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EFFECT OF STABILITY AND ADAPTABILITY ON TEA QUALITY IN DIVERSE GROWING ENVIRONMENTS OF TANZANIA

Solomon W. Msomba[1]*, Samson M. Kamunya[2], Cornel.L. Rweyemamu[3] and Shazia O.W.M. Reuben[3]

[1]Tea Research Institute of Tanzania (TRIT), P.O. Box 2177, Dar-Es-Salaam, Tanzania.

[2]Kenya Agricultural and Livestock Research Organization-Tea Research Institute-P. O Box 820 â€ "20200, Kericho, Kenya.

[3]Sokoine University of Agriculture, Department of Crop Science and Horticulture, P. O. Box 3005 Morogoro, Tanzania.

ABSTRACT

Catechins in tea crop are correlated with quality and valued for healthy benefits. The components vary with conditions such as cultivar, season, elevation and soils. A study underscored the effect of genotype × environment interaction on tea quality. Complete Randomized Block Design in 3-replicates was adopted during wet and dry seasons in 2016at 3-locations. Genotypes were analyzed for quality using ISO 14502-2:2005 procedure. ANOVA showed significant ($p = 0.05$) variation among catechins. Genotypes responded differently for locations and seasons on quality variables. EGCG was the most abundant catechin. TRIT 201/16, TRIT 201/43 and TRFK 303/577 had significantly similar and higher % TC but non-significantly different % EGCG. TRIT 201/43 excelled on %EGC, %CAFF, %ECG and %TC, while TRIT 201/16 for %GA. Main location effects influenced higher %EGC, %ECG, %EGCG and %TC at Ilenge. Significantly higher %EGC, %ECG, %EGCG and %TC were evident during wet season. Genotype × location exhibited highest %EGCG and %TC for TRIT 201/43 at Ilenge, while TRIT 201/16 for %CAFF and %ECG at Marikitanda. Genotype × season had highest effect on %EGCG and %TC for TRIT 201/16 during wet season. TRFK 6/8-dry season excelled on %EGC; SFS150-dry season on %C; TRIT 201/16-dry season on %ECG and TRIT 201/43-wet season on %CAFF. Location × season had highest %EGCG and % TC at Ilenge during wet season. %GA was highest at Ngwazi-during both seasons, and only during wet season at Marikitanda. TRIT 201/16 had all desirable stability parameters for %GA at Ngwazi, while SFS150 for %EGC at Ilenge. TRIT 201/16 and TRIT 201/43 had higher %CAFF and %ECG at Marikitanda. TRIT 201/43 excelled on %EGCG and %TC at Ilenge. Significant positive correlations were for %EGC with %ECG and %catechin; %caffeine with %EGCG and %TC; %EGCG with %TC. TRFK 6/8 and TRFK 303/577 met stability requirements for %GA; TRIT 201/16 for %Caffeine, while TRFK 303/577 and SFS150 for %EGC and %ECG and TRIT 201/43 for %TC.

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

INTRODUCTION

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), proposed optimal tea growing conditions as warm

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humid tropical climate with fairly well distributed rainfall at least 1000 mm annually; a wide range of soils, with loamy soils or red clays of volcanic origin more preferred. Harvestable green leaf (GL) for processing tea beverage is obtained from tender shoots (2leaves + a bud). The quality of made varies with growth and maturity of tea shoots (Wijeratne, 2003; Owour et al., 2011).

In Tanzania, tea is grown from low altitude i.e. 790 m asl at Usambara mountainsto over 22 000 m asl, at the Dansland, in Njombe district, Southern Highlands of Tanzania. The weather at Usambara Mountains is bimodal rainfall with hot-(December-March) and cool dry (May or October) seasons (Carr, 2010). Short (Vuli) and long (Masika) rains occur in November and from April to May respectively averaging 1500mm. Such environment influences fast tea growth giving high yields, but low quality of black tea (Owour et al., 2011).

