Physico-Chemical characteristics of three tea experimental sites in Tanzania during 2014-2015

Location	Chemical Properties							Physical Properties			
	Soil pH (H_2O)	CEC cmol (+) kg	Total N (%)	Available			OM (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class*
				K^+ ($cmolkg^{-1}$)	P (mg/kg)	Mg^{2+} ($cmolkg^{-1}$)					
NTRS (A)	4.3	14.76	0.18	0.69	15.37	0.91	2.39	46.2	18.3	35.5	Sandy clay loam
MTRS (B)	3.9	14.43	0.21	0.12	12.81	0.36	3.34	46.9	18.3	34.8	Sandy clay loam
Ilenge (C)	4.4	19.91	0.34	0.75	7.26	1.11	6.36	67.5	21.7	10.8	Sandy loam
Interpretation*	Low	Medium	Low to medium	Medium	Medium	Low to medium	Medium to high				

*= interpretation according to Landon (1991).

3.6 Elution of Gallic Acid, Caffeine and Catechin content using HPLC analysis

The chromatogram illustrates general elution order of Gallic Acid (GA), Epigallatecatechin (EGC), Catechin (C), Caffeine (Caffe.), Epigallatecatechin gallate (EGCG) and Epicatechin gallate (ECG). Retention time (RT) for tea leaf samples (Figure 1B) was compared with that of the standards (Fig. 3.1A). Quantification of tea quality components were performed by comparing obtained peak area (PA) (Figure 3.1B) of HPLC chromatograms with the standards (Fig. 3.1A) below. The most abundant catechin (with highest peak) was Epigallocatechin gallate (%EGCG), followed by phenolic %Caffeine, whereas the lowest was %Epigallate Catechin (EGC).

3.7 Effect of variation in Catechins among 5 tested tea genotypes

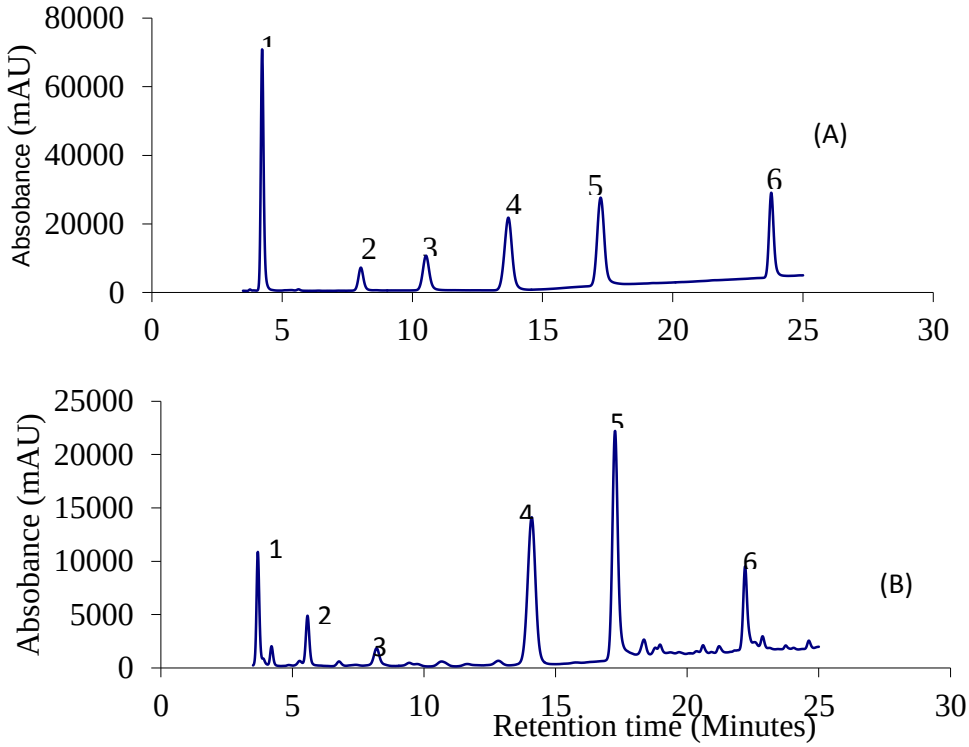

Figure 3.1:a & b: Chromatogram of Caffeine presenting profile of elution time (Min.) and elution of Gallic acid and individual Catechins (C) i.e. 1= Gallic Acid (GA), 2 = Catechin (C), 3 = Epigallate catechin (EGC), 4= Caffeine (CAFF), 5 = Epigallatecatechin gallate (EGCG) and 6= Epicatechin gallate (ECG). 1A = represents chromatograms for standards; 1B = represents chromatograms for tested tea samples.

Table 3.3: The minimum and maximum range of individual catechins, caffeine and Total catechins in green tea (*Camellia sinensis* L.)

Tea component	Quality content % by dry weight
Epigallatecatechin gallate (EGCG)	9 – 13
Epigallate catechin (EGC)	3 – 6
Epicatechin gallate (ECG)	3 – 6
Individual Catechins (C)	1 – 2
Caffeine (CAFF)	3 – 4
Total catechin (TC)	18- 32

According to Punyasiri (2011).

The maximum and minimum levels of catechins components in green tea are presented in Table 3.3 according to Punyasiri (2011). Variation in levels of tea components in the present study could be as a result of effect of storage duration on the analyzed tea samples.

3.8 Results

3.8.1 The main effects of genotypes for the studied tea quality variables

The significant variation among genotypes were obtained for GA, EGC, CAFF, ECG and Total Catechin (TC) (Table 3.4). The GA ranged from 0.04 for standard SFS150 to 0.06 for improved TRIT 201/16. Other genotypes had moderate GA. For EGC, the highest concentration was 0.00015 for TRIT 201/43, while the lowest EGC was for two standards TRFK 6/8 and SFS 150 of 9.8E-05 and 9.6E-05, with mean of 0.00012%. The %Caffeine ranged from 2.18% for TRFK 6/8 to 2.85% for TRIT 201/43 with mean of 2.61%. The mean %ECG varied from 0.28% for SFS150 to 0.31% for TRIT201/43. Improved genotype TRFK 303/577 and two standards TRFK 6/8 and SFS150 accumulated moderate %ECG content which was non-significant among them. Except standard TRFK 6/8, improved genotypes TRIT 201/16, TRIT 201/43, TRFK 303/577 and standard SFS150 (31) had significantly higher %Total Catechin (10.27% - 10.63%).

Table 3.4: Main effects of tea genotypes for GA. CAFF and Catechin variables

Genotype	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
TRIT201/16	**0.06**	0.00011	1.34	**2.85**	**8.77**	**0.31**	**10.59**
TRIT 201/43	0.05	**0.00015**	1.31	**2.73**	8.98	0.28	**10.46**
TRFK 303/577	0.05	0.00013	1.23	2.71	7.74	0.29	**10.39**
TRFK 6/8	0.05	0.00009	1.19	2.18	7.59	0.29	9.08
SFS150	0.04	0.00010	1.22	2.25	8.89	0.29	**10.40**
Mean ($\bar{x}$)	**0.05**	**0.00012**	**1.26**	**2.54**	**8.39**	**0.29**	**10.18**
S.e.d (n = 4)	0.005	0.0003	0.29	0.29	1.57	0.02	1.19
LSD ($p \leq 0.05$)	0.014	0.0007	0.59	0.58	3.23	0.03	2.38
CV (%)	16.8	34.6	28.7	13.7	21.3	6.8	14.2

S.e.d =Standard error of differences of means; LSD =Least significant differences; CV (%) = Coefficient of variation.

3.8.2 Main effects of locations

The main effects of locations for Gallic Acid, Caffeine and Catechins are presented in Table 3.5. There were variations among locations for evaluated tea quality variables. Among the three locations, highest GA (0.06%) was accumulated at Ngwazi location. Significantly highest tea quality components of C (1.30%), Caffeine (2.81%) and ECG (0.30%) were accumulated at Marikitanda. Highest contents of EGC (0.00018%), EGCG (10.57%), ECG (0.30%) and Total Catechin (12.30%) were recorded at Ilenge site.

Table 3.5: Main effects of locations for Gallic, Caffeine and Catechin tea quality variables

Location	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
Ngwazi	**0.06**	0.00005	1.17	2.52	6.60	0.29	8.64
Marikitanda	0.05	0.00013	**1.30**	**2.81**	8.07	**0.30**	9.67
Ilenge	0.05	**0.00018**	1.27	2.49	**10.57**	**0.30**	**12.30**
Mean ($\bar{x}$)	**0.05**	**0.00012**	**1.25**	**2.61**	**8.40**	**0.29**	**10.20**
S.e.d (n = 4)	0.005	0.00003	0.29	0.29	1.34	0.12	1.19
LSD ($p \leq 0.05$)	0.01	0.00001	0.59	0.59	2.69	0.03	2.38
CV (%)	16.8	34.6	28.7	13.7	19.5	6.8	14.2

S.e.d =Standard error of differences of means; LSD=Least significant differences; CV (%) = Coefficient of variation.

3.8.3 Main effects of seasons for GA, Caffeine and Catechins tea quality variables

The main effect of seasons for GA, Caffeine and Catechins tea quality variables is showed in Table 3.6. Higher accumulation of EGC (0.000128%), Caff (2.72%), EGCG (9.07%) and TC (10.85%) were observed during the wet season. Similarly, the dry season had higher accumulation of Catechin (1.40%) and ECG (0.30%). However, the GA did not alter with variation in seasons whereby GA of 0.05% was recorded during each season. Due to season main effect the EGCG contributed 83.6% to the TC during the wet season.

Table 3.6: Main effects of seasons for GA, Caffeine and Catechins tea quality variables

Season	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
Wet	0.05	**0.000128**	1.10	**2.72**	**9.07**	0.29	**10.85**
Dry	0.05	0.000108	**1.40**	2.49	7.72	**0.30**	9.58
Mean ($\bar{x}$)	**0.05**	**0.000118**	**1.25**	**2.61**	**8.40**	**0.29**	**10.28**
S.e.d (n= 4)	0.003	0.000019	0.17	0.17	0.77	0.01	0.69
LSD ($p \leq 0.05$)	0.008	0.000039	0.34	0.34	1.55	0.013	1.37
CV (%)	16.8	34.6	28.7	13.7	19.5	6.8	14.2

S.e.d =Standard error of differences of means; LSD=Least significant differences; CV (%) = Coefficient of variation.

3.8.4 Combination of genotype (G) × location (L) for the studied tea quality variables

The interaction of genotype × location for seven studied tea quality variables is presented in Table 3.7. The highest GA content of 0.07% was accumulated by improved genotypes TRIT 201/16 and TRFK 303/577 at Ngwazi location. The significant lower GA was 0.03% recorded for TRFK 303/577 at Ilenge. The highest Catechin (C) was 1.53 in SFS150 –Ngwazi, while for ECG it was 0.33 with TRIT 201/16-Marikitanda. However, with C all combinations were statistically similar except for TRIT 201/16-Ngwazi (0.93) and TRFK 6/8 –Ngwazi (0.90) with significantly lowest values. Similarly, with ECG; TRIT 201/16 - Marikitanda (0.33), TRIT201/43-Marikitanda (0.30) and TRIT 201/43

(0.31)-Ngwazi had significantly similar and highest values than the rest of the combinations. TRIT 201/43 (2) had significantly higher EGCG (12.05%) and Total catechin (13.65%) at Ilenge site. The EGCG (4.89%) and TC (6.06%) accumulated significant lower contents for TRFK 6/8 at Ngwazi site. Among the tea quality components, due to combinations of genotype × location EGCG contributed 88.3% of the Total catechin for TRIT 201/43 at Ilenge site.

Table 3.7: Combination of genotype (G) × location (L) for GA, Caffeine and Catechins concentration of tea qualities

Genotype × Location	**%GA**	**%EGC**	**%C**	**%CAFF**	**%EGCG**	**%ECG**	**%TC**
TRIT201/16-Ngwazi	**0.07**	8E-05	0.93	2.67	7.33	0.30	9.23
TRIT 201/16-Marikitanda	0.05	1E-04	1.38	**2.94**	9.37	**0.33**	11.07
TRIT 201/16-Ilenge	0.06	1E-04	1.21	2.07	9.71	0.28	11.20
TRIT201/43-Ngwazi	0.06	9E-05	1.22	2.69	7.54	0.31	9.08
TRIT 201/43-Marikitanda	0.04	2E-04	1.47	**2.93**	7.37	**0.32**	9.17
TRIT201/43-Ilenge	0.05	2E-04	1.32	2.92	**12.05**	0.29	**13.65**
TRFK303/577-Ngwazi	**0.07**	5E-05	1.26	2.89	6.04	0.29	9.82
TRFK 303/577-Marikitanda	0.05	2E-04	1.22	2.75	8.40	0.27	9.89
TRFK303/577-Ilenge	0.03	2E-04	1.20	2.48	8.78	0.30	11.32
TRFK 6/8-Ngwazi	0.05	1E-04	0.90	1.68	4.89	0.27	6.06
TRFK6/8-Marikitanda	0.05	1E-04	1.24	2.53	7.40	0.30	8.95
TRFK 6/8-Ilenge	0.05	2E-04	1.44	2.33	10.49	0.30	12.24
SFS150-Ngwazi	0.04	2E-05	**1.53**	2.64	7.22	0.27	9.02
SFS150-Marikitanda	0.04	8E-05	1.20	2.92	7.79	0.27	9.26
SFS150-Ilenge	0.04	2E-04	1.19	2.63	11.61	0.30	13.10
Mean ($\bar{x}$)	**0.05**	**1E-04**	**1.25**	**2.60**	**8.39**	**0.29**	**10.20**
S.e.d (n = 4)	0.05	2.4E-05	0.21	0.21	0.95	0.012	0.84
LSD ($p \leq 0.05$)	0.01	4.7E-05	0.42	0.42	1.90	0.023	1.68
CV (%)	16.8	34.6	28.7	13.7	19.5	6.8	14.2

S.e.d = Standard error of differences of means; LSD =Least significant differences; CV (%) = Coefficient of variation.

3.8.5 Combination of genotype (G) × season (S) for the studied tea quality variables

The genotype × season interaction is illustrated in Table 3.8. The mean GA content ranged from 0.04% for SFS150 dry season to 0.07% for TRIT 201/16 (3) during wet season. Significantly highest EGC also was recorded for improved standard TRFK 6/8 (30) during the dry season. Percentage individual catechin (1.58%) accumulated significantly highest content in SFS150 (31) during the dry season. Genotype TRIT 201/43 (4) had significantly highest Caffeine (2.98%) during wet season, while TRIT 201/16 (3) accumulated significantly highest EGCG (9.88%) and TC (11.66%) also during wet season. Three combinations viz. TRIT 201/16-wet (11.66%), SFS150-wet (11.19%) and TRFK 303/577 (10.84%)-wet seasons had significantly highest values of TC. Due to genotype × season combination, over 84.7% of the TC was contributed by EGCG during the wet season.

Table 3.8: Combination of genotype (G) × season (S) for the studied tea quality variables

Genotype × Season	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
TRIT 201/16-Wet	**0.07**	1E-04	1.04	2.87	**9.88**	0.30	**11.66**
TRIT 201/16-Dry	0.05	9E-05	1.30	2.25	7.73	**0.31**	9.34
TRIT 201/43-Wet	0.05	1E-04	1.20	**2.98**	9.15	0.29	10.64
TRIT 201/43-Dry	0.05	1E-04	1.48	2.71	8.82	0.32	10.62
TRFK 303/577-Wet	0.05	1E-04	1.16	2.74	7.94	0.29	10.84
TRFK 303/577-Dry	0.05	1E-04	1.30	2.68	7.54	0.29	9.81
TRFK 6/8-Wet	0.06	1E-04	1.06	2.24	8.52	0.29	9.87
TRFK 6/8-Dry	0.05	**9E-04**	1.33	2.13	6.66	0.30	8.29
SFS150-Wet	0.05	1E-04	1.03	2.75	9.87	0.29	11.19
SFS150-Dry	0.04	8E-04	**1.58**	2.71	7.87	0.28	9.73
Mean ($\bar{x}$)	**0.05**	**1E-04**	**1.25**	**2.61**	**8.40**	**0.30**	**10.20**
S.e.d (n = 4)	0.004	1.9E-05	0.17	0.17	0.77	0.01	0.69
LSD ($p \leq 0.05$)	0.008	3.8E-05	0.24	0.34	1.55	0.02	0.97
CV (%)	16.8	34.6	28.7	13.4	19.5	6.8	14.2

S.e.d =Standard error of differences of means; LSD = Least significant differences; CV (%) = Coefficient of variation.

3.8.6 Combination of location (L) × season (S) for the studied tea quality variables

The combination of location × season for seven studied tea variables is presented in Table 3.9. Combinations of Ngwazi –wet, Ngwazi-dry and Marikitanda-wet had statistically similar and highest GA each of 0.6%. The lowest GA content was 0.03% at Marikitanda during the dry season. Least EGC of 2.00E-05% was accumulated at Ilenge during wet season, whereas significantly highest EGC of 2E-04% was recorded at Marikitanda and Ilenge during the dry season. The highest C was 1.51% during the dry season at Marikitanda, while the least C was 1.09% during the wet season at Ngwazi and Marikitanda sites. Statistically similar and highest CAFF accumulations were Marikitanda-wet (2.91%), Marikitanda-dry season (2.72%) and Ngwazi-wet season (2.65%). The significantly lowest CAFF of 2.38% was accumulated during dry season at Ilenge and Ngwazi locations. For EGCG and TC the highest concentrations were 11.49% and 12.91% respectively accumulated during wet season at Ilenge site. The least EGCG and TC were 6.29% and 8.46% during wet and dry seasons respectively all at Ngwazi location. The contribution of EGCG to TC due to combination of location (L) × season (S) at Ilenge during dry season was 82.4%.

Table 3.9: Combination of location (L) × season (S) for the studied tea quality variables

Location × Season	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
Ngwazi-Wet	**0.06**	6E-05	1.09	2.65	6.29	0.29	8.82
Ngwazi-Dry	**0.06**	5E-05	1.25	2.38	6.92	0.29	8.46
Marikitanda-Wet	**0.06**	**2E-04**	1.09	**2.91**	9.44	0.28	10.81
Marikitanda-Dry	0.03	1E-04	**1.51**	2.72	6.69	**0.32**	8.52
Ilenge-Wet	0.05	2E-05	1.12	2.59	**11.49**	0.30	**12.91**
Ilenge-Dry	0.05	**2E-04**	1.43	2.38	9.56	0.29	11.69
Mean ($\bar{x}$)	**0.05**	**9E-04**	**1.25**	**2.61**	**8.40**	**0.30**	**10.20**
S.e.d (n = 4)	0.003	1.5E-05	0.13	0.13	0.60	0.01	0.53
LSD ($p \leq 0.05$)	0.004	3.0E-05	0.26	0.26	0.85	0.01	0.75
CV (%)	16.8	34.6	28.7	13.7	19.5	6.8	14.2

S.e.d =Standard error of differences of means; LSD=Least significant differences; CV (%) = Coefficient of variation.

3.8.7 Correlations among Gallic Acid, Caffeine and Catechins Components at Ngwazi location

The correlation analysis among Gallic Acid, Caffeine and Catechins components at Ngwazi location are presented in Table 3.10. All evaluated tea quality variables at Ngwazi location had consistently significant and positive associations among themselves except the GA with EGCG which had a weak negative association.

Table 3.10: Correlations of Gallic Acid, Caffeine and Catechin components at Ngwazi Tea Research Station (NTRS)

Quality variable	%GA	%EGC	%Catechins	%Caffeine	%EGCG	%ECG	%TC
%GA	-						
%EGC	0.584**	-					
%Catechins	0.730***	0.824**	-				
%Caffeine	0.447*	0.613***	0.846***	-			
%EGCG	-0.085	0.615**	0.483*	0.724***	-		
%ECG	0.555**	0.957***	0.660***	0.485*	0.583**	-	
%T Catechins	0.459*	0.589**	0.829***	0.999***	0.711***	0.470*	-

** and *** = significantly different at $p \leq 0.05$ and at $p \leq 0.001$respectively.

3.8.8 Correlations among Gallic Acid, Caffeine and Catechins Components at Marikitanda location

The associations among Gallic Acid, Caffeine and Catechin components at Marikitanda site are presented in Table 3.11. The Gallic acid (GA) content correlated significantly positive with EGCG and TC, but significantly negative with Caffeine. The EGC also had significantly positive association with Catechin and ECG. The catechin significantly and positively correlated with Caffeine (CAFF) and ECG. The Caffeine also had significantly positive correlation with EGCG and the TC. The EGCG was significantly and positively

associated with TC. Percentage caffeine had significant negative and positive associations with GA and Catechin, respectively, while EGCG also correlated significantly and positively with GA and Caffeine. The ECG with EGC and Catechin had significant and positive associations. The TC also correlated positively with GA, Caffeine and EGCG components.

Table 3.11: Correlations among Gallic Acid, Caffeine and Catechin components at Marikitanda Tea Research Station (MTRS)

Quality variable	%GA	%EGC	%Catechin	%Caffeine	%EGCG	%ECG	%TC
%GA	-						
%EGC	0.274	-					
%Catechins	-0.112	**0.731*** **	-				
%Caffeine	**-0.510****	-0.262	**0.427***	-			
%EGCG	**0.545****	0.220	0.054	**0.378***	-		
%ECG	-0.072	**0.432***	**0.871*** **	0.244	0.121	-	
%TC	**0.519****	0.327	0.216	**0.440***	**0.986*** **	0.268	-

** and *** = significantly different at p≤0.05and at p≤ 0.001respectively.

3.8.9 Correlations among Gallic Acid, Caffeine and Catechins Components at Ilenge location

Table 3.12 illustrates the correlations among Catechins components at Ilenge location. Results showed significant positive correlations between Garlic acid with individual Catechins (C) and EGCG, but significantly negatively associated with EGC and ECG. The EGC significantly positively associated with Caffeine, ECG and TC. There was a significant positive association between the EGCG with TC. Similarly, %caffeine significantly and positively associated with EGCG and TC. The TC showed significant positive correlations with EGC, Caffeine and EGCG.

Table 3.12: Correlations of Catechins components at Ilenge site

Quality variable	%GA	%EGC	%Catechins	%Caffeine	%EGCG	%ECG	%TC
%GA	-						
%EGC	**-0.628*** **	-					
%Catechins	**0.428***	0.151	-				
%Caffeine	-0.185	**0.745*** **	0.058	-			
%EGCG	**0.418***	0.339	0.264	**0.688*** **	-		
%ECG	**-0.682*** **	**0.658*** **	0.299	0.004	-0.292	-	
%TC	0.198	**0.567****	0.266	**0.857*** **	**0.958*** **	-0.123	-

** and ***= Significantly different at p≤0.05and at p≤ 0.001 respectively.

3.8.10 Associations across all locations

Results on association among evaluated tea quality components across 3-locations are presented in Appendix 3.2. Averaged over 3-locations, the GA was significantly and positively associated with ECG component. The EGC component correlated significantly positively with individual Catechin (C), Caffeine, TC and ECG components. The Catechin was significantly positively associated with Caffeine, and ECG. The EGCG and TC revealed significant and positive correlation. Percentage caffeine had significant and positive association with EGC and Catechin, while ECG were significantly and positively correlated with GA, EGC and C. The TC was consistently significantly and positively associated with EGC, Caffeine and EGCG. The rest of the associations were not significantly associated.

At each location, however, significant positive associations were consistent for %EGC with %ECG and individual %catechin (%C); %caffeine (%CAFF) with %EGCG and %TC; %EGCG with %TC (Appendix 3.3).

3.8.11 Stability and adaptation of 5-genotypes for Catechins concertation across environments

Results, revealed stability variation among tea genotypes on catechin contents across 3-locations (Table 3.13; Appendices 3.4 and 3.5). Genotype TRIT 201/16 (0.06%) excelled the overall mean in variable %GA and the least was SFS150 (0.04%). Genotypes TRFK 6/8, SFS150, TRIT201/16, TRFK 303/577 and TRIT201/43 had a positive significant response. All these genotypes except TRIT 201/43 had average response. They were all stable ($S^2d_i \approx 0$) and with high predictability in response ($R^2_i = 99\%$).

Genotypes TRFK 303/577 (0.00013%) and TRIT 201/43 (0.00015%) excelled the overall mean (0.00012%) for EGC. All the five genotypes responded positively with environmental indices but one genotype TRIT 201/16 responded on average. All five genotypes were stable with low S^2d_i ($S^2d_i = 0$) and high coefficient of determination ($R_i^2 = 99\%$).

Genotypes TRIT 201/16 and TRIT 201/43 excelled the overall mean for %C while all but two genotypes TRFK 303/577 and TRIT 201/43 among the five responded positively with environmental indices. All but the latter two among the five genotypes responded on average ($\beta_i = 0$) with environments. All the genotypes were stable with high coefficient of determination.

Genotypes TRIT 201/16 (2.85%) and TRFK 303/577 (2.71%) and TRIT 201/43 (2.73%) excelled the overall mean for CAFF, while all the five except TRIT 201/16 and TRFK 303/577 responded significantly to environmental indices. Only TRFK 6/8 and SFS150 responded on average with environmental indices. All the five genotypes were stable with high coefficients of determination.

All genotype except TRFK 6/8 and TRFK 303/577 excelled the overall mean in EGCG. Among the five responded significantly and all had had average responses. All the five except TRIT 201/16 and TRIT 201/43 were stable ($S^2d_i \approx 0$) while only SFS150 and TRFK 303/577 had high coefficients of determination.

Genotype TRIT 201/16 (0.31%) excelled the overall mean for %ECG and all the five except TRIT 201/43 responded significantly to environmental indices. All the five except TRIT 201/43 responded on average and all were stable with high coefficients of determination.

All the genotypes except TRFK 6/8 excelled the overall mean in %TC quality variable. All did not respond significantly to environmental changes but responded on average. Only TRIT 201/16 and TRFK 3036/577 were not stable and only TRIT 201/43 had high coefficient of determination.

Table 3.13: Stability parameters for GA, Caffeine and Catechin concentrations on 5 genotypes across 3 environments over 2 seasons (Wet and Dry 2016).

Serial No.	Q-Parameter/ Genotype	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
1.	TRIT 201/16	0.06	0.00011	1.34	2.85	8.77	0.31	10.59
2.	TRIT 201/43	0.05	0.00015	1.31	2.73	8.98	0.28	10.46
3.	TRFK 303/577	0.05	0.00013	1.23	2.71	7.74	0.29	10.39
4.	TRFK 6/8 (CK-1)	0.05	0.00009	1.19	2.18	7.59	0.29	9.08
5.	SFS150 (CK-2)	0.04	0.00010	1.22	2.25	8.89	0.29	10.40
$\bar{x}$		**0.05**	**0.00012**	**1.2**	**2.54**	**8.39**	**0.29**	**10.18**
		($\beta_i - 0$) or (β_i)						
1.	TRIT 201/16	1.33±0.476	0.53±0.248	1.41±0.635	-0.02±0.289	0.74±0.338	1.63±0.573	1.09±0.289
2.	TRIT 201/43	0.62±0.493	0.71±0.247	-0.62±0.625	0.63±0.289	0.89±0.338	-0.56±0.573	1.19±0.289
3.	TRFK 303/577	1.32±0.476	0.98±±0.247	0.39±0.628	-0.23±0.289	0.80±0.338	1.34±0.573	0.47±0.289
4.	TRFK 6/8(CK-1)	0.92±0.476	1.25±0.297	1.39±0.628	1.15±0.288	1.31±0.385	1.09±0.573	1.52±0.288
5.	SFS150 (CK-2)	0.78±0.476	1.32±0.248	1.09±0.628	2.63±0.313	1.18±0.320	1.17±0.573	0.65±0.313
		(1 - β_i)						
1.	TRIT 201/16	1.33***	0.53**	1.41***	-0.02ns	0.74ns	1.63***	1.09ns
2.	TRIT 201/43	0.62***	0.71***	-0.61ns	0.63***	0.89ns	-0.56ns	1.19ns
3.	TRFK 303/577	1.32***	0.98***	0.39ns	-0.23ns	0.80ns	1.34***	0.47ns
4.	TRFK 6/8(CK-1)	0.92***	1.25***	1.39**	1.15**	1.31ns	1.09***	1.52ns
5.	SFS150 (CK-2)	0.78***	1.32***	1.09**	2.63***	1.18*	1.17***	0.65ns
		(S^2d_i)						
1.	TRIT 201/16	0.00004	5.93E-10	0.007	0.052	4.273***	0.00014	2.501***
2.	TRIT 201/43	0.00006	6.02E-10	0.021	0.019	3.477***	0.00014	0.402
3.	TRFK 303/577	0.00018	2.24E-10	0.035	0.084	0.385	0.00032	0.809**
4.	TRFK 6/8(CK-1)	0.00006	1.63E-09	0.168	0.055	1.593	0.00018	0.835
5.	SFS150 (CK-2)	0.00003	1.74E-09	0.117	0.114	0.283	0.00046	2.214
		(R^2_i)						
1.	TRIT 201/16	0.99	0.99	0.99	0.97	-1.14	0.99	-0.25
2.	TRIT 201/43	0.99	0.99	0.99	0.99	-0.74	0.99	0.80
3.	TRFK 303/577	0.99	0.99	0.98	0.96	0.81	0.99	0.59
4.	TRFK 6/8(CK-1)	0.99	0.99	0.92	0.97	0.20	0.99	0.58
5.	SFS150 (CK-2)	0.99	0.99	0.94	0.94	0.86	0.99	-0.11

($\bar{x}$)= Mean, β_i= Coefficient of regression, $\beta_i - 0$ = deviation from average, $1 - \beta_i$ = deviation of regression from unit, S^2d_i= variance of deviation from regression and R^2_i = Coefficient of determination. *Bold figures for Mean ($\bar{x}$) = above mean.

3.9 Discussions

3.9.1 Mean squares (MS) for Catechins components

Results indicated variations among evaluated tea genotypes on tea quality parameters. The significant genotype effect on all Catechin components concentrations except for C and EGCG, implied that the Catechin components synthesis among tea genotypes were genetically controlled. Significant location and season effects, suggested that the governing conditions among locations and between seasons varied and influenced the synthesis of Catechin components among tea genotypes (Mutuku *et al.,* 2016). The results conform with Cherotich *et al.* (2013) reports and Langat *et al.* (2015) on similar clonal tea studies. Different genotypes with variation in tea Catechin contents biosynthesis also were reported.

The variations due to location and season effects could be explained to differences in recorded physical and chemical soil conditions and climatic weather over seasons at three-locations. Thus, necessitates for evaluation over several seasons in order to develop improved genotypes on tea quality. The results are in agreement with that of Cherotich *et al.* (2013) and Mutuku *et al.* (2016), who also observed variations in Catechin concentrations among tea clones at two varied geographical locations over seasons in Kenya.

The significant genotype (G) × season (S) interaction indicated some genotypes considerably varied in their capacity to synthesize tea phenolics or catechins during different growing seasons (Cherotich *et al.*, 2013; Liu *et al.,* 2015). The location (L) × season (S) interaction effect implied that, ranking of different locations in synthesis of catechin contents among genotypes may vary from season to season. Significant effect of

G × L × S indicated inconsistency of tea genotypes with respect to synthesis catechin contents. Therefore, there is a need for detailed analysis of genotypic stability on Catechin synthesis in order to select genotypes of acceptable tea qualities for specific environments.

3.9.2 The main effects of genotypes for studied tea quality variables

The variation in tea quality biosynthesis among genotypes indicated that accumulation of tea biochemical varied with genotypes (Kaur *et al.*, 2015). Cherotich *et al.* (2013) and Makola (2013), reported similar results and concluded that, each genotype is distinctive in the synthesis of tea biochemical levels. Among genotypes, TRIT 201/16, TRIT 201/43 and TRFK 303/577 accumulated higher catechin components levels compared to others. Such catechin accumulation could be an attribute to active expression of genes anthocyadin reductase (ANR), Anthocyanidin reductase (ANS) and Leucoantho Anthocyanidin reductase (LAR) and two enzymes F3'H and F3'5'H which determine both Epigallate and non-Epigallate catechins (Wang *et al.*, 2016). Cherotich *et al.* (2013), also contend that differences in levels of catechin composition among tea clones is an attribute to up regulation or down regulation of the enzyme flavanone 3-hydroxylase (F3H). The gene expression is described to be under the influence of environmental conditions (Liu *et al.*, 2015). Therefore, due to higher capacity to accumulate tea catechins genotypes TRIT 201/16, TRIT 201/43 and TRFK 303/577 may be recommended for tea rich in Catechins contents especially for EGCG and TC.

3.9.3 Main effect of locations

Among the three locations, Ilenge recorded relatively higher levels of catechin components of EGC, EGCG, ECG and TC. The site is located at altitude of 1 464 m. a.s.l with warm wet weather almost throughout the year. Such conditions favoured higher

accumulation of the above specified catechin components (Caffin *et al.,* 2004; Ahmed *et al.*, 2014; Liu *et al.*, 2015). Warm wet weather also favours the expression of genes Phenylalanine Ammonia Lyase (PAL) and Dihydroflavonol reductase (DFR) which influence higher accumulation of EGCG and contributed higher TC (83.6%) (Kaur *et al.*, 2015). Therefore, Ilenge site could be a potential site for production of Catechin rich content of Tanzanian tea. The emphasis should be more improved tea inputs application such as tea cultivars and fertilizer rates be recommended to improve production of tea rich in EGCG catechins.

3.9.4 Main effects of seasons for GA, Caffeine and Catechins tea quality variables

Regardless of season variations, GA content did not alter. Kaur *et al.* (2015) had similar observation on tea in Kenyan green tea. Han *et al.* (2016) also noted unaltered GA in green tea at 3-geographical areas which varied in elevations. Results suggests that environment has minimal effects on the expression of GA. Thus, indicates strong genetic influence. Higher EGC, Caffeine, EGCG and TC accumulation during wet season was favoured by higher precipitation which increased individual secondary metabolites of EGC (Langat *et al.*, 2015). This is because during wet season the expression of genes Flavonoid 3 –hydroxylase (F3H) and Anthocyanidin reductase (ANS) are up-regulated to release higher catechins such as EGC (Liu *et al.*, 2015).