In the Southern Tanzania, the weather 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). At higher altitude tea crop grows slowly giving low yields due to restricted shoots growth (Carr, 2012) but of better quality of black tea (Owour et al., 2011). This confirms the findings that tea grown at higher altitudes is of superior quality unlike that at low altitude (Makola, 2013). Therefore, interaction of tea grown genotypes with 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 derived from phenylpropanoid and flavonoid biosynthetic pathways. Studies reports that different tea cultivars differ in types and quantity of catechins (Cherotich et al., 2013). Also, catechins concentration declines with aging leaves from young tender leaves (Thea et al., 2012). The most abundant active catechins components are Epigallocatechin gallate (EGCG), epigallocatechin (EGC) and catechins (C) constitute over 70% of the total catechin content and are related to tea quality. 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).Cherotich et al. (2013), noted non-significant catechins content variation with seasons, but reported lower and high caffeine content variations during wet-and dry seasonsrespectively. Higher levels of EGCG and ECG, are noted during warmer months while 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, potentially high producing tea areas may be becoming less productive (FAOSTAT, 2014). Also, stressed tea plants will likely to produce more secondary metabolites leading to improved tea flavour (Andrei, 2014; Ahmend, 2015).

At the international markets, the Tanzanian tea is judged as plain or of low quality (Anonymous, 2012), thus fetches low prices. Reliance on seedling propagated teas (>85%) and adoption of improvedclonal cultivars without verification for site suitability at target environments partly

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contributes to poor tea performance (Wachira et al., 2002; Owour et al., 2011). This is because 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/acquired tea genotypes on quality stability and adaptability.

MATERIALS AND METHODS

Chemicals and reagents

Chemicals used in this study were purchased from various sources through the Tea Research Institute of Tanzania (TRIT). The standards viz. gallic acid (GA, 98%) was 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 (C2H3N; MUMBAI 400-002, India), Methanol (CH3OH), Gallic acid (C6H2(OH)3COOH; sd Fine Chem Ltd, Maharashtra, India), EDTA (C10H16N2O8; Avon Chem LTD), Ascorbic Acid (C6H8O6; Carlo ERBA, SA), Acetic Acid (CH3COOH; Jenway Chemicals, England), Water (H2O; Rankem, RFCL LTD, India) all were of HPLC grade unless otherwise stated.

Leaf sample collection and preparation

Leaf shoots were collected at the peak of wet and dry seasons. Approximately 500g of fresh tea shoots (2 leaves + a bud) sample was harvested and immediately dried to deactivate the oxidizing enzyme polyphenol oxidase (PPO) using microwave (RISING, China) at 90°C for 3 min. The leaf samples were dried overnight in Oven (European Union, Poleko - Aparatura SP. J) at 85°C. Dried leaf samples were grounded using grinding machine (MIIS, Germany, IKA WERKER & Comp.). Obtained leaf powder samples were kept in aluminium laminated paper bags at room temperature in dark room prior to analysis.

Samples Extraction

Leaf powder samples were extracted using the International Organization for standardization (ISO) 14502-2 (2005) procedure. 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. Approximate 200g extract 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.

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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 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 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) = Cstd/Astd……. (1)

Where, RF = Standard Response Factor

Cstd = The concentration of standard

Astd= Peak area of the standard

The concentration of individual components was estimated using the formula; Individual components (%)

= Astd × RF × V × d…… (2)

M × 1000

Where,

Astd = 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

Statistical analysis

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

Description of Tea Genotypes

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Table 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= Checks for good and poor tea Quality, respectively.

3.7: Soil Physico-and Chemical Characteristics

Table2: 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^+ (ppm)	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).

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RESULTS

Mean squares for Gallic Acid, Caffeine and Catechins contents

Based on combined analysis of variance (ANOVA), there were variations in catechin contents among the five tested genotypes. The variation was mainly due to genotypes (G), locations (L), seasons (S) and the interactions between genotype (G) with locations (L), genotypes (G) with seasons (S), locations (L)