Faster tea growth during wet season associated with higher temperatures favoured higher %Caffeine biosynthesis (Alam and Chowdhury, 2007; Liu *et al.*, 2015). During wet season, genes Flavonoid 3 –hydroxylase (F3H) and Anthocyanidin reductase (ANS) expressions are down-regulated, while Phenylalanine Ammonia Lyase (PAL) and Dihydroflavonol reductase (DFR) are up-regulated leading to increased EGCG

biosynthesis (Liu *et al.,* 2015). Cherotich *et al.* (2013) reported similar findings at two varied locations in Kenya. Accumulation of these catechins indicates the importance of season in determining quality of the Tanzanian tea. This emphasize the need to effectively utilize wet season to produce Tanzanian tea rich in healthy benefit Catechins EGC, Caffeine and EGCG.

3.9.5 Combination of genotype (G) × location (L) for the studied tea quality variables

The biosynthesis of tea phytochemicals is influenced by environmental conditions as well as cultivar type. Different genotypes vary in their response to abiotic stress. Higher GA biosynthesis for TRIT 201/16 (1) and TRFK 303/577 (3) genotypes at Ngwazi could be an attribute to high moisture stress. A combination of low annual precipitation (895.3 mm) and low temperatures favoured the accumulation of higher Gallic acid for genotypes TRIT 201/16 (1) and TRFK 303/577 (3) in response to abiotic stress (Cherotich *et al.*, 2013; Mutuku *et al.*, 2016). Genotype SFS150 accumulated higher Catechin at Ngwazi. Langat *et al.* (2015) had similar observation on genotype SFS150 and associated Catechin content with water stress in tea crop.

The accumulation of higher EGC for SFS150 (5) at Ilenge; EGCG and TC for TRIT 201/43 (2) also at Ilenge could be under the influence of higher precipitation (2 304.8 mm) and max. (24.8^{o}C - 28.3^{o}C) temperature (Ahmed *et al.*, 2014). The medium altitude (1 426 m.a.s.l) with relatively higher precipitation (>2 000 mm annually) and maximum temperatures (≥24.0^{o}C) at Ilenge location also may have influenced higher accumulation of EGCG (Wachira *et al.*, 2002; Han *et al.*, 2016). This may have contributed to higher TC proportion (83.6%).

Higher accumulation of Caffeine and ECG for TRIT 201/16 (1) at Marikitanda could be under the influence of higher precipitation (1 508.7mm), higher temperature (both min and max) and low altitude (970 – 1 000 m.a.s.l) (Han *et al.*, 2016). This implies that, investment for EGCG rich tea should focus at Ilenge site for genotypes such as TRIT 201/16 (1). Mutuku *et al.* (2016) showed similar tea genotypes variation in Catechin synthesis. The author concluded that for higher tea quality production, two factors of location and genotypes imparts significant levels of tea biomolecules synthesis.

3.9.6 Combination of genotype (G) × season (S) for the studied tea quality variables

Tea quality formation is influenced by cultivar as well as the production season (Kaur *et al.*, 2015). Accumulation of GA, EGCG and TC on TRIT 201/16 (1) and Caffeine on TRIT 201/43 (2) during wet season could be attributed to higher precipitation and temperature which form warm wet conditions. During wet season tea shoots are at rapid growth (peak) (Alam and Chowdhury, 2007) and genes Anthocyanidin reductase (ANR) and Leucoantho Anthocyanidin reductase (LAR) are actively expressed leading to higher accumulation of tea phytochemicals such as Caffeine and EGCG contributing significantly to TC (Liu *et al.*, 2015). Mutuku *et al.* (2016) also noted the effect of higher precipitation which stimulates faster shoot growth leading to higher tea yield but low tea quality. On the other hand, higher EGC, C and ECG were accumulated on TRFK 6/8, SFS150 (5) and TRIT 201/43 (2), respectively during the dry season. Dry season which is associated with cool dry and warm dry conditions induces some dormancy stage on tea shoot growth rate. This results into accumulation of some catechin components such as EGC, C and ECG (Cherotich *et al.*, 2013; Mutuku *et al.*, 2016).

Higher accumulation of tea quality determining catechins during wet season emphasizes the importance of effective use of wet season and cultivars such as TRIT 201/16 (1) and

TRIT 201/43 (2) to produce tea crop rich in EGCG and Caffeine components. The variation in quality production among tea genotypes due to season is well reported (Cherotich *et al.*, 2013; Kaur *et al.*, 2015; Mutuku *et al.*, 2016).

3.9.7 Combination of location (L) × season (S) for the studied tea quality variables

The tea quality formation is influenced by the geographical location and production season (Kaur *et al.*, 2015). Conditions at each location and during seasons interact with genetically varied genotypes to influence the differential biosynthesis of phenolics and Catechin contents (Mutuku *et al.*, 2016). In the present study, higher GA, EGC and Caffeine accumulation during wet season at Marikitanda could be an attribute to favourable higher annual precipitation (1 508.1 mm) associated with higher temperatures (min.: 12.1^{o}C-14.8^{o}C; max.: 27.6^{o}C – 31.9^{o}C). Higher Caffeine (Kaur *et al.*, 2015) and EGC contents (Mutuku *et al.*, 2016) also were noted when tea shoots growth was at peak during wet season. However, this contradicted with Cherotich *et al.* (2013) who reported higher Caffeine during dry season. This could be attributed to differential genotypes used by various studies that could behave differently.

Higher EGCG content at Ilenge during wet season was mostly favoured by similar conditions as above. Higher accumulation in TC at Ilenge was as a result of higher accumulation of EGCG (89.0%) at same location (Cherotich *et al.*, 2013). Previous studies indicated that EGCG constitute higher proportion (>80%) of the TC (Cabrera *et al.*, 2003, Cherotich *et al.*, 2013; Kaur *et al.*, 2015). This indicates that Ilenge could be considered a productive site for tea cultivars with rich EGCG content during wet season.

3.9.8 Correlations among Gallic Acid (GA), Caffeine and individual Catechin contents in 5-tea genotypes

Correlating chemical composition with various green tea grades indicate that astringency and bitterness are determined by contents of Catechins and some phenolic compounds

(Charturvedula and Prakash, 2011). Significant positive correlations among almost all evaluated tea quality attributes at Ngwazi indicated that various green tea variables can be improved together at Ngwazi location. During both seasons, Ngwazi location was characterized with less precipitation with relatively cool temperatures (low minimum and maximum temperatures). Liu *et al.* (2015) noted expression of genes PAL, F3'5'H and DFR with accumulation of most catechins during both wet and dry seasons, thus, making it possible to improve the variables together. Low precipitation associated with cool and warm dry seasons favors the expressions of such genes as PAL, F3'5'H and DFR. Cabrera *et al.* (2003), also noted positive correlation among tea catechins based on their genes and enzymes functioning.

Significant positive correlations of TC with GA, Caffeine and EGCG at Ngwazi location reflects that the accumulation of both TC and EGCG are controlled by expression of PAL and DFR genes. The genes are noted to positively influence these catechins. Cherotich *et al.* (2014) had similar results and concluded that significantly positive association of EGCG with TC is due to EGCG being the major and abundant catechin in tea. Therefore, there is high possibility to improve together both of these catechins viz. TC with EGCG and GA with Caffeine (Liu *et al.*, 2015). The EGCG and Caffeine in green tea contributes to astringency and bitterness respectively which are key factors for good tea quality (Charturvedula and Prakash, 2011).

Significant positive association of ECG with EGC and individual Catechin at Marikitanda location indicates the three quality variables can be improved together. The GA with Caffeine also at Marikitanda correlated significantly negative indicating that an increase in one quality variable leads to the decline of the other. Therefore, an effort to improve the

two quality variables together cannot be feasible, or rather one will be improved at the expense of the other.

Total catechin (TC) concentration is used as an indicator of the quality potential in tea crop. For Ilenge location, TC correlated significantly positive with EGC, Caffeine and EGCG. The implication is that, accumulation of green tea variables EGC, Caffeine and EGCG are controlled mainly by the expression of two genes PAL and DFR (Liu *et al.*, 2015). The relative expression levels of PAL and DFR in tea plants also is significantly positively correlated with increased TC. Therefore, all three tea quality variables can involve concurrent improvement at Ilenge location. Due to being rich in EGCG and Caffeine components obtained green tea infusion at Ilenge may have a taste of strong astringency and bitterness (Charturvedula and Prakash, 2011).

Similarly, Caffeine with EGCG was significantly and positively associated also at Ilenge indicating the possibility of improving tea genotypes rich in both Caffeine with EGCG due to concurrent expression of PAL and DFR genes (Liu *et al.,* 2015). Together develops a typical green tea infusion of strong astringency and bitterness at Ilenge location (Charturvedula and Prakash, 2011). The significant negative correlation of GA with EGC and ECG implies that there is minimal chance to concurrently improve GA with increased levels of EGC and ECG due to expression of gene Anthocyanidin reductase (ANS) which also is significantly negatively correlated with accumulation of EGC and ECG.

Consistent associations at each location of EGC with individual Catechin (C) and ECG, C with EGCG and TC, suggests that such associations are not influenced by environmental changes and that they are genetically controlled. Thus, improvement of the respective tea quality components may be feasible at all the three tested locations.

3.9.9 Stability of Catechin Components among 5-Tea Genotypes at 3 Environments over 2 Seasons

Chaturvedula and Prakash (2011) reported that Caffeine and EGCG contribute to bitterness and astringency of tea quality respectively. It is the bitterness and astringency that contributes to good tea quality. Therefore, identification of genotypes with stable quality parameters such as Caffeine and EGCG may be important for improvement of tea quality in Tanzania.

To determine the genotypic stability, a genotype would be considered stable by having high mean Catechin concentration ($\bar{x}$), a unit β_i =1.0, minimum deviation from regression ($S^2d_i = 0$) (Eberhart and Russell, 1966) and high coefficient of determination ($R^2_i \geq 70\%$) (Pinthus, 1978).

A genotype should have either equal mean the same or greater than overall mean of genotypes at each location for wider adaptability and average response (β_i =1.0), stable ($S^2d_i \approx 0$) and reliable in its response across environments.

For GA, TRFK 6/8 (CK-1) and TRFK 303/577 (3) met the stability requirements. For CAFF, TRIT 201/16 (1) had all the stability requirements and β_i was negative, suggesting that it performs well in poor environments for this tea quality variable. For EGCG and ECG, TRFK 303/577 (3) and SFS150 (5) met all the stability requirements while for TC, TRIT 201/43 (2) was identified as having met all the stability parameters. The rest of genotypes had varying levels of stability and performance necessitating for inter-crosses to complement characters in similar backgrounds.

3.10 Conclusion

The present study demonstrated variation among genotypes and environments (locations, seasons) on tea quality variables and significant differences on performance among test environments over two seasons were evident. Genotype TRIT 201/16 (1) accumulated relatively higher catechins content followed by TRIT 201/43 (2).

Among the three locations, more catechins components were accumulated at Ilenge site while at Ngwazi location GA was the most accumulated catechin component. However, at Marikitanda highest C, CAFF and ECG accumulation were evident. Among genotypes variation in seasons did not alter the accumulation of GA. A large proportion of important catechins were accumulated during wet season, while the dry season favoured accumulation of individual Catechin and ECG.

Genotypes TRIT 201/16 (1) and TRFK 303/577 (3) had higher interaction with location at Ngwazi for GA. TRIT 201/43 accumulated higher EGCG and TC at Ilenge location. Genotype TRIT 201/16 (1) also had more Caffeine and ECG variables at Marikitanda location.

The genotype TRIT 201/16 (1) interacted with wet season to accumulate higher GA, EGCG and TC and higher ECG during the dry season. Genotype TRIT 201/43 (2) accumulated higher Caffeine content during wet season. The Marikitanda site had higher GA, EGC and Caffeine during wet season. At same location more of individual catechin and ECG were accumulated during the dry season. At Ilenge site, higher EGCG and TC were accumulated during wet season, while EGC during the dry season.

Correlations were evident among tea quality variables at different locations. Locations varied in some of the associations and were consistent in others. Consistently positive and significant correlations at each location were between EGC with individual Catechin and ECG; Caffeine with EGCG and TC; EGCG with TC.

Genotype TRIT 201/43 (2) demonstrated higher accumulation of catechins components and was mostly stable for TC accumulation. This may be considered most promising for accumulation of important catechins for higher quality tea production in Tanzania.

3.11 Recommendations

i. Genotype **TRIT 201/16 (1)** should be used to improve other genotypes for higher accumulation of catechin levels of GA, C, CAFF, ECG and TC.
ii. Genotype **TRIT 201/43 (2)** should be used to improve other genotypes for higher accumulation of catechin levels of EGC and EGCG.
iii. Specific combinations of genotypes × locations should be earmarked for higher accumulation of GA, EGCG, TC, EGC and Caffeine.
iv. Specific combinations of genotypes × season should be earmarked for higher accumulation of GA, EGCG, TC, ECG, EGC and individual catechin (C).
v. Specific combinations of location × season should be earmarked for higher accumulation of GA, EGC, ECG, EGCG and TC.
vi. The EGC should be improved/ selected together with Catechin and ECG, Caffeine with EGCG and TC; EGCG with TC.
vii. Genotypes TRFK 6/8 (CK-1), TRFK 303/577 (3), SFS150 (5) and TRIT 201/43 (2) should be inter-crossed to attain progenies with higher means and stability for GA, CAFF, EGCG, ECG and TC catechins.

viii. The wet season should be utilized for higher levels of EGC, CAFF, EGCG and TC catechins.

ix. The dry season should be utilized to realize higher levels of C and ECG catechins.

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CHAPTER FOUR

4.0 Evaluation of improved tea genotypes to differential levels of drip-irrigation in Tanzania

4.1 Abstract

A study was conducted to determine the optimum drip irrigation level for yield, shoot density and water use efficiency on tea (*Camellia sinensis L.*) crop. Thirty-one (31) improved tea genotypes and five irrigation treatments (I_0 - I_4 =100%) were investigated for 2-seasons (2014/15 and 2015/16) at Ngwazi site in Tanzania. The experiment was established in a Complete Randomized Block Design (CRBD) in 3 replications with irrigations arranged in split-plot. Genotypes and irrigations were assigned as main- and sub-plots respectively. Irrigation was scheduled based on a simple soil water balance equation. Evapotranspiration was calibrated based on daily evaporation B-Pan (E_{pan}) data. Under fully-irrigated treatment (I_4 =100%), TRIT 303/577 (19) had significantly higher tea yield (2 037kgmtha^{-1}). Under deficit irrigation (I_1= 25%), TRIT 303/259 (18) recorded highest shoot density (207 shoots m^{-2}). Under no-irrigation treatment (I_0); genotypes 201/43 (4) and 303/259 (18) produced significantly higher yields of 1 136 and 1 138 kg mt ha^{-1}, respectively. Between seasons, significantly higher shoot density (159 shoots m^{-2}) and yield (1570 kg mt ha^{-1}) were obtained during 2014/15 and 2015/16, respectively. The yield and shoot density showed significant positive correlation r = 0.999*** ($p \leq 0.001$). Yield r = 0.725*** ($p \leq 0.001$) and shoot density r = 0.701*** ($p \leq 0.001$) were significantly positively correlated with water use efficiency (WUE). Yield-Applied drip irrigation relationship described a quadratic significant function with average R^2_i = 0.538*($p \leq 0.05$) in 2014/15 and linear function with higher and significant R^2_i = 0.983***($p \leq 0.001$) in 2015/16. Yield-WUE relationship explained linear function with

very weak R^2_i = 0.041value in 2014/15 season. The relationship also was linear with higher and significant R^2_i = 0.718***($p \leq 0.001$) in 2015/16 season. Compared to fully drip irrigation, irrigating tea at I_1= 25% in 2014/15, improved yield by 1.4% and saved water by 74.6%. In 2015/16, irrigating tea at I_1 = 25% improved tea yield by 37.9% and saved water by 68.3%. Due to recorded higher yield under fully-drip irrigated treatment, genotype TRFK 303/577 can be recommended in tea areas where water availability is not a constraint. In areas where water for drip-irrigation may be a constraint, genotypes TRIT 201/43 and TRFK 303/259 can be considered for production.

Key words: *Deficit irrigation, yield, shoot density, water use efficiency.*

4.2 Introduction

Tea (*Camellia sinensis* L. (O.) Kuntze) is one of the most important commercial grown crop worldwide. In Tanzania, tea contributes over 50 000 USD annually, equivalent to over 0.12% of the national GDP (TBT, 2016). The crop provides employment to over 50 000 households, especially the smallholders. Over 2.0 million families earn their living through tea production and processing (TBT, 2015). Among the important cash crops in the country, tea ranks between 4th and 5th.

The tea growing environments in Tanzania vary, ranging from climatic, edaphic to biotic conditions (Carr, 2012). The conditions interact differently with the tea crop affecting growth. Tanzania produces over 33 000 metric tons annually of processed tea (TBT, 2016). Over 70% of this tea quantity is produced from the Southern Highlands (SH). Over 80% of the produced tea is realized during the wet season (Oct/Nov to April/May), while 20% is realized during the long dry season (May/June to Sept/October). The dry spell, in the Southern Highlands is divided into cool- (May/June to July/ Mid-August) and warm dry (Mid-August to Mid-Nov.) seasons (Carr, 2012). The condition restricts shoot growth,

while yield (Burgess and Carr, 1996; Wachira *et al.,* 2002) and quality (Owour *et al*., 2011) are mainly influenced by soil water deficit (SWD). Yield losses of up to 25% of processed tea are reported due to drought stress during the long dry season in Southern Highlands of Tanzania (Carr, 2012).

Until late 1990's in Tanzania, the drought stress on tea crop has mainly been mitigated using sprinkler irrigation method (Carr, 2012). However, the demerit with sprinkler method has mainly on significant uncontrolled water loss (Nagaz *et al*., 2012). Continue dependence on this technique could not sustain tea growers due to reported global climate change effect which signals the critical decline in water resources (Mattee *et al*., 2015).

Efforts to maintain high tea production using sprinkler irrigation was not feasible due to higher water demand using this method. When water resource becomes scarce, farmers tend to opt for water serving techniques such as drip irrigation (Möller and Weatherhead, 2007). The essence being to maximize crop production per unit water used rather than per unit land area (Möller and Weatherhead, 2007). Two independent drip-irrigation studies on tea in Tanzania, indicated that using drip irrigation on mature tea crop there was a yield gain between 50% to 52% (Möller and Weatherhead, 2007; Kigalu *et al*., 2008).

The global climate reports indicate the decline in water resource, posing significant challenge to tea growers in the country (Mattee *et al*., 2015). The effects on tea crop indicate that previously potential tea areas are turning to marginal areas for tea (FAO, 2014; Kamau, 2008). When water becomes a scarce resource, crop growers opt to maximize crop production per unit water used rather than per unit land area (Möller and Weatherhead, 2007). Condon *et al*. (2012), suggested adoption of genotypes responsive to drip irrigation as one of the best alternative to serve the declining water resource.

Information on identified responsive tea genotypes to deficit irrigation on yield and shoot density, especially of recently developed 29-genotypes are scarce. Therefore, the intent of the present study was to determine the optimum irrigation regime on tea yield, shoot density and water use efficiency (WUE) in drought prone areas of Tanzania.

4.3 Materials and Methods

4.3.1 Description of study areas and planting of tea genotypes

The study was conducted for two seasons (2014/15 to 2015/16) at Ngwazi Tea Research Station (NTRS), Southern Highlands of Tanzania in Mufindi District (8°32'S, 35°10'E and altitude of 1 840 m.a.s.l) (Section 2.1, Fig. 4.1). The experiment was set in formerly established tea farm No.17 in March, 2005. The sampled soil was sampled according to Landon (1991) and described as sandy clay loamy with optimal organic matter (2.3%) and pH (H_2O) of 4.3 within 0 to 90cm depth. This was slightly below the optimal range (pH 4.5 -5.5) for tea (Othieno *et al.*, 1992). Available P was analyzed using Bray No. 1 Extract method (Bray and Kurtz, 1945). Total N, available potassium (K+), exchangeable cation capacity (ECE) and available Mg^{2+} were determined using Ammonium Acetate method (Schollenberger and Simon, 1945). The Walkley-Black Titration method was adopted to determine OM; the soil textural status was determined according to Beretta *et al.,* (2014). Results for sampled soils were summarized in Table 4.1 below. The experiment was conducted from September to December in 2014/15 season and from May to December during 2015/16 season The climatic weather is as detailed by Burgess and Carr (1996) and presented herein Tables 4.2.

4.3.2 Soil Physico-and chemical characteristics

Table 4.1: Soil Physico-chemical characteristics of the tea experimental site at Ngwazi Tea Research Station (NTRS) in Tanzania in 2014-2015.

Soil parameters	Physical properties	Chemical properties	Remarks[§]
Cation Exchange Capacity (CEC) (cmol kg^{-1})		14.76	Medium
N (%)		0.18	Low
Available K^+ (cmol kg^{-1})		0.69	Medium
Available P (ppm)		15.37	Medium
Mg^{2+} (cmol kg^{-1})		0.91	Medium
Organic Matter (%)		2.39	Medium
pH		4.3	Acidic
Sand (%)	46.2		
Silt (%)	18.3		
Clay (%)	35.5		
Textural Class	Sandy Clay Loam		

§=interpretation according to Landon (1991).

4.3.3 Weather information

Table 4.2: Recorded Weather at Ngwazi tea Research Station during 2014/5 and 2015/16.

	2014/15[a]				2015/16[b]			
Month	**Temperature (°C)**			**Precipitation (mm)**	**Temperature (°C)**			**Precipitation (mm)**
	Max	Min	Mean		Max	Min	Mean	
April					21.6	14.1	17.9	112.0
May					19.6	10.9	15.3	20.0
June					19.9	9.4	14.7	0
July					19.7	9.2	14.5	0
August					20.5	9.5	15.0	0
September	20.8	10.3	16.4	0	22.6	10.2	16.4	0
October	23.9	11.9	18.4	22	24.7	12.3	18.5	0
November	24.7	12.7	19.0	3.8	24.9	13.0	19	24.0
December	24.4	12.8	18.7	102	24.1	13.3	18.7	31.2
Mean	23.5	11.9	Total:	127.8	22.0	11.3	Total:	187.2

[a] = experiment irrigated from September to December; [b] = experiment irrigated from May to December.

4.3.4 Genotype treatments

A total of 31- tea genotypes were evaluated, comprising different varietal types i.e. Chinery, Assam, Cambod and their hybrids (Table 4.3). Genotype SFS150 was included for yield comparison based on its commercial importance in the East and Central African tea growing regions. Fertilizer was applied at 250 kg N $ha^{-1}year^{-1}$ in two splits (TRIT, 2006). The first fertilizer application was carried out in December (at the start of wet season), while the second during late March of each season. Other agronomic management practices were done according to TRFK (2005). A complete randomized block design (CRBD) with five irrigation levels (I_0 – I_4) arranged in split-plot in 3 replications was adopted. Irrigation levels(I_0 – I_4) and genotypes (1 – 31) were assigned as main- and sub-plots, respectively.

4.3.5 Irrigation treatments

Water for irrigation was pumped from the Natural Lake Ngwazi using electrical pump (3-phase Motor; 175HP; 415V, CATCO, U.K). Water was delivered to storage plastic tank (5 000 lt. capacity) approx. 800 m fixed at 2 m height from ground. Scheduling of drip irrigation was based on the soil water balance equation as detailed in Kigalu *et al.* (2008). Determination of water quantity for each irrigation treatment was estimated from the sunken evaporation pan (B-pan) placed at Ngwazi meteorological station 300m from the experimental site (Figure 4.1). The experimental plots were irrigated whenever E-Pan recorded 75 mm of evaporated water (TRIT, 2007). Five irrigation treatments were studied labelled I_0 = no-drip irrigation (Control), I_1 = 25%, I_2 =50%, I_3 = 75% and full-irrigated (I_4 =100%), each represented 25%, 50%, 75% reduction soil water deficit and 100% being full soil water deficit replacement (at field capacity), respectively. These were equivalent to 0.0, 0.95, 1.91, 2.86 and 3.82 l per hour flow rate.

Figure 4.1: Set up of drip irrigation experiment at Ngwazi Tea research Station (NTRS) (2014/15-2015/16).

Table 4.3: List of 31-Tea Genotypes Evaluated under Drip irrigation (I_0 –I_4) at Ngwazi Tea Research Station during 2014/15 and 2015/16.

Serial No.	Genotype	Source of origin	Varietal Type
1	TRFK 11/4	Kenya local selection	Assam
2	TRFK 12/19	Kenya local selection	Assam
3	TRIT 201/16	Tanzania local selection	Assam/Chinery hybrid
4	TRIT 201/43	Tanzania local selection	Assam
5	TRIT 201/44	Tanzania local selection	Assam
6	TRIT 201/47	Tanzania local selection	Assam/Chinery hybrid
7	TRIT 201/50	Tanzania local selection	Assam
8	TRIT 201/55	Tanzania local selection	Assam/Chinery hybrid
9	TRIT 201/73	Tanzania local selection	Assam/Chinery hybrid
10	TRIT 201/75	Tanzania local selection	Assam/Chinery hybrid
11	TRIT 201/82	Tanzania local selection	Assam/Chinery hybrid
12	TRFK 301/4	Kenya local selection	Cambod
13	TRFK 301/5	Kenya local selection	Cambod
14	TRFK 301/6	Kenya	Cambod
15	TRFK 303/1199	OP progeny TRFK 6/8	Assam/Chinery hybrid
16	TRFK 303/178	OP progeny TRFK 6/8	Assam
17	TRFK 303/216	OP progeny TRFK 6/8	Assam
18	TRFK 303/259	OP Progeny TRFK 6/8	Assam
19	TRFK 303/577	OP progeny TRFK 6/8	Assam/Chinery hybrid
20	TRFK 31/8	Kenya	Assam
21	TRFK 371/2	Kenya	Assam
22	TRFK 371/3	OP progeny AHP S15/10	Assam
23	TRFK 371/6	OP progeny AHP S15/10	Assam
24	TRFK 371/8	OP progeny AHP S15/10	Assam
25	TRFK 381/5	BB35 × BB2	Assam
26	TRFK 400/10	Kenya	Assam
27	TRFK 400/4	OP progeny AHP S15/10	Assam
28	TRFK430/63	TRFC × EPK TN 14/3	Assam/Chinery hybrid
29	TRFK 430/7	TRFCA SFS 150× EPKTN14/3	Assam/Chinery hybrid
30	TRFK 6/8 (Ck-1)	Kenya local selection	Assam
31	SFS150 (Ck-2)	Malawi local selection	Assam

With permission from Makola (2013).

4.3.6 Evapotranspiration (mm)

Scheduling of drip irrigation treatments and calculation of daily and cumulative potential soil water deficit (SWD)(mm) was carried based on the soil water balance equation for tea (Kigalu *et al.,* 2008) (2) below;

Soil water deficit (mm) $SWD = SWD_{i-1} - R_i + E_{pan}$ ……..…….... (1)

Where,

SW_{Di-1} represented the soil water deficit during the previous $(_{i-1})^{th}$ day;

R_i = precipitation and

E_{pan} = evaporation from the sunken evaporation pan (B-pan) measured during the i^{th} day in mm using the Automatic IMETOS©R Meteorological station installed within 300 m distance from the experiment N17 at Ngwazi Tea Research Station (NTRS). Since tea bushes were mature (11 yrs.) with almost 100% crop ground cover, the estimated water loss from the soil surface was assumed almost to be negligible. Whenever 75 mm of water evaporated from the evaporation B-Pan located 300 m from the experimental site, it was considered time to drip irrigate tea crop (Kipangula, Pers. Comm.).

Before imposing the drip irrigation treatments, the experiment was uniformly irrigated to harmonize the experimental soil moisture content. The differential drip irrigation treatments were commissioned from 1st September to 17th December 2015 during first dry season and 1st May to 31st December 14th 2016 during second season, when irrigation was stopped and wet season (rainfall) set in.

4.3.7 Data collection

4.3.7.1 Shoot density (shoots m^{-2})

Data on shoot density was collected and estimated based on Nyabundi *et al.* (2016). Collection of shoot density data began a month after imposing irrigation treatment in

October during 2014/15 and June in 2015/16 season. Shoots count was carried out a day prior harvesting green leaf for yield determination. Shoots were counted using a 0.2 m^2 wooden grid randomly thrown over the tea plucking table at a frequency of five grids per plot. The total fresh mass of the shoots from each plot was weighed at each harvest. Average shoots was calibrated from each plot and converted into number of shoots per m^2 according to Makola (2013 and Nyabundi *et al.* (2016) and as shown below:

$$\text{Shoot density } (m^{-2}) = \frac{\text{Number of shoots}}{\text{Land area } (m^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

4.3.7.2 Mean yield (kg mt ha^{-1})

Yield data were collected from harvested green leaf (2 leaves + a bud). Weight of harvested green leaf from each plot was recorded and expressed in gram or kg per plot. Harvested green leaf was further converted into annual made tea yields (kg mt ha^{-1}) by multiplying with a 0.225 outturn factor (Makola *et al.*, 2013), and expressed as kilogram made tea per hectare (kg mt ha^{-1}).

4.3.7.3 Water Use Efficiency (WUE)

This is defined as the ratio of yield to evapotranspiration (ET) or yield obtained per unit of applied water from irrigation including that from precipitation (Nagaz *et al.*, 2012). In tea crop the productivity of tea is quantified in terms of weight of made tea per unit land area per year. Therefore, WUE measures the productivity of applied water irrigation. WUE of tea is influenced by water availability, nitrogen application and season (Carr, 2012). During wet season, WUE is higher than in cool dry season and the response of WUE to irrigation increases with increasing nitrogen fertilizer. The WUE values were adopted to determine productivity of irrigation among treatments (Kuşçu and Demir, 2012) and calculated according to Nagaz *et al.* (2012);

WUE (kg. $ha^{-1}.mm^{-1}$) = Yield (kg. ha^{-1})/total applied water (mm) ……..……. (3)

In case of a perennial crop, tea inclusive, this period will cover beginning when the first irrigation treatments were imposed until when it was stopped following the set in of wet season.

4.3.8 Data analysis

Obtained data were analyzed both in separate and combined analysis (ANOVA) using Genestat statistical software Version 15. Means for genotypes, irrigations, seasons and their interactions were separated using the Duncan Multiple Range Test (DMRT) at probability level of $p \leq 0.05$. The statistical model was adopted as described below;

$Y_{ijkl}=\mu+R_i + I_j + \varepsilon_{ij} + G_k + (G*I)_{jk} + \varepsilon_{ijkl}$ ..... (4)

Y_{ijk}= Response variable: Observation in the i^{th} replication, j^{th} irrigation, k^{th} genotype and l^{th} plot.

μ = the general mean;

R_i, I_j and G_k = effects of i^{th} replication, j^{th} irrigation and k^{th} genotype, respectively.

ε_{ij} = random error for factor A;

$(G*I)_{jk}$ =interaction effect;

ε_{ijkl} = error for factor B

4.4 Results

4.4.1 Applied Irrigation Water and Evapotranspiration (ET) (mm)

The effect of irrigation and evapotranspiration on water use and yield response is presented in Table 4.4. Within and between two seasons, both applied irrigation water and evapotranspiration varied (Table 4.4). More applied irrigation water and evapotranspiration amounts were recorded during 2014/15 than 2015/16. Applied irrigation water varied from 167 to 658 mm averaged 407.3 mm in 2014/15. The values ranged from 165 to 521 mm, averaged 338.5 mm during 2015/16. The evapotranspiration ranged from 127.8 to 704 mm and averaged 454 mm in 2014/15. The evapotranspiration

ranged from 187.2 to 554 mm in 2015/16, averaged 370 mm. Applied drip irrigation water increased with evapotranspiration during both seasons.

Irrigating tea at I_1 = 25%, I_3 = 75% and I_2 = 50% levels increased yield by 1.40% and 1.9% respectively, however, it decreased yield by 6.2% for all levels and saved drip irrigation water by 74.6%, 47.7% and 30.1% in 2014/15, respectively. Similarly, on the basis of 2015/16 results, irrigating clonal tea at I_1= 25%, 50% and 75% of field capacity improved tea yield by 37.9%, 31.2% and 17.1% and saved drip irrigation water by 68.3%, 53.0% and 18.8%, respectively.

Table 4.4: Effect of drip irrigation and evapotranspiration treatments on water use efficiency (WUE) and yield response during 2014/15 and 2015/16.

Season	Irrigation treat. (mm)	Evapotranspiration (mm)	Applied irrigation (mm)	Yield (kg mt ha^{-1}) ¥	WUE (kg m^{-3})
2014/15[a]	I_0	127.8	-	300	-
	I_1	214	167	425	2
	I_2	391	344	393	1
	I_3	507	460	427	0.8
	I_4	704	658	419	0.6
Mean		454	407.3	393	1.1
Sed (n=)				28.4	
LSD (p≤0.05)				56	
CV (%)				7.2	
2015/16[b]	I_0	187.2	-	1 096	-
	I_1	197	165	1 336	6.8
	I_2	277	245	1 481	5.3
	I_3	455	423	1 785	3.9
	I_4	554	521	2 153	3.9
Mean		370.8	338.5	1 689	5.0
Sed (n=)				6.8	
L.S.D (p≤0.05)				13.4	
P-value				0.05	
CV (%)				0.4	

¥=kg mt ha^{-1} stands for kilogram made tea per hectare. [a]= experiment irrigated from September to December; [b]= experiment irrigated from May to December; s.e.d=Standard error of differences of means; LSD=Least significant differences; CV(%) = Coefficient of variation.

4.4.2 Yield (kg mt ha^{-1})

Higher mean tea yields were recorded during 2015/16 than in 2014/15. Mean yields varied from 300 to 427 kg mt ha^{-1} and averaged 393 kg mt ha^{-1} in 2014/15 in all irrigation treatments. In 2015/16, the yields ranged from 1 096 to 2 153 kg mt ha^{-1} with average of 1 689 kg mt ha^{-1}. Yields increased with applied irrigation and evapotranspiration during 2015/16, but, inconsistent was evident during 2014/15.