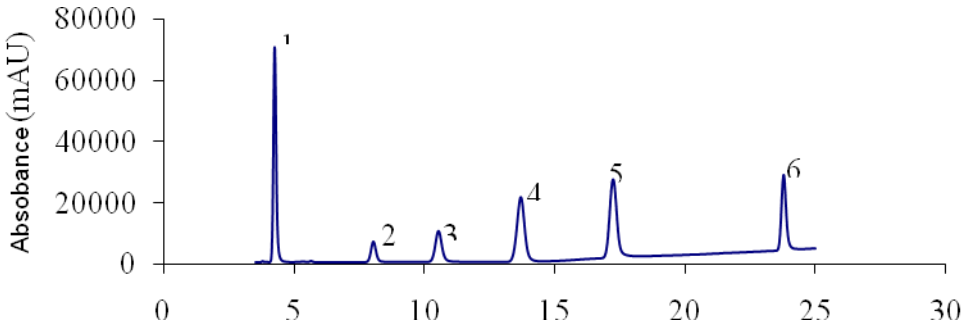
The genotype effect was highly significant to all Catechin components except for %C and %EGCG. Location (L) effect was highly significant on all Catechin components except individual %Catechins (C). The season (S) effects displayed highly significant variations on %EGC, %Caffeine and %E with seasons (S) and genotypes (G), locations (L) with seasons (S).

The genotype (G) ×location (L) interaction effect was highly significant on all variables except % Catechin and %EGCG. Among the assessed variables, significant effect due to genotype (G)× season (S) interaction was evident for %GA and %ECG components. The location (L) × season (S) interaction effect apparently was significant for %GA, %EGCG, %ECG and %TC. The effect due to second order interaction i.e. genotype (G) × location (L) × season (S) interaction revealed highly significantly ($p \leq 0.01$) effect for %EGCG and %EGC.

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

The chromatogram (Figure 1A and 1B) 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 (Figure 1A). Quantification of tea quality components were performed by comparing obtained peak area (PA) (Figure 1B) of HPLC chromatograms with the standards (Figures 1A) below. The most abundant catechin (with highest peak) was Epigallocatechin gallate (%EGCG), followed by phenolic %Caffeine, whereas the lowest was %Epigallate Catechin (EGC).

Effect of variation in Catechins among 5-tested tea genotypes



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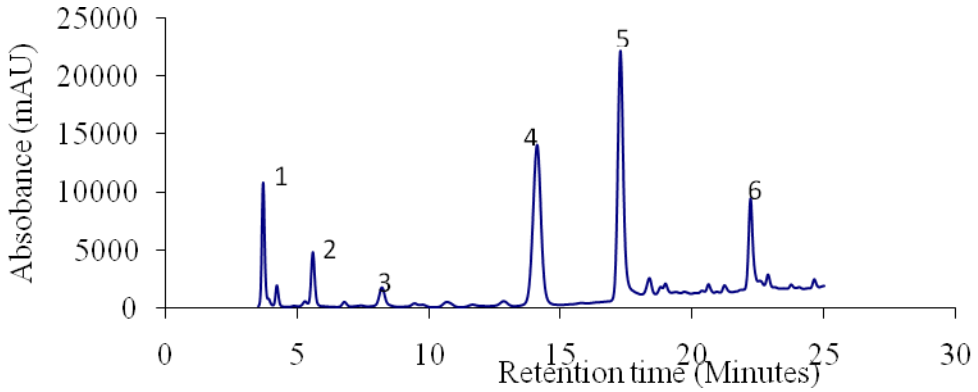

Figure1:a & b: Chromatogram of Caffeine presenting profile of elution time (Min.) and elution of Gallic acid and individual Catechins (C) i.e. 1= Gallic Acid (GA), 2 = Catechin (C), 3 = Epigallate catechin (EGC), 4 = Caffeine (CAFF), 5 = Epigallatecatechin gallate (EGCG) and 6 = Epicatechin gallate (ECG). 1A = represents chromatograms for standards; 1B = represents chromatograms for tested tea samples.

The main genotype effects for the studied tea quality variables

The significant variation among genotypes were recorded for %GA, %EGC, %CAFF, %ECG and %Total Catechin (TC) (Table 3). Highest %GA (0.06%) was for TRIT 201/16 while the least was for standard SFS150 (0.04%). Highest %EGC was recorded for TRIT 201/43 and the lowest %EGC was for two standards TRFK 6/8 and SFS150. The %Caffeine was in the range of 2.18% - 2.85% for TRFK 6/8 and TRIT 201/43 respectively. The %ECG varied from 0.28% to 0.31% for SFS150 and TRIT201/43. Genotypes TRIT 201/16, TRIT 201/43, TRFK 303/577 and standard SFS150 (31) had significantly higher %TC (10.27% - 10.63%).