4.4.3 Water use efficiency (kg m^{-3})

During both seasons, WUE values decreased with applied drip irrigation water but with increased evapotranspiration (Table 4.4). The WUE generally decreased with increased tea yields. Least WUE values were recorded during 2014/15 than in 2015/16. The WUE values varied from 0.6 to 2.0 kg m^{-3} with average of 1.1 kg m^{-3}, whereas, the same variable varied from 3.9 to 6.8 kg m^{-3}, averaged 5.0 kg m^{-3} during 2015/16.

4.4.4 Effects of drip irrigation (I) on yield and shoot density

Results of yield and shoot density according to applied drip irrigation levels are presented in Table 4.5. The effect of applied drip irrigation on tea genotypes with respect to yield was significant (Table 4.5 and Appendix 4.1).

Table 4.5: Main effect of irrigation regimes on yield and shoot density

Irrigation regime (mm)	Yield (kg mt ha^{-1})¥	Shoot density (Shoots m^{-2})
I_0 = No irrigation	698	118
I_1= 25%	878	148
I_2 = 50%	937	139
I_3= 75%	1 102	140
I_4 = 100% (Fully irrigated)	1 284	149
Mean	980	139
S.e.d (±)	15.8	16.0
LSD (±) ($p \leq 0.001$)	31.1	22.0
P-value	0.05	0.05
CV (%)	1.6	11.5

¥=kg mt ha^{-1} stands for kilogram made tea per hectare; S. e. d = Standard error of differences of means; LSD=Least significant differences; CV (%) = Coefficient of variation.

The yield varied with applied drip irrigation, with maximum mean yield (1 284 kg mt ha^{-1}) recorded at drip irrigation I_4=100%. The least mean yield (698 kg mt ha^{-1}) was attained at no-drip irrigation (I_0).

The shoot density also varied with applied drip irrigation. All drip irrigated treatments I_1=25%, I_2=50%, I_3 = 75% and I_4 = 100% had significantly ($p \leq 0.001$) greater mean shoot density than in non-irrigated treatment (I_0). There was no significant difference on mean shoot density among the drip irrigated treatments. However, I_4=100% had greatest numerical mean shoot density of 149 shoots m^{-2} which was non-significantly different among all irrigated treatments. Irrigating tea at I_1 = 25%, I_2 = 50%, I_3 = 75% and I_4=100% levels *versus* no-irrigation treatment had gain in shoot density of 15.1% to 20.8%.

4.4.5 Main-effect of genotypes for yield and shoot density

Results for response of genotypes on yield and shoot density traits are presented in Table 4.6 and Appendix 4.1. The difference among genotypes were significant ($p \leq 0.05$) for yield. The highest mean yield of 1 564 kg mt ha^{-1} was recorded for TRFK 303/577 (19), while the lowest (628 kg mt ha^{-1}) was obtained for TRIT 201/16 (3). The best genotype TRFK 303/577 (19) exceeded the control, overall mean and the least yielding genotype by 16.5%, 37.3% and 59.8%, respectively. The differences among genotypes for shoot density also were significant. Genotype TRFK 303/259 (18) had significantly highest mean shoot density (184 shoots m^{-2}). The genotype surpassed the control (SFS150), the overall mean and least performing genotype by 10.3%, 24.5% and 41.8%, respectively. Significant lower mean shoot density was registered for TRFK 11/4 (107 shoots m^{-2}) and TRIT 201/16 (108 shoots m^{-2}).

Table 4.6: Main-effect of genotypes for yield and shoot density

Serial No.	Genotype	Yield (kg mt ha^{-1}) ¥	Shoot density (shoots m^{-2})
1	TRFK11/4	683u	107p
2	TRFK 12/19	803q	142g-k
3	TRIT 201/16	628v	108p
4	TRIT 201/43	1 103g	137i-l
5	TRIT 201/44	619v	122no
6	TRIT 201/47	1 055ij	162b-e
7	TRIT 201/50	712t	117op
8	TRIT 201/55	1 045j	142g-k
9	TRIT 201/73	975m	155d-g
10	TRIT 201/75	748s	122no
11	TRIT 201/82	847p	156c-f
12	TRFK 301/4	1 340b	172b
13	TRFK **301/5**	1 029k	149f-i
14	TRFK 301/6	1 056ij	125l-o
15	TRFK 303/1199	1 182f	148f-i
16	TRFK 303/178	743s	123no
17	TRFK 303/216	966m	151e-h
18	TRFK **303/259**	1 291c	**184a**
19	**TRFK 303/577**	**1 564a**	167bc
20	TRFK 31/8	768r	145f-j
21	TRFK 371/2	904o	127k-n
22	TRFK 371/3	1 080h	137i-l
23	TRFK 371/6	803q	124m-o
24	TRFK 371/8	1 007l	140h-k
25	TRFK 381/5	1 196e	135i-m
26	TRFK 400/10	938n	127l-o
27	TRFK 400/4	1 216d	130j-n
28	TRFK 430/63	1 063i	146f-j
29	TRFK 430/7	1 009l	125l-o
30	TRFK 6/8	701t	124m-o
31	SFS150 (CK)	1 306c	165b-d
	Mean	980	139
	Sed (±)	7.2	7.5
	P-value	0.05	0.05
	CV (%)	2.8	14.4

¥=kg mt ha^{-1} stands for kilogram made tea per hectare. Means followed by the same letter indicate no differences according to Duncan Multiple Range test (DMRT) at the probability level of 0.05; S.e.d=Standard error of differences of means; CV (%) =Coeffient of variation.

4.4.6 Main-effect of seasons on yield and shoot density

The effect of growing seasons for yield and shoot density is illustrated in Table 4.7 and Appendix 4.2. Significant differences were revealed between growing seasons for yield and shoot density traits. The season 2015/16 recorded significantly higher mean yield of 1 570 kg mt ha^{-1} with seasons average of 980 kg mt ha^{-1}. The yield was higher over the overall mean yield by 37.6%. Highest mean shoot density of 159 shoots m^{-2} was attained during 2014/15. The mean shoot density was higher by 12.6% over the overall mean.

Table 4.7: Main-effect of seasons on yield and shoot density

Season	Yield (kg mt ha^{-1})¥	Shoot density (shoots m^{-2})
2014/15[a]	390	159
2015/16[b]	1 570	119
Mean	980	139
S.e.d (±)	10.1	7.5
LSD ($p \leq 0.05$)	19.9	2.6
CV (%)	1.0	5.4

¥=kg mt ha^{-1} stands for kilogram made tea per hectare. [a] = experiment irrigated from September to December; [b] = experiment irrigated from May to December; S.e.d = Standard error of differences of means; LSD = Least significant differences; CV(%) = Coefficient of variation.

4.4.7 Interaction effect between genotypes and irrigation levels on yield and shoot density

The interaction effects between genotypes and drip irrigation levels on yield and shoot density are presented in Table 4.8 and Appendix 4.2. The interaction effects between genotypes and drip irrigation revealed genotype TRFK 303/577 (19) had significant higher yield (2 037 kg mt ha^{-1}) response at irrigation treatment I_4 = 100%. The genotype also responded significantly higher at irrigation treatments I_1 = 25% and I_3 = 75%. Two genotypes TRIT 201/43 (4) and TRFK 303/259 (18) recorded significantly higher mean yield response at non-irrigated treatment (I_0). Genotype TRFK 303/577 (19) had significantly highest yield response at irrigation treatment I_4 = 100%.

Table 4.8: Interactions of genotype × Irrigation (G*I) on yield (kg mt ha^{-1})¥

	Irrigation	**I_0**	**I_1**	**I_2**	**I_3**	**I_4**
Serial No.	**Genotype**					
1	TRFK11/4	451p	606w	678r	787qr	893q
2	TRFK 12/19	545m	677s	634t	987m	1 171n
3	TRIT 201/16	400r	567x	607u	511t	1 060o
4	TRIT 201/43	**1 137a**	834p	1 027h	1 226gh	1 291kl
5	TRIT 201/44	478o	617v	467v	551t	979p
6	TRIT 201/47	543m	1 013i	1 222e	1 331e	1 259lm
7	TRIT 201/50	672i	609vw	606u	704s	968p
8	TRIT 201/55	711h	1 035h	724q	1 233g	1 520ef
9	TRIT 201/73	693h	994k	903l	1 242fg	1 039o
10	TRIT 201/75	514n	651t	930k	837pq	805r
11	TRIT 201/82	426q	616v	762s	1 142ij	1 407i
12	TRFK 301/4	775g	1 049g	1 424a	1 697b	1 755b
13	TRFK **301/5**	649j	952mn	999i	1 093jk	1 452gh
14	TRFK 301/6	850e	945n	1 148d	1 014lm	1 318jk
15	TRFK 303/1199	803f	927o	1 189c	1 389d	1 600d
16	TRFK 303/178	487o	628v	742p	877o	981p
17	TRFK **303/216**	600k	1 112e	730q	923no	1 463gh
18	TRFK **303/259**	**1 137a**	1 300b	1 023h	1 297ef	1 698c
19	TRFK 303/577	970b	**1 476a**	1 404b	**1 933a**	**2 037a**
20	TRFK 31/8	935c	751r	969j	760r	426t
21	TRFK 371/2	705h	773q	757o	1 052kl	1 229m
22	TRFK 371/3	911d	1 002j	844m	1 172hi	1 473g
23	TRFK 371/6	773g	652t	781n	750rs	1 058o
24	TRFK 371/8	641j	966l	1 094f	910o	1 423hi
25	TRFK 381/5	924cd	1 059f	1 130e	1 219gh	1 628d
26	TRFK 400/10	555lm	522z	1 075g	1 277e-g	1 263lm
27	TRFK 400/4	853e	1 191d	1 095f	1 408d	1 538e
28	TRFK 430/63	667i	983k	930k	1 241fg	1 488fg
29	TRFK 430/7	572l	956m	1 027h	1 148i	1 341j
30	TRFK 6/8	458p	540y	907l	973mn	627s
31	SFS150 (CK)	788fg	1 216c	1 410b	1 499c	1 616d
Mean		698	878	937	1 102	1 284
P-value				0.05		
CV (%)		1.8	0.6	0.8	3.4	2.4

¥=kg mt ha^{-1} stands for kilogram made tea per hectare. Means followed by the same letter indicate no differences according to Duncan Multiple Range test (DMRT) at the probability level 0.05; CV (%) = Coefficient of variation.

4.4.8 Interaction effect between genotypes and irrigation levels on shoot density

The interaction effect between genotypes and irrigation treatments was significant on shoot density trait (Table 4.9 and Appendix 4.2). Genotypes TRFK 303/259 (18), TRFK 303/577 (19) and TRIT 201/73 (9) displayed significantly higher shoot density responses

at I_1=25%. Genotypes TRFK 301/5 (13) and TRFK 303/216 (17) presented significantly higher shoot densities at irrigation I_4=100%.

Table 4.9: Interactions of genotype × irrigation (G*I) on shoot density (shoots m^{-2})

	Irrigation	**I_0**	**I_1**	**I_2**	**I_3**	**I_4**
Serial No.	**Genotype**					
1	TRFK11/4	90i-k	102j	105k-m	101hi	141ef
2	TRFK 12/19	115d-i	153c-f	168b-d	123f-i	151de
3	TRIT 201/16	105e-k	122g-j	105k-m	104hi	102g
4	TRIT 201/43	135cd	131e-i	128f-l	147d-g	141ef
5	TRIT 201/44	84k	130e-i	111i-m	130e-h	156c-e
6	TRIT 201/47	124c-g	182ab	169b-d	177a-c	156c-e
7	TRIT 201/50	103f-k	102j	124g-m	105hi	149d-f
8	TRIT 201/55	111d-i	150c-g	129f-l	175a-d	144d-f
9	**TRIT 201/73**	103f-k	**192a**	166b-d	159a-d	147d-f
10	TRIT 201/75	99h-k	141c-i	102lm	114hi	155c-e
11	TRIT 201/82	129c-e	161b-d	662s	179ab	169b-d
12	TRFK 301/4	159ab	187ab	163c-e	174a-d	178a-c
13	TRFK **301/5**	121d-h	148c-h	152c-f	126e-i	**200a**
14	TRFK 301/6	121d-h	141c-i	135f-i	120g-i	109g
15	TRFK 303/1199	128c-e	149c-g	155c-f	150c-f	160c-e
16	TRFK 303/178	92i-k	147c-h	99m	128e-i	148d-f
17	**TRFK 303/216**	112d-i	165bc	132f-k	154b-e	**200a**
18	**TRFK 303/259**	**174a**	**207a**	191ab	162a-d	184ab
19	**TRFK 303/577**	120d-h	199a	**197a**	174a-d	147d-f
20	TRFK 31/8	168a	149c-g	173a-c	110hi	124fg
21	TRFK 371/2	103f-k	153c-f	113h-m	130e-h	136ef
22	TRFK 371/3	135cd	154c-e	106k-m	152b-e	139ef
23	TRFK 371/6	114d-i	152c-f	107j-m	105hi	141ef
24	TRFK 371/8	106e-k	138c-i	150c-g	165a-d	140ef
25	TRFK 381/5	118d-h	125f-j	136f-i	152b-e	142ef
26	TRFK 400/10	100g-k	115ij	138e-i	118hi	153de
27	TRFK 400/4	126c-f	142c-i	123g-m	116hi	143ef
28	TRFK 430/63	124c-g	134d-i	137e-i	**185a**	150d-f
29	TRFK 430/7	86jk	126e-j	140e-h	131e-h	143ef
30	TRFK 6/8	116d-h	119h-i	134f-j	114hi	136ef
31	SFS150(CK)	146bc	181ab	191ab	169a-d	138ef
	Mean	118	148	139	140	149
	P-value	0.05	0.05	0.05	0.05	0.05
	CV (%)	12.4	11.4	11.9	12.1	10.1

Means followed by the same letter indicate no differences according to Duncan Multiple Range test (DMRT) at the probability level 0.05; CV (%)= Coefficient of variation.

4.4.9 Correlations of yield and shoots density with Water use efficiency (WUE) stabilities

The correlations between yield and shoot density, yield and WUE and shoot density with WUE are presented in Table 4.10. Results revealed significantly positive association between yield and shoot density r = 0.725*** and water use efficiency r = 0.994***. The shoot density correlated positively and significantly r = 0.701*** with the water use efficiency (WUE).

Table 4.10: Correlation of yield and shoots density with Water use efficiency stabilities

	Yield	Shoot density	WUE
Yield	-		
Shoot density	0.725***	-	
WUE	0.994***	0.701***	-

***=significant at p≤ 0.001; Degrees of freedom = n -2 = 463; WUE=Water use efficiency.

4.4.10 Yield - evapotranspiration relationship

The relationship between tea yield and evapotranspiration is presented in Figure 4.2. The relationship described a positive quadratic function with average coefficient of determination of R^2i = 0.583*** in 2014/15 season. The slope (+0.6372x) indicates that made tea yield increased with evapotranspiration at the rate of 0.637 kg ha^{-1} mm^{-1} during 2014/15 season. The equation also showed, an estimated 260.5 kg mt ha^{-1} could be produced without application of irrigation water. Yield increased from 300 kg mt ha^{-1} to maximum of 427 kg mt ha^{-1} with ET = 502 mm. Further increase of ET to 704 mm reduced yield to 419 kg mt ha^{-1}. In 2015/16, the yield-evapotranspiration relationship was positively linear with strong coefficient of determination of R^2i= 0.948***. The relationship revealed that the tea yield increased with evapotranspiration at the rate of

2.448 kg ha^{-1} mm^{-1}. The equation also demonstrated that an estimated 752.4 kg mt ha^{-1} could be produced during 2015/16 without applying drip irrigation.

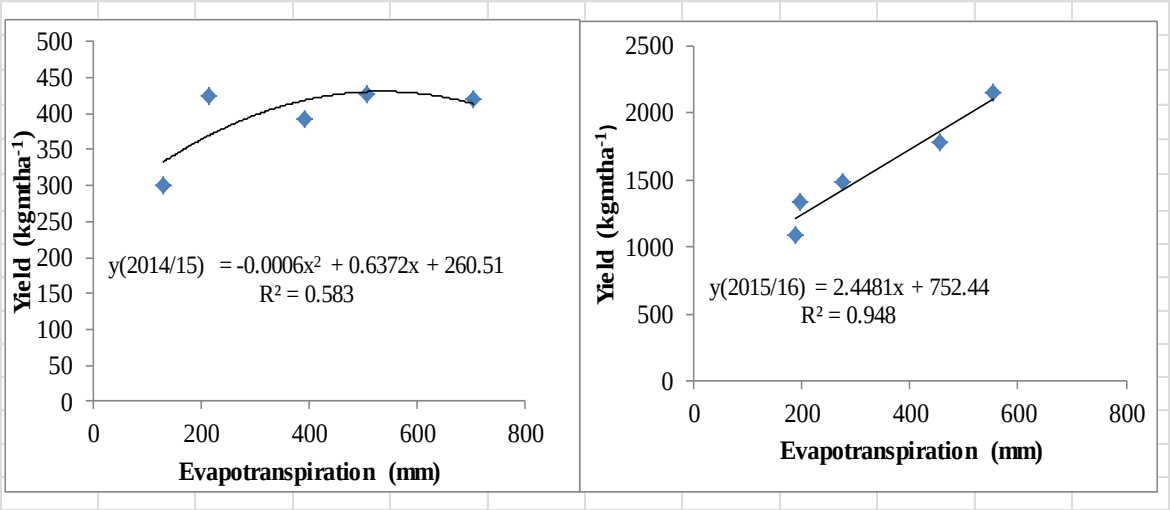

Figure 4.2: Relationship between Yield (kg mt ha^{-1}) and evapotranspiration mm) for tea crop at Ngwazi Tea Research Station (NTRS) during 2014/15 and 2015/16.

4.4.11 Yield-water use efficiency relationship

The yield-water use efficiency association is presented in Figure 4.3. During 2014/15, the yield-water use efficiency (WUE) described a positive linear increase relationship (R^2i = 0.041). Thus, yield increased with increase in WUE during 2014/15. In 2015/16 the equation function was negatively linear with significant coefficient of determination (R^2 = 0.781**). WUE increased with decrease in tea yield during 2015/16.

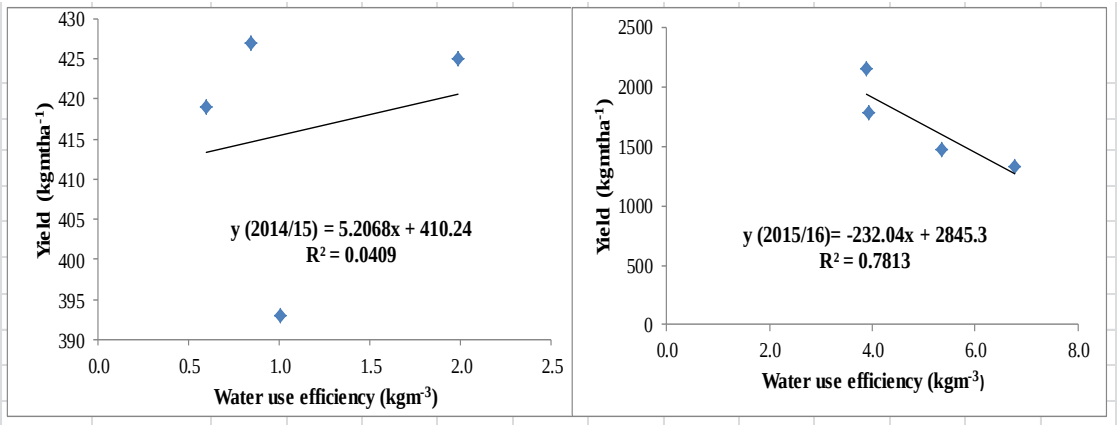

Figure 4.3: Relationship between water use efficiency (kg m^{-3}) and yield (kg mt ha^{-1}) for tea crop at Ngwazi Tea Research Station (NTRS) during 2014/15 and 2015/16.

4.5 Discussions

4.5.1 Analysis of variance (ANOVA)

Both separate and combined analysis (ANOVA), showed significant ($p \leq 0.001$) effects of irrigation, genotypes and season both on tea yield and shoot density traits. This suggested that there is opportunity to select or identify optimum irrigation level, suitable genotype and season for yield and shoot density in tea production.

The effects of genotype × irrigation, genotype × season and irrigation × season interactions on yield and shoot density were significant ($p \leq 0.001$), suggesting differential responses of genotypes among irrigation levels and seasons and that irrigation effects also depended on season. The significance of genotype × season interaction, also suggested that the genotypic performance varied among seasons due to differences in climatic conditions and genotypes. Thus, specific combinations of factors need to be identified for optimum expressions. In a similar clonal tea study, Kigalu *et al.* (2008) reported significant combined effects on irrigation, genotypes, seasons and their respective interaction on yield. However, Squire *et al.* (1993) reported non-significant G × I effect on

tea yield. Such contrasting findings could be attributed to different set of populations/ genotypes and environments that were evaluated.

4.5.2 Applied irrigation water and evapotranspiration (ET)

During 2014/15, the applied irrigation and evapotranspiration had similar trend of increase as in 2015/16. This was probably as a result of relatively higher minimum and maximum temperatures together with low precipitations during the two seasons (Table 4.2) which could have influenced higher ET. Karasu *et al.* (2015) reported similar results on silage maize (*Zea mays* indentata Sturt.). Irrigating tea crop at I_1 = 25% increased an estimated ET by 69.6% and 64.4% in 2014/15 and 2015/16, respectively (Table 4.4). Reducing soil water deficit by 75% (I_3), increased an estimated ET by 27.9% and 17.9% in 2014/15 and 2015/16, respectively (Table 4.4).

The irrigation × season interaction was highly significant ($p \leq 0.001$) on yield and shoot density, suggesting that irrigation levels responses varied inconsistently with season. Burgess and Carr (1996) reported similar variation in irrigation level responses with seasons under sprinkler irrigation system both on tea yield and shoot density.

4.5.3 Yield (kg mt ha^{-1})

Higher yields in 2015/16 than in 2014/15 may be attributed to differences in climatic weather between the two seasons. The mean minimum (11.3^{o}C) and maximum (22.1^{o}C) temperatures were relatively optimal with high precipitations (187.1mm) in 2015/16. In addition, adequate drip irrigation water was applied and well distributed from May to Mid-December (Table 4.2), causing more water availability to tea crop in all treatments. On the other hand, the 2014/15 was relatively warmer (11.9^{o}C and 23.1^{o}C) with low precipitation

(127.1mm) leading to high water evaporative demand which affected tea yields (Djaman *et al.*, 2013) during 2014/15. Due to untimely irrigation logistical set up, during 2014/15, the experiment was irrigated only for relatively short duration (4-months) from September to December, indicating the water was insufficient to adequately meet the required soil moisture among the irrigation treatments.

4.5.4 Water use efficiency (kg m^{-3})

The WUE ranged from 0.6 to 2.0 kg m^{-3} during 2014/15 and from 3.9 to 6.8 kg m^{-3} in 2015/16 (Table 4.4). During both seasons, the WUE values decreased with increased applied drip irrigation water. Higher WUE values were obtained at deficit water supply of I_2 = 25% level, while, the least WUE at fully drip irrigated level I_4 =100% during both seasons. The results suggested that during the seasons higher levels of irrigation provided more than necessary required moisture, hence was less economical. De Costa *et al.* (2007) explained that higher WUE values at I_1=25% was due to increased promotion of Absicic Acid (ABA) causing decreased stomata conductance, therefore, increased water use efficiency (WUE). According to Edwards *et al.* (2012), decreased stomatal conductance reduced water loss more than the quantity of carbon fixation. In contrast, applied fully irrigated treatment (I_4 = 100%) influenced more water and nutritional uptakes which maintained favourable tea plant growth status.

4.5.5 Effects of drip irrigation (I) on yield and shoot density

Yield increase at I_4 = 100% was due to sufficient available soil moisture content during the entire growing period (Karasu *et al.*, 2015). Higher water availability is likely to have caused optimum transpiration and higher growth of the aerial tea plant parts (Netto *et al.*, 2010). However, the results contradict the report by Kigalu *et al.* (2008). The author

reported highest tea yields at I_2 = 50% at Kibena Tea Company (KTC). The variation could be attributed to soils types. At KTC soils are described as clay loam with high organic matter and high water holding capacity; whereas, at Ngwazi site, the soils are sandy clay loam with medium to high organic matter (OM). The clay soils at KTC is likely to affect tea growth through poor drainage. Soils at Ngwazi provides good drainage and controlled effect of excess water in the soils (Makweta, Pers. Comm).

Statistically there were similar shoot densities at I_1 = 25%, I_2 = 50%, I_3 = 75% and I_4 = 100% (Table 5). This implies that the tea crop at the test location need only I_1= 25% of moisture level, thus economical supply of moisture should be applied. Lower shoot density at (I_0), was due to reduced photosynthetic capacity (assimilation of CO_2) and stomata conductance (gs) causing stomata closure and reduced transpiration rate (Netto *et al.*, 2010; Nir *et al.*, 2014). Water stress at (I_0) also reduced shoot density through restriction of tea shoot growth (Carr, 2012) leading to high water evaporative demand (Wijeratne and Fordharm, 1996). In the absence of water deficit, greater numerical shoot density was recorded at I_4 = 100% (149shoots m^{-2}) due to higher rates of shoot initiation and extension as influenced by air temperature (De Costa *et al.*, 2007). In tea plant, air temperature is described to be positively associated with rates of shoots initiation.

4.5.6 Main-effects of genotypes for yield and shoot density

The differences among tea genotypes for yield could be an attribute to genetic composition. This creates an opportunity for tea breeders to exploit the variability in the course of improving yield in tea populations. Burgess and Carr (1996) and Kigalu *et al.* (2008) had similar conclusion on sprinkler- and drip-irrigated clonal tea studies respectively. Genotype TRFK 303/577 (19) gave significantly highest mean yield of 1 564

kg mt ha^{-1}. Similar results were reported by Nyabundi *et al.* (2016) on the same tea genotype. Highest mean yield for mature tea genotype TRFK 303/577 (19) also can be linked to genetic and physiological factors. Being a Chinery type, higher yielding may be associated with small size, dark green coloured leaves with semi erect to erect posture which intercepts higher light intensity to influence higher photosynthesis rate and yield (De Costa *et al.,* 2007).

4.5.7 Main-effects of seasons on yield and shoot density

Recorded highest yield during 2015/16 than in 2014/15 may be an attribute to differences in climatic conditions. Djaman *et al.* (2013) reported differences in minimum and maximum temperatures between seasons which caused variation in maize crop performance. The weather during 2015/16 was relatively lower min. (11.3^{o}C) and max. (22.1^{o}C) temperatures and relatively higher precipitation (187.1mm). During 2015/16, applied irrigation provided a large sufficient water irrigation to all treatments from May to November months, the condition which assured adequate availability of water for normal tea growth. Payero *et al.* (2006) had similar observation in corn (*Zea mays* L.), where due to weather variation more corn yield was recorded during 2004 than in 2003.

Similarly, higher shoot density in 2014/15 could be ascribed to compensatory plant growth effects which upon commencement of irrigation in September (peak of dry season) it directly influenced the initiation of dormant tea shoots within the plucking table following the unfavourable cool dry weather (Wijeratne, 2003; De Costa *et al.*, 2007). In tea, under insufficient water supply or water stress, shoot density is less affected than shoot weight (De Costa *et al*., 2007). However, yield was not increased because the governing conditions did not influence immediate shoot expansion and extension which ultimately affects shoot weight per unit area, hence the tea yield (De Costa *et al*., 2007).

4.5.8 Interaction effect between genotypes and irrigation levels on yield and shoot density

The interaction effects between genotypes and drip irrigation revealed TRFK 303/577 (19) gave significantly highest yield (2 037 kg mt ha^{-1}) response at fully drip irrigated level I_4=100%. Several previous findings have reported similar results (Burgess and Carr., 1996; Kigalu *et al*., 2008; Kuslu *et al*., 2013). Variation in yield response to differential drip irrigation can be due to differences in genetic composition among tested tea genotypes. Considering the evidence that there are different responses of genotypes to varying moisture regimes, thus, specific combinations of genotypes with moisture regime is crucial for tea yield determination. Similarly, the observed higher yield performance at I_4 = 100% was attributed to continuous availability of drip irrigation water at this particular treatment.

Genotypes TRIT 201/43 (4) and TRFK 303/259 (18) displayed significantly higher yield responses at non-irrigated treatment (I_0). This could be due to higher genotypic ability to partition large proportion of dry matter to leaves (sink) and less to structural roots (Burgess and Carr, 1996). Netto *et al.* (2010) suggested that, such genotypes use advantage of full ground canopy (100%) cover to conserve water from reduced water loss through evaporation. In addition, well-established tea root structure at mature age aids to extract stored water from deep in the soil. Burgess and Carr (1996) reported clonal genotype S 15/10 to have out-yielded other five genotypes based on its ability to partition more dry matter to leaves (sink). Therefore, the present results provide a scope for identification and selection of improved tea genotypes responsive to fully and deficit soil moisture conditions.

4.5.9 Interaction effect between genotypes and irrigation levels on shoot density

The interaction effect between genotypes and irrigation treatments was significant on shoot density trait. Significantly highest shoot density (207 shoots m^{-2}) was recorded for genotype TRFK 303/259 (18) at I_1 = 25%. Such genotype indicated higher ability to partition a larger proportion of dry matter during dry season in shoots (sinks) than in the root zone (Burgess and Carr., 1996). This may be similar reasoning for same genotype under non-irrigated treatment (I_0). In contrast, significantly higher shoot density at irrigation treatment I_4 =100% for genotypes TRFK 301/5 (13) and TRFK 303/216 (17) can be due to sustained available water throughout the growing seasons which favoured normal growth of tea shoots. Thus, there are genotypic differences on shoot density that make it possible to identify tea cultivars with high shoot density under moisture stress (e.g. TRFK 303/259 (18)) and under ample moisture regime (e.g. TRFK 301/5 (13) and TRFK 303/216 (17).

4.5.10 Correlations among yield, shoots density and Water Use Efficiency (WUE) variables

Results for correlations between yield and shoot density (r = 0.725***) was expected because shoot density is one of the key tea yield components (Wijeratne, 2003; Carr, 2012; Nyabundi *et al.*, 2016). Tea shoot density contributes 80% - 89% of tea yield variations (Wijeratne, 2003; Nyabundi *et al.*, 2016). The relation indicates the importance of shoot density in determining tea yield (Nyabundi *et al*., 2016). This implies that, tea genotypes with higher mean yield also present higher shoot densities. Therefore, this offers a scope for either concurrent improvement of tea yield with shoot density or through improved shoot density alone (Wijeratne, 2003).

Correlations between tea yield with WUE (r = 0.994***) and shoot density with WUE (r = 0.701***) in that order are significantly and positively correlated. Thus, increased WUE is pertinent for increased yield and shoot density of tea crop. Working in wheat crop, Condon *et al*. (2012) reported increased yield and shoot density with less amount of water. This presents opportunity of breeding high water use efficient tea genotypes. Kang *et al.* (2002) reported that, under limited water resource, genotypes with high WUE use less water. That is, are able to assimilate higher rate of carbon per unit water used and accumulate more biomass.

4.5.11 Yield - evapotranspiration relationship

The yield-evapotranspiration quadratic function in 2014/15 also are reported by Burgess and Carr (1996) and Kigalu *et al.* (2008) under sprinkler and drip irrigation systems, respectively. The regression showed that significant average increase in coefficient of determination of $R^2_i = 0.583*$ in tea yield was on average proportional to the increment of ET. The regression also indicated that tea amounting to 260 kg mt ha^{-1} could be produced without water irrigation due to effect of available sufficient residual moisture in the soil (Djaman *et al.*, 2013). Yield-ET indicated that small irrigation application increased crop ET, more or less linearly beyond which it turns to curvilinear. This was as a result of lost water upon attaining maximum ET (Payero *et al*., 2008).

Strong positive linear relationship of $R^2_i = 0.948***$ in 2015/16 season, indicated tea yield increased with evapotranspiration (ET) showing no point of maximum attainment for further increased yield with ET. Maximum yield point may not be specified due to lack of excessive irrigation application during 2015/16. The slope showed the tea yield increased with evapotranspiration at the rate of 2.448 kg ha^{-1} mm^{-1} during 2015/16 season. However,

this rate of increase was relatively low to that by Kigalu *et al.* (2008) who reported increased clonal genotypes response of 7.2 kg ha^{-1} mm^{-1} to drip irrigation. The results variation could be due to differences in tested genotypes and soil types in the present study. Such relationship also is widely reported in other crop species such as; Alfalfa (*Medicago sativa* L.) (Kuslu *et al.,* 2013) and maize (*Zea mays* L.) Kuşçu and Demir, 2012).

At Ngwazi site, the dry period is divided into cool (April/May-July/August) and warm dry (Sept-Dec.) seasons. In 2014/15 season, the tea crop was irrigated with drip water only during warm dry season (Sept-Dec.), leaving the crop to suffer from drought stress during cool dry season. But, during 2015/16, the crop was gradually and consistently supplied with water during the entire cool and warm dry periods favouring normal tea crop growth.

4.5.12 Yield-water use efficiency relationship

The tea yield-WUE relationship during 2014/15 and 2015/16 was associated with WUE under drought and freely available water conditions. According to Edwards *et al.* (2012) and Nir *et al.* (2014), under water–limited condition, higher WUE during 2014/15 could be attributed to enhanced plant leaf chlorophyll level which positively affects CO_2 fixation and contributes to better tea plant performance. In other words, under water limited condition tea genotypes use available limited water conservatively influencing higher stomata conductance (Wg) causing better tea plant performance. However, this may depend on whether the tea genotype is either susceptible or tolerant to drought stress. Similarly, due to well-watered condition, tea genotypes seems not to use water conservatively causing low stomata conductance (Wg) and keeping good tea plant performance (Edwards *et al.,* 2012).

During 2014/15, tea plants were under stressful condition (drought) which possibly used the limited available moisture more conservatively to maintain normal tea growth. Ultimately, this influenced a relatively low tea yield-WUE predictability value of R^2 = 4.1%. In contrast, due to more freely available drip irrigated water, tea plants during 2015/16 did not utilize the freely available water conservatively leading to revealed negatively strong yield-WUE association with higher predictability value of R^2 =78.1%.