Table 3: Main effects of genotypes for %GA, %CAFF and %Catechin variables

Genotype	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
TRIT201/16	**0.06a**	0.00011bc	1.34a	**2.85a**	**8.77a**	**0.31a**	**10.59a**
TRIT 201/43	0.05b	**0.00015a**	1.31a	**2.73a**	8.98a	0.28c	**10.46a**
TRFK 303/577	0.05b	0.00013ab	1.23a	2.71ab	7.74a	0.29b	**10.39a**
TRFK 6/8	0.05b	0.00009c	1.19a	2.18c	7.59a	0.29b	9.08b
SFS150	0.04c	0.00010c	1.22a	2.25ab	8.89a	0.29b	**10.40a**
Mean ($\bar{x}$)	**0.05**	**0.00012**	**1.26**	**2.54**	**8.39**	**0.29**	**10.18**
S.e.d (±)	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

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

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Main effects of locations

Evaluated tea quality variables varied among locations (Table 4). 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 %EGCG, %ECG and %Total Catechin were recorded at Ilenge site.

Table 4: 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	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

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

Higher %EGC, %Caff, %EGCG and %TC were noted during wet season (Table 5). The dry season accumulated higher %Catechin and %ECG. However, %GA did not alter with variation in seasons. Due to season main effect the %EGCG contributed 83.6% to the %TC during the wet season.

Table 5: 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	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

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

The genotype (G) × location (L) interaction for studied tea quality variables indicated highest %GA content of 0.07% was accumulated by improved genotypes TRIT 201/16 and TRFK 303/577 both at Ngwazi location (Table 6). The significant lower %GA was 0.03% for TRFK 303/577 at Ilenge site. The highest %catechin (%C) was 1.53% for SFS150-Ngwazi, while for %ECG it was 0.33% with TRIT 201/16-Marikitanda. However, with %C all combinations were

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statistically similar except for TRIT 201/16-Ngwazi (0.93) and TRFK 6/8 -Ngwazi (0.90) with significantly lowest values. 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 %TC (13.65%) at Ilenge site. The %EGCG (4.89%) and %TC (6.06%) accumulated significantly 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 %TC for TRIT 201/43 at Ilenge site.

Table 6: Combination of genotype (G) × location (L) for %GA, %Caffeine and Catechins concentration of tea qualities

Genotype × Location	%GA	%EGC	%C	%CAFF	%EGCG	%ECG	%TC
TRIT 201/16-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
TRIT 201/43-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
TRIT 201/43-Ilenge	0.05	2E-04	1.32	2.92	**12.05**	0.29	**13.65**
TRFK 303/577-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
TRFK 303/577-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
TRFK 6/8-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	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

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

The mean %GA content ranged from 0.04% for SFS150 dry season to 0.07% for TRIT 201/16 (3) during wet season (Table 7). Significantly highest %EGC 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

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201/43 (4) had significantly highest %Caffeine (2.98%) during wet season. 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 7: 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	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

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

Combinations of Ngwazi -wet, Ngwazi-dry and Marikitanda-wet had statistically similar and highest %GA each of 0.6% (Table 8). 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)atIlenge during dry season was 82.4%.

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Table 8: 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	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

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

The correlation analysis among %Gallic Acid, %Caffeineand %Catechins components at Ngwazi location are presented in Table 9. 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 9: 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

Correlations among Gallic Acid, Caffeine and Catechin Components at Marikitanda location

The %Gallic acid (%GA) content correlated significantly positive with %EGCG and %TC, but significantly negative with %Caffeine (Table 10). 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

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%Caffeine. The %ECG with %EGC and %Catechin had significant and positive associations. The %TC also correlated positively with %GA, %Caffeine and %EGCG components.

Table 10: 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.

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

Table 11, 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 associated significantly positively 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 11: 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.

Associations across all locations

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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.

Stability and adaptation of 5-genotypesforCatechin concertation across environments

Results, revealed stability variation among tea genotypes on catechin contents across 3-locations (Table 12). Genotype TRIT 201/16 (0.06%) excelled the overall mean in %GAvariable, 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 (S2di ≈ 0) and with high predictability in response (R2i = 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 01/16 responded on average. All five genotypes were stable with low S2di and high coefficient of determination.