At hormonal level, under water-limited condition, tea genotypes response involves accumulation of Absicic acid (ABA) hormones which regulate specific gene expression for chemical signals which initiates stomatal closure a crucial water-conserving response for adaptation to drought stress (Prakash *et al.*, 2017).

4.6 Conclusion

Applied drip irrigation levels significantly affected both tea yield and shoot density traits. Deficit drip irrigation levels decreased tea yield and to a lesser extent shoot density. From the present study, applying drip irrigation at full treatment (I_4=100%) contributed significantly higher tea yields. However, application of drip irrigation at I_1 (25% reduction of moisture stress) gave comparable yields with I_4 (100% reduction of moisture stress). For shoot density significant difference was evident between no-drip irrigation (I_0) with the rest of irrigation regimes I_1 = 25% - I_4 =100%. Irrigation × Genotype interaction indicated highest tea yield was recorded for TRFK 303/577 (19) at full-drip irrigation treatment (I_4=100%), while TRFK 303/259 (18) was promising for shoot density both at no-drip irrigation (I_0) - and deficit drip irrigation I_1 = 25%. Under limited water resource (I_0), genotypes TRIT 201/43 (4) and TRFK 303/259 (18) recorded significantly highest tea yields.

Yield correlated significantly positive (r = 0.725***) with shoot density. Also, significantly positive association (r = 0.994***) was between tea yield and water use efficiency (WUE). Shoot density and water use efficiency presented significant positive associations (r = 0.701***). Yield-Evapotranspiration described positive quadrant with average R^2_i = 0.583* in 2014/15 and linear significant R^2_i = 0.983*** in 2015/16 relationship. Yield -WUE relationship was linear and very weak (R^2_i = 0.041) in 2014/15, but strongly negative and linear (R^2_i = 0.781***) in 2015/16.

Due to high yield performance at fully drip-irrigated treatment (I_4 = 100%), TRFK 303/577 (19) was promising under tea areas with adequate water availability. Genotypes TRIT 201/43 (4) and TRFK 303/259 (18) were equally considered promising under low water availability areas due to higher yield performance under no-drip irrigation (I_0) treatment. The latter two genotypes also were more efficient in utilizing low water available to generate higher tea yields.

4.7 Recommendations

i. Tea genotype TRFK 303/577 (19) can be considered for commercialization in areas where water for drip-irrigation may not be a limiting factor (adequate).
ii. Genotype TRIT 201/43 (4) can be recommended for yield production where water for drip-irrigation can be a limiting factor (inadequate).
iii. Genotypes TRFK 303/259 (18), TRFK 303/577 (19) and TRIT 201/43 (4) can be incorporated in tea breeding programmes for generation of improved tea genotypes for yield and WUE.
iv. For maximum yield production it is recommended to replace soil water deficit on tea crop at full drip irrigation treatment (I_4 = 100%).

v. In areas with moisture stress, high yields can be realized by replacing soil water deficit at 25% (I_1).

4.8 References

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CHAPTER FIVE

5.0 GENERAL CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The overall study objective was to address the understanding on the stability and adaptability of developed or introduced tea genotypes for improved yield and quality productivity in selected environments of Tanzania.

The objective was addressed through the three specific objectives; (i) to assess improved tea genotypes to diverse environments for stability, adaptability of yield and yield components in Tanzania (ii) to evaluate new developed or introduced tea genotypes on quality stability and adaptability, and (iii) to determine the optimum irrigation regime on tea yield, shoot density and water use efficiency in drought prone areas of Tanzania.

With respect to specific objective one, tea genotypes expressed high genetic variability on tested environments both for yield and shoot density. The variability was due to genetic as well as recorded varied growing conditions at specific environment. Therefore, to recommend the promising genotype (s) the option should be to select a group of genotypes instead of single genotype for each location. Two genotypes TRIT 201/43 and TRFK 303/577 demonstrated high tea yielding and stability in high tea yielding environments.

Results on specific objective two, revealed variation in accumulation of tea quality variables among genotypes with environment. Higher tea quality variables of Gallic acid (%GA), Catechin (%C), Caffeine (%Caff), Epicatechin gallate (%ECG) and Total catechin (%TC) were accumulated by genotype TRIT 201/16, while Epigallate catechin (%EGC)

and Epigallate Catechin gallate (%EGCG) by TRIT 201/43, all at Ilenge during wet season. This performance was under the influence of higher precipitation (>2000mm annually) and maximum temperature of 24ºC.

In specific objective three, the study indicated that genotypes varied with drip irrigation levels. Application of water at full-drip irrigation treatment (I_4 = 100%) recorded highest tea yield for genotype TRFK 303/577. This could be attributed to genetic and physiological factors. The genotype is a Chinery tea type, with small size, dark green, semi- to erect posture leaves. The posture of leaves facilitates higher light interception to influence photosynthesis rate and tea yield. Similarly, genotypes TRIT 201/43 and TRFK 303/259 had highest tea yield under no-irrigation (I_0) treatment. Such performance was due to higher genotypic ability to partition large proportion of the dry matter to leaves and less to structural roots.

5.2 Recommendations

The present study demonstrated that the variation in tea growing environments in Tanzania affect yield, yield components such as shoot density and quality. This provides an avenue for locally developed or introduced improved tea genotypes to undergo field evaluation in target areas prior to making recommendation.

i. Thus, genotype TRIT 201/43 can be considered for commercialization in high tea growing areas. The genotype expressed high yield performance, high stability and wide adaptability.

ii. Similarly, genotype TRIT 201/43 may be recommended for higher tea quality production. The genotype met all studied stability parameters and accumulated a

large proportion of main catechins during wet seasons in favourable environments such as Ilenge site.

iii. Genotype TRFK 303/577 can be considered for production in tea growing areas where water for drip irrigation is not a constraint (adequate). Under fully-drip irrigated treatment it gave higher tea yield. On the other hand, under tea growing areas where availability of water for drip irrigation may be a constraint (inadequate), genotypes TRIT 201/43 and TRFK 303/259 can be recommended. The genotypes gave significantly higher tea yield under non-irrigated (I_0) as well as at partial irrigated treatments (I_1=25%).

iv. More studies are needed to inter-cross different identified genotypes to gain useful backgrounds into new improved tea genotypes for recommendation in the near future.

APPENDICES

APPENDICES FOR CHAPTER TWO

Appendix 2.1: Combined analysis (ANOVA) for shoot density and mean yield for 31-tea genotypes across 3 varied locations and 2 seasons.

		Shoot density			Yield		
SOV	**Df**	**SS**	**MS**	**%MS**	**SS**	**MS**	**%MS**
Replication	2	8978.4	4489.2ns	0.3	1047173	523586ns	1.0
Genotype (G)	30	332072.1	11069.1***	0.8	41948471	1064949***	1.9
Location (L)	2	2294014.7	1147007.4***	85.8	133744130	41872055***	76.3
Season (S)	1	99.8	99.8ns	0.0	2371695	2371695**	4.3
(G) x (L)	60	197711.4	3295.2***	0.2	65151754	1085863***	2.0
(G) x (S)	30	52228.5	1740.9***	0.1	5208070	173602ns	0.3
(L) x (S)	2	333490.2	166745.1ns	12.5	14545895	7272947***	13.3
(G) x (S) x (L)	60	73382.3	1207.3***	0.1	16369750	272829ns	0.5
Residual	370	193985.7	524.3ns	0.0	21893438	221334ns	0.4
Total	**557**	**3488792**	**1336178.3**	**100**	**302280376**	**54858860**	**100**

, * Significant at $p \leq 0.01$ and $p \leq 0.001$, respectively; ns = non-significant. SOV = source of variation; Df = degree of freedom; SS = sum of squares; MS = means of squares; %MS = percentage of means of square.

Appendix 2.2: Maximum and minimum (°C) and Rainfall (mm) at Ngwazi Tea Research Station during 2014-15 and 2015-16.

	2014-May 2015			2015-May2016		
Month	**Maximum (°C)**	**Minimum (°C)**	**Rainfall (mm)**	**Maximum (°C)**	**Minimum (°C)**	**Rainfall (mm)**
June	19.0	10.3	1.7	19.9	9.4	0
July	18.7	9.1	0.6	19.7	9.2	0
August	20.2	10.3	1.3	20.5	9.5	0
September	20.8	10.3	0	22.6	10.2	0
October	23.9	11.9	22	24.7	12.3	0
November	24.7	12.7	3.8	24.9	13.0	66.1
December	24.4	12.8	102	24.1	13.3	137
January	23.6	14.3	209	23.6	14.4	237.3
February	24.2	13.4	128.5	24	13.4	192.4
March	24.9	14.1	177.2	24.8	14.1	196.1
April	21.8	14.1	46.7	21.6	14.1	120.2
May	19.4	10.9	8.3	19.6	10.9	96.8
Total			701.1			1045.9
Mean	22.1	12.0		22.5	12.0	

Appendix 2.3: Maximum and minimum (°C) and Rainfall (mm) at Ilenge site in Rungwe district during 2014-15 and 2015-16.

Month	**June 2014-May 2015**			**June 2015-May2016**		
	Maximum (°C)	**Minimum (°C)**	**Rainfall (mm)**	**Maximum (°C)**	**Minimum (°C)**	**Rainfall (mm)**
June	24.5	6.3	251.8	24	6.3	4
July	23	6.5	28.9	24	6.5	14.5
August	23.8	10.3	23.3	25.3	10.3	21.7
September	22.8	10	58.3	24.6	10	9.7
October	25	8.3	168	24.5	8.3	0
November	26.6	10	243.5	25	10	302.4
December	26.7	10.2	160	23.7	10.2	230.8
January	25	13.5	287.6	25.8	13.5	293.05
February	26	12	181.4	25	12	254.3
March	26.5	12	228.2	25.5	12	222.9
April	24.7	12	301.2	24	12	667.4
May	24.3	8.2	92.5	22.5	8.2	162.1
Total			2024.7			2182.9
Mean	24.9	9.9		24.5	9.9	

Appendix 2.4: Maximum and minimum (°C) and Rainfall (mm) at Marikitanda Tea Research Station during 2014-15 and 2015-16.

	June 2014-May 2015			June 2015-May2016		
Month	Maximum (°C)	Minimum (°C)	Rainfall (mm)	Maximum (°C)	Minimum (°C)	Rainfall (mm)
June	22.4	16.1	78.9	18	10.8	76.9
July	21.6	15.2	59.1	17.7	11.6	129.8
August	22.2	14.7	62.7	17.7	10.8	78.6
September	22.4	14.8	100.7	18.6	11	55.5
October	24.3	15.8	150.4	20.4	13.7	153.4
November	25.4	16.2	269.6	21.1	14.4	308.7
December	27.6	18	133.2	22.3	12.9	66.1
January	0	0	91.2	22.4	16.4	64.1
February	0	0	5.5	22.3	14.8	20.6
March	33.1	13.4	208.8	23.2	14.2	3.9
April	30.4	14.8	217.8	21.5	16	706.5
May	27.9	15.5	272.0	21.0	16.2	61.2
Total			1649.9			1725.3
Mean	21.4	12.9		20.5	13.6	

Appendix 2.5: Yield (kg mt ha^{-1}) of 31 different tea genotypes at 3 varied locations during 2014-15 to 2015-16.

		2014-15				2015-16				2014-16
Serial No.	**Genotype**	**Ngwazi E1**	**Marikitanda E2**	**Ilenge E3**	**Mean**	**Ngwazi E4**	**Marikitanda E5**	**Ilenge E6**	**Mean**	**Overall mean**
1.	11/4	3084g-k	2833b-e	1826e-h	2581f-h	2767b-g	2283de	2529g-h	2526e-h	2554g-k
2.	12/19	3053g-k	3411a-d	2266d-h	2910b-h	1956hi	2662a-e	2772e-f	2663b-g	2687d-i
3.	201/16	3848b-d	3484a-c	3079a-c	3470a	2535b-i	2477b-e	2772e-f	2995b-g	3032a-c
4.	201/43	3247e-j	3646a-c	2242d-h	3045a-g	2292d-i	2674a-e	2778e-f	2581b-g	2813c-h
5.	201/44	2451l	3293a-d	2266d-h	2670e-h	2415c-i	2769a-e	2581g-h	2588b-g	2629f-i
6.	201/47	3180f-j	2911b-e	2193d-h	2761d-h	2488c-i	2387c-e	2124i-l	2333c-g	2547f-j
7.	201/50	2865i-l	3585a-c	2095d-h	2848c-h	2116f-i	2899a-e	2095i-l	2370b-g	2609e-i
8.	201/55	3247e-j	3678a-c	2118d-h	3014a-e	2807a-g	3148a-c	2714f-g	2890a-e	2952b-f
9.	201/73	2891i-l	3111a-e	2622b-e	2875b-h	2940a-e	2642a-e	2957b-c	2846a-d	2861b-f
10.	201/75	2755j-l	3582a-c	2297d-h	2878b-g	2090g-i	3018a-d	2882c-d	2663b-g	2771e-i
11.	201/82	3032h-k	3090a-e	1557h	2560fg	2388c-i	2497b-e	1814l	2233f-h	2396i-k
12.	301/4	3495d-h	3180a-d	1727gh	2801d-h	2866a-e	2441c-e	2714f-g	2674c-g	2737f-j
13.	301/5	3643c-f	2598c-e	2494c-g	2912b-g	2865a-e	3050a-d	3056ab	2990a-d	2951b-f
14.	301/6	3536c-g	4202a	2269d-h	3336ab	2691b-h	2867a-e	3611a	3056ab	3196ab
15.	303/1199	4178b	2057e	1788f-h	2674e-h	2759b-g	1325f	2222h-l	2102h	2388k
16.	303/178	3981bc	2662b-e	2497c-g	3047a-g	2847a-f	3255ab	2297h-i	2800b-g	2923f-j
17.	303/216	3313e-j	2948b-e	1970d-h	2744d-h	2797a-g	2309de	2992a-c	2699b-c	2722c-g
18.	303/259	3316e-j	2888b-e	2309d-h	2838c-h	3495a	2465b-e	2795e-f	2918b-f	2878b-c
19.	303/577	4948a	3171a-d	2407c-g	3709a	3212ab	2752a-e	2772e-f	2912a-d	3210a
20.	31/8	2784j-l	3296a-d	2396c-g	2825d-h	2579b-i	2413c-e	2818d-e	2603b-g	2714b-f
21.	371/2	3337e-i	3565a-c	2685a-d	3196a-d	2350c-i	2815a-e	2164i-l	2443b-g	2819c-h
22.	371/3	3967b-d	3226a-d	2020d-h	3071a-f	3003a-d	2367c-e	2859c-d	2743c-g	2907h-k
23.	371/6	2888i-l	2821b-e	2060d-h	2590f-h	2089g-i	2133e	2676e-g	2299e-h	2445h-k
24.	371/8	3675c-e	3742c-e	2552c-f	3323a-c	2454c-i	2769a-e	2505h-i	2576b-f	2950a-c
25.	381/5	4207b	2549c-e	3287ab	3348ab	2577b-i	2679a-e	2720f-g	2659a-c	3003a-c
26.	400/10	2784j-i	2296de	2174d-h	3043a-g	2078g-i	2141e	2719f-g	2313gh	2365jk
27.	400/4	3519c-h	3562a-c	2049d-h	3395a	2859a-e	2688a-e	2691e-g	2746b-g	2895c-g
28.	430/63	4210b	2613b-e	3362a	2909b-g	3068a-c	3322a	3050ab	3147a	3271a
29.	430/7	3119g-k	3605a-c	2002d-h	2592f-h	2216e-i	2700a-e	2558g-h	2491d-g	2700f-j
30.	6/8	2633kl	2960b-e	2183d-h	2592f-h	1940i	2274de	2535g-h	2250f-h	2421h-k
31.	SFS150 (CK)	3877b-d	3157a-e	2231d-h	3088a-e	3053a-c	2480b-e	2112i-l	2548b-g	2818b-f
Environ. Index (Ij)		602	365	-496		-188.0	-184.0	-145.9		
Mean Site: ($\bar{x}$)		3397	3152	2291	2944	2600	2603	2641	2615	2787
LSD($P \leq 0.05$)		***	***	***		***	***	0.130		
CV (%)		7.5	17.8	17.5		14.3	15.5	14.5		

*Means bearing the same letter (s) in a column are not statistically different at $P \leq 0.05$ by Duncan Multiple Range test. Environments: E1: Ngwazi 2014-15; E2: Marikitanda 2014-15; E3: Ilenge 2014-15; E4: Ngwazi 2015-16; E5: Marikitanda 2015-16 and E6: Ilenge 2015-16; LSD=Least Significant Difference; CV (%)=Coefficient of variation.

Appendix 2.6: Shoot density (shoots m^{-2}) of 31 different tea genotypes at 3-varied locations during 2014-15 to 2015-16.