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 with environments. All the genotypes were stable with high coefficient of determination.

Genotypes TRIT 201/16 (2.85%), TRFK 303/577 (2.71%) and TRIT 201/43 (2.73%) excelled the overall mean for %CAFF while all five genotypes 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 (R2i≥70%).

All genotypes 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 (S2di ≈ 0) while only SFS150 and TRFK 303/577 had high coefficients of determination.

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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 12: 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}$0.05	**0.00012**	**1.26**	**2.54**	**8.39**	**0.29**	**10.18**		
			($\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
				$(1 - \beta_i)$				
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.

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DISCUSSIONS

Mean squares (MS) for Catechins components

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

The variations due to location and season effects could be explained to differences in recorded physical and chemical soil conditions (Table 3.2) and climatic weather (Table 3) over seasons among the 3-locations. Thus, necessitate for evaluation over several seasons in order to developimproved tea 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 under different growing seasons (Cherotich, et al., 2013; Liu et al., 2015). The location (L) × season (S) interaction effect implied that, ranking of different tested locations on Catechin contents synthesis among genotypes may vary from season to season. Significant effect of G × L × S indicated the inconsistency of tea genotypes with respect to Catechin contents synthesis. Therefore, there is a need for detailed analysis of genotypic stability on Catechin synthesis/performance in order to select genotypes of acceptable tea qualities for specific environments.

The main effects of genotypes for the 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), had similar results and concluded that, each genotype is distinctive in synthesizing tea biochemical levels. Among the genotypes, TRIT 201/16, TRIT 201/43 and TRFK 303/577 accumulated higher levels of catechin components. Such catechin accumulation could be attributed to active expression of genes anthocyadin reductase (ANR), ANS and LAR and two enzymes F3'H and F3'5'H which determine both Epigallate and non-Epigallate catechin compositions (Wang et al., 2016). Cherotich et al. (2013) also contend that differences in the levels of catechin composition among tea clones is an attribute to the up - or down regulations of the enzyme flavanone 3-hydroxylase (F3H). The gene expression is described to be under the

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influence of environmental conditions (Liu et at., 2015). Therefore, due to higher capacity to accumulate higher tea catechins genotypes TRIT 201/16, TRIT 201/43 and TRFK 303/577 may be recommended for tea rich in Catechins contents especially %EGCG and %TC.

Main effects of locations

Among the three locations, Ilenge recorded relatively higher levels of catechins including %EGC, EGCG, %ECG and %TC. The site is a medium altitude (1464m asl) with warm wet weather (associated with higher precipitation and min and max. temperatures) almost throughout the year. Such conditions favoured higher accumulation of %EGC, %EGCG, %ECG and %TC catechin components (Caffin et al., 2004, Ahmed et al., 2014, Liu et al., 2015). Warm wet weather also favours the expression of genes PAL and DFR which influence higher accumulation of %EGCG and contributed higher (83.6%) to %TC (Kaur et al., 2014). Therefore, Ilenge site could be a potential site for production of Catechin rich content of Tanzanian tea. This also implies that, application of tea inputs including tea cultivars and fertilizer rates that lead to improved production of tea rich in catechins of %EGCG need be emphasized.

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

Regardless of season variation, the %GA content did not alter. Kaur et al. (2013) 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 expression of %GA, thus, a strong genetic influence on the expression of the trait. 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). Also, during wet season the expression of genes F3H and 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 favours higher %Caffeine biosynthesis (Alam and Chowdhury, 2007, Liu et al., 2015). During wet season, genes F3H and ANS expressions are down-regulated, while PAL and DFR up-regulated causing increased %EGCG biosynthesis (Liu et al., 2015). Cherotich et al. (2013) had similar reports at two varied locations in Kenya. Accumulation of these catechins indicates the importance of season in determining quality of the Tanzanian tea. This implies that wet season need be effectively utilized to produce Tanzanian tea rich in healthy benefit Catechin components of % EGC and %Caffeine, %EGCG.

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 attributed to high moisture stress. A combination of low annual precipitation (895.3mm) and temperatures favoured the accumulation of %gallic acid for TRIT 201/16 (1) and TRFK 303/577 (3) genotypes as 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

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on genotype SFS150 and associated the Catechin content with water stress in tea crop. The accumulation of high %EGC for SFS150 (5) at Ilenge; %EGCG and %TC for TRIT 201/43(2) also at Ilenge location could be explained as under influence of higher precipitation (2304.8mm) and max. (24.8oC - 28.3oC) temperature (Ahmed et al, 2014). The medium altitude (1426masl) at Ilenge location may also have influenced higher accumulation of %EGCG (Wachira et al., 2002, Han et al., 2016) which contributed higher proportion (83.6%) for %TC. Higher accumulation of %Caffeine and %ECG for TRIT 201/16 (1) at Marikitanda could be under the influence of higher precipitation (1508.7mm), higher temperature (both min and max) and low altitude (970 – 1000masl) (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 high tea quality production, two factors of location and genotypes impart significant levels of tea biomolecules synthesis.

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 ANR and 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 in stimulating 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).

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 interacts 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 (1508.1mm) associated with higher temperatures (min.: 12.1oC-14.8oC; max.: 27.6oC – 31.9oC). Higher %Caffeine (Kaur et al., 2015) and %EGC contents (Mutuku et al., 2016) also

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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 different 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.

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 variables 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 reflected that 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

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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 tea quality improvement at Ilenge location. Due to being rich in %EGCG and %Caffeine components green tea infusion 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 site, 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 ANS which also is significantly negatively correlated with %EGC and %ECG accumulation.

Consistent associations at each location of %EGC with individual %Catechin (%C) and %ECG, %C with %EGCG and %TC, suggest 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

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

Chaturvedula and Prakash (2011) reported that Caffeine and EGCG contributes 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 $\beta i = 1.0$, minimum deviation from regression ($S2di=0$) (Eberhart and Russell, 1966) and high coefficient of determination ($R2i \geq 70\%$) (Pinthus, 1973).

A genotype should have same means or greater than the overall genotypic mean at each location for wider adaptability and average response ($\beta i = 1.0$), stable ($S2di \approx 0$) 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 βi 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 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.

CONCLUSION

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The study on effect of genotype × environment interaction demonstrated variation among evaluated genotypes and environments (locations, seasons) on tea quality variables. Significant genotypic performance differences across 3-environments over two seasons were evident. Improved genotype TRIT 201/16 (1) accumulated higher %GA, %C, %CAFF, %ECG and %TC concentrations. TRIT 201/43 (2) had highest %EGC and %EGCG tea quality components. Among the three locations, tea variables; more accumulation of %EGC, %EGCG, %ECG and %TC were evident at Ilenge site, while conditions at Ngwazi favoured more accumulation of %GA. At Marikitanda highest %C, %CAFF and %ECG accumulation were apparent. Variation in seasons did not alter the accumulation of %GA among the genotypes. However, higher accumulation of %EGC, %CAFF, %EGCG and %TC were noted during wet season. The dry season favoured accumulation of %individual Catechin and %ECG.

Genotypes TRIT 201/16 (1) and TRFK 303/577 (3) had better interaction at Ngwazi location for %GA accumulation, whereas, TRIT 201/43 accumulated higher %EGCG and %TC at Ilenge location. Genotypes TRFK 303/577 (3), standards TRFK 6/8 (4) and SFS 150 (5) also accumulated higher %EGC at Ilenge site. Genotype TRIT 201/16 (1) had more %Caffeine and %ECG variables at Marikitanda location.

The tested genotype TRIT 201/16 (1) interacted with wet season to accumulate higher %GA, %EGCG and %TC, but the genotype also accumulated higher %ECG during the dry season. Standards TRFK 6/8 (4) and SFS150 (5) displayed higher %EGC and %individual Catechin respectively during the dry season, while improved genotype TRIT 201/43 (2) accumulated higher %Caffeine content during the wet season. The Marikitanda site had higher %GA, %EGC and %Caffeine during wet season, but 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 highest %EGC was during the dry season. The variation in seasons did not alter the accumulation of %GA at Ngwazi location.

Correlations were evident among tea quality variables at different tested locations. Locations varied in some of the associations but 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 (TRFK 6/8 (CK-1) and TRFK 303/577 (3) were suitable for %GA in mean and stability parameters. TRIT 201/16 (1) performed well in poor