Serial No	Genotype	2014-15				2015-16				Overall genotypic mean
		NTRS E1	MTRS E2	Ilenge E3	Mean	NTRS E4	MTRS E5	Ilenge E6	Mean	
1.	11/4	180 e-i	219 d-f	296 c-f	231g-l	101f	291e-h	344ab	245e-i	238h-k
2.	12/19	198 b-f	220 d-f	313 b-e	244e-i	124b-f	286e-h	315a-d	241f-j	243g-k
3.	201/16	199 b-f	296 ab	395 a	297b	109 ef	322c-e	315a-d	249d-h	273bc
4.	201/43	163 h-m	253 b-d	330 b-e	249e-h	120 c-f	303d-g	295a-e	239f-j	244f-k
5.	201/44	182 e-i	271 bc	353 ab	269c-e	131b-e	324c-e	346a	267b-e	268cd
6.	201/47	186 d-h	261 b-d	320 b-e	256e-h	139 b-d	300d-g	318a-d	252c-g	254d-h
7.	201/50	172 g-k	244 c-e	317 b-e	244e-j	114d-f	312c-f	316a-d	247d-h	246f-k
8.	201/55	218 b	321 a	302 b-f	280b-d	144a-c	404a	320a-d	289a	285b
9.	201/73	187 d-h	236 c-e	311 b-e	245e-h	121b-f	303d-g	293a-e	239f-j	242g-k
10.	201/75	169 g-l	300 ab	313 b-e	261c-f	122b-f	392a	311a-e	275a-c	268cd
11.	201/82	200 b-e	200 b-e	304 b-f	257d-g	146a-c	347bc	319a-d	271a-d	253c-e
12.	301/4	169 g-l	235 c-e	331 b-d	245e-h	150ab	320c-e	277c-f	249d-h	247e-j
13.	301/5	163 h-m	152 hi	276 d-f	197mn	141b-d	275f-i	270d-f	229g-m	213m-o
14.	301/6	149 k-m	296 ab	292 d-f	246e-h	124b-f	397a	312a-e	278ab	262c-f
15.	303/1199	211 bc	238 c-e	302 b-f	250e-h	135b-e	311c-f	289b-f	245e-i	248e-j
16.	303/178	166 g-m	166 g-m	327 b-e	218i-m	131b-e	321c-e	304a-e	252d-g	236i-l
17.	303/216	209 b-d	254 b-d	292 d-f	252e-h	141b-d	296d-g	291a-e	243e-j	247e-j
20.	31/8	166 g-m	218 d-f	304 b-f	229h-l	121b-f	233j	286c-f	213k-n	221l-n
21.	371/2	173 g-k	210 e-g	321 b-e	232g-l	120c-f	257h-j	304a-e	227h-m	231k-m
22.	371/3	176 f-j	235 c-e	284 d-f	231g-l	124b-f	279f-i	274c-f	226h-n	229k-m
23.	371/6	144 m	197 e-h	288 d-f	209k-n	108ef	244ij	274c-f	209l-n	209no
24.	371/8	162 h-m	195 e-h	273 ef	210k-n	126b-f	247ij	258ef	210k-n	210no
25.	381/5	161 i-m	138 i	273 ef	191n	108ef	268g-j	290a-f	222i-n	206no
26.	400/10	153 j-m	184 f-i	285 d-f	207i-n	122b-f	246ij	289b-f	219j-n	213m-o
27.	400/4	145 lm	194 e-h	253 f	197mn	108ef	241ij	270c-f	206mn	202o
28.	430/63	189 c-g	149 hi	350 a-c	229h-l	122b-f	331cd	304a-e	256b-f	241g-k
29.	430/7	191 c-g	341 a	320 b-e	284bc	125b-f	300d-g	274c-f	233f-k	259c-g
30.	6/8	171 g-k	229 c-f	307 b-f	236f-k	121b-f	267g-j	303a-e	230g-l	233j-l
31.	SFS150 (Ck)	184 e-i	255 b-d	321 b-e	253e-h	148a-c	292d-h	308a-e	249d-h	251d-i
Mean site		179	234	310	241	127	301	298	242	242
LSD(P≤0.05)		***	***	***		***	***	***		
CV (%)		7.0	10.9	9.1		11.6	6.7	7.7		

*Means bearing the same letter (s) in a column are not statistically different at P≤0.05 by Duncan Multiple Range test. Environments: E1: Ngwazi 2014-15; E2: Marikitanda 2014-15; E3: Ilenge 2014-15; E4: Ngwazi 2015-16; E5: Marikitanda 2015-16 and E6: Ilenge 2015-16; LSD = Least Significant Difference; CV (%) = Coefficient of variation.

Appendix 2.7: Genotypes adopted to high yield performing environments, stable (S^2d_i = 0) with average response (βi ≈1.0), x>$\bar{x}$ and high coefficient of determination (R^2_i).

Identity No	Genotype	Low performing env.	Stable (low s^2d_i)	Average response (βi≈1.0)	x>$\bar{x}$	high R^2_i
2	TRFK 12/19	+	+	+	+	+
5	TRIT 201/44	+	+	x	+	x
6	TRIT201/47	+	+	+	+	+
9	TRIT201/73	+	+	x	X	+
10	TRIT201/75	+	+	x	X	+
15	TRFK303/1199	+	X	x	+	x
16	TRFK303/178	+	+	x	X	+
18	TRFK303/259	+	+	x	X	+
20	TRFK 31/8	+	+	+	+	+
25	TRFK381/5	+	X	x	X	x
26	TRFK400/10	+	+	x	+	+
30	TRFK6/8	+	+	+	+	+

+ and x = reflection of higher and poor performance on specific stability parameter respectively.

Appendix 2.8: Genotypes adopted to low yield performing environments, stable (S^2d_i = 0) with average response (βi ≈1.0), x>$\bar{x}$ and high coefficient of determination (R^2_i).

Identity No	Genotype	Low performing env.	Stable (low s^2d_i)	Average response (βi≈1.0)	x>$\bar{x}$	high R^2_i
2	TRFK 12/19	+	+	+	+	+
5	TRIT 201/44	+	+	x	+	x
6	TRIT201/47	+	+	+	+	+
9	TRIT201/73	+	+	x	X	+
10	TRIT201/75	+	+	x	X	+
15	TRFK303/1199	+	x	x	+	x
16	TRFK303/178	+	+	x	X	+
18	TRFK303/259	+	+	x	X	+
20	TRFK 31/8	+	+	+	+	+
25	TRFK381/5	+	x	x	X	x
26	TRFK400/10	+	+	x	+	+
30	TRFK6/8	+	+	+	+	+

+ and x = reflection of higher and poor performance on specific stability parameter respectively.

Appendix 2.9: Genotypes adopted to high shoot density performing environments, stable ($S^2d_i = 0$) with average response ($\beta_i \approx 1.0$), $x>\bar{x}$ and high coefficient of determination (R^2_i).

Identity No	Genotype	High performing env.	Stable (low s^2d_i)	Average response ($\beta i \approx 1.0$)	$x>\bar{x}$	high R^2_i
1	TRFK 11/4	+	+	+	X	+
3	TRIT201/16	+	+	+	+	+
4	TRIT201/43	+	+	+	+	+
5	TRIT 201/44	+	+	+	+	+
7	TRFK 201/50	+	+	+	X	+
8	TRIT201/55	+	X	+	+	+
9	TRIT201/73	+	+	+	+	+
10	TRIT201/75	+	X	+	+	+
14	TRFK301/6	+	X	+	+	+
15	TRFK 303/1199	+	X	+	+	+
16	TRFK303/178	+	+	+	X	+
19	TRFK 303/577	+	+	+	+	+
21	TRFK 371/2	+	+	+	X	+
22	TRFK371/3	+	X	+	X	+
24	TRFK371/8	+	X	+	X	+
27	TRFK400/4	+	X	+	X	+
28	TRFK430/63	+	X	+	X	+

+ and x = reflection of higher and poor performance on specific stability parameter respectively.

Appendix 2.10: Genotypes adopted to low shoot density performing environments, stable ($S^2d_i = 0$) with average response ($\beta i \approx 1.0$), $x>\bar{x}$ and high coefficient of determination (R^2_i).

Identity No	Genotype	Low performing env.	Stable (S^2d_i)	Average response ($\beta i \approx 1.0$)	$x>\bar{x}$	high R^2_i
13	TRFK301/5	+	+	x	x	+
15	TRFK303/1199	+	+	+	+	+
16	TRFK303/178	+	+	x	x	+
17	TRFK303/216	+	+	+	+	+
18	TRFK303/259	+	+	x	x	+
20	TRFK 31/8	+	+	x	x	+
22	TRFK371/3	+	+	x	x	+
24	TRFK371/8	+	+	x	x	+
25	TRFK381/5	+	+	+	x	+
26	TRFK400/10	+	+	x	x	+
27	TRFK400/4	+	+	x	x	+
29	TRFK430/7	+	x	+	+	+
31	SFS150	+	+	x	x	+

+ and x = reflection of higher and poor performance on specific stability parameter respectively.

APPENDICES FOR CHAPTER THREE

Appendix 3.1: Location, Altitude, Temperature and Precipitation characteristics at 3 tea growing environments in Tanzania.

Month	Ngwazi (8°32´S, 35°10´E; 1840m a.s.l)				Marikitanda (5°08´S, 38°35E; 970 m a.s.l)				Ilenge (09° 12´S, 33° 34´E; 1,426m a.s.l)			
	Temp. (° C)			Rainfall (mm)	Temp. (°C)			Rainfall (mm)	Temp. (°C)			Rainfall (mm)
	Max.	Min.	Mean	65.10	Max.	Min.	Mean		Max.	Min.	Mean	
WET SEASON-2015/16												
November15	24.1	12.6	18.4	137.5	30.9	14.4	21.1	308.7	25.0	10.5	17.8	225.6
December15	24.2	13.3	18.7	237.3	32.2	12.8	22.3	229.9	23.7	9.33	16.5	215.0
January16	23.6	14.4	19.0	192.4	32.1	16.4	22.4	64.1	25.8	10.5	18.2	371.9
February	24.0	13.4	18.7	196.1	32.2	14.8	22.3	20.6	25.0	12.0	18.5	290.3
March	24.9	14.1	19.7	112.0	34.1	14.2	23.2	3.9	25.5	12.5	19.0	244.0
April	21.6	14.1	17.9	20.0	29.8	16.0	21.5	706.5	24.0	12.5	18.3	739.8
Total				**895.3**				**1333.7**				**2086.7**
Mean	**23.7**	**13.7**	**18.7**		**31.9**	**14.8**	**22.1**		**24.8**	**11.2**	**18.1**	
DRY SEASON-2015/16												
May	19.6	10.9	15.3	0	-	-	-	61.2	22.5	6.5	14.5	168.2
June	19.9	9.4	14.7	0	25.8	10.8	18.0	45.9	24.0	6.3	15.2	4.0
July	19.7	9.2	14.5	0	24.8	11.6	17.7	1.4	24.0	6.5	15.3	14.5
August	20.5	9.5	15.0	0	25.8	10.8	18.6	66.5	25.3	10.3	17.8	21.7
September16	22.6	10.2	16.4	0	28.2	11.0	20.4	0	24.6	10.0	17.8	9.7
October16	24.7	12.3	18.5	0	28.9	13.7	21.1	0	24.5	8.3	17.3	0
Total				**0**				**175**				**218.1**
Mean	**25.1**	**12.5**	**18.9**		**27.6**	**12.1**	**19.7**		**28.3**	**9.9**	**19.3**	

Appendix 3.2: Correlations of % Gallic Acid (GA), % Caffeine (CAFF) and Catechin components averaged over 3-locations.

Quality variable	%GA	%EGC	%Catechin	%Caffeine	%EGCG	%ECG	%TC
%GA	-						
%EGC	0.279	-					
%Catechin	0.138	**0.915*** **	-				
%Caffeine	-0.271	**0.653*** **	**0.473***	-			
%EGCG	-0.213	0.183	0.130	**0.667*** **	-		
%ECG	**0.734*** **	**0.681*** **	**0.633*** **	0.229	0.317	-	
%T Catechins	-0.119	**0.515****	0.257	**0.947*** **	**0.745*** **	0.269	-

** and ***=significantly different at p≤0.05and at p≤ 0.001, respectively. Degrees of freedom: n-2 = 90.

Appendix 3.3: Associations among tested tea quality variables at each location.

	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
%GA							
%EGC							
%C		+					
%CAFF							
%EGCG				+			
%ECG		+					
%TC				+	+		

+= consistently significantly and positively correlated.

Appendix 3.4: Summary of desirable mean and all stability parameters for the genotypes.

Genotype	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
TRIT 201/16	×	×	×	×	×	×	×
TRIT 201/43	×	×	×	×	×	×	×
TRFK 303/577	+	×	×	×	×	+	×
TRFK 6/8	×	×	×	×	×	×	×
SFS150	×	×	×	×	×	×	×

Key: + = Desirable mean and stability; × = Undesirable mean and stability.

Appendix 3.5: Summarized performance and stabilities for tea quality variables.

Genotype	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
TRIT 201/16							
Mean ($\bar{x}$)	> $\bar{x}$	< $\bar{x}$	> $\bar{x}$	> $\bar{x}$	> $\bar{x}$	> $\bar{x}$	> $\bar{x}$
β_i:+ve; -ve	+ve	+ve	+ve	-ve	+ve	+ve	+ve
$\beta_i = 0$	×	×	×	∨	∨	×	∨
$\beta_i = 1$	×	×	×	∨	×	×	×
$S^2d_i = 0$	∨	∨	∨	∨	×	∨	×
R^2_i	High	High	High	High	Low	High	Low
TRIT 201/43							
Mean ($\bar{x}$)	$\bar{x}$	> $\bar{x}$	> $\bar{x}$	> $\bar{x}$	> $\bar{x}$	$\bar{x}$	> $\bar{x}$
β_i:+ve; -ve	+ve	+ve	-ve	+ve	+ve	-ve	+ve
$\beta_i = 0$	×	×	∨	×	∨	∨	∨
$\beta_i = 1$	×	×	×	×	∨	×	∨
$S^2d_i = 0$	∨	∨	∨	∨	×	∨	∨
R^2_i	High	High	High	High	Low	High	High
TRFK 303/577							
Mean ($\bar{x}$)	$\bar{x}$	> $\bar{x}$	$\bar{x}$	> $\bar{x}$	$\bar{x}$	$\bar{x}$	> $\bar{x}$
β_i:+ve; -ve	+ve	+ve	+ve	-ve	+ve	+ve	+ve
$\beta_i = 0$	×	×	∨	∨	∨	×	∨
$\beta_i = 1$	∨	×	×	×	∨	∨	∨
$S^2d_i = 0$	∨	∨	∨	∨	∨	∨	∨
R^2_i	High	High	High	High	High	High	Low
TRFK 6/8 (CK-1)							
Mean ($\bar{x}$)	$\bar{x}$	< $\bar{x}$	< $\bar{x}$	< $\bar{x}$	< $\bar{x}$	$\bar{x}$	< $\bar{x}$
β_i:+ve; -ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
$\beta_i = 0$	∨	∨	∨	∨	×	∨	×
$\beta_i = 1$	∨	×	×	×	×	×	×
$S^2d_i = 0$	∨	∨	∨	∨	∨	∨	∨
R^2_i	High	High	High	High	Low	High	Low
SFS150 (CK-2)							
Mean ($\bar{x}$)	< $\bar{x}$	< $\bar{x}$	< $\bar{x}$	< $\bar{x}$	> $\bar{x}$	$\bar{x}$	> $\bar{x}$
β_i:+ve; -ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
$\beta_i = 0$	×	×	×	×	×	×	∨
$\beta_i = 1$	∨	∨	∨	∨	∨	∨	∨
$S^2d_i = 0$	∨	∨	∨	∨	∨	∨	∨
R^2_i	High	High	High	High	High	High	Low

Key: High = $R^2_i \geq 70\%$, Low = $R^2_i \leq 70\%$; Concentration below mean Ck-1 and Ck-2 = Checks for excellent and poor quality respectively.

APPENDICES FOR CHAPTER FOUR

Appendix 4.1: Analysis of variances (ANOVA) for yield (kg mt ha^{-1}) and shoot density (shoots m^{-2}) during 2014/15 and 2015/16 dry seasons.

		2014/15		2015/16	
		Mean of Sum of Squares (MSS)			
Source of variation	**Df**	**Yield**	**Shoot density**	**Yield**	**Shoot density**
Replication (R)	2	2614.7	6801.3	1.195E+03	35.7
Genotype (G)	30	565216.6***	8755.2***	1.597E+06***	6325.03***
Irrigation (I)	4	246882.0***	14620.5***	1.558E+07***	19348.81***
G* I	120	100360.5***	2356.5***	20216E+05***	663.35***
Residual	308	942.3	745.8	5.600E+02	2.45
Total	464				

***=Indicates significant at 0.001 level of probability.

Appendix 4.2: Combined analysis (ANOVA) for yield and shoot density variables: 2014/15-2015/16.

		Mean of Sum of Squares (MSS)	
Source of variation	**Df**	**Yield**	**Shoot density**
Replication (R)	2	3.661E+03	2934.6
Genotype (G)	30	1.604E+06***	10646.8***
Irrigation (I)	4	9.252E+06***	28254.8***
Season (S)	1	3.234E+08***	372201.5***
G* I	120	1.707E+05***	1963.9***
G*S	30	5.580E+05***	4433.4***
I*S	4	6.570E+06***	5714.5***
G*I*S	120	1.512E+05***	1055.9***
Residual	310	7.478E+02	398.1
Total	501		

***=Indicates significant at the 0.001 level of probability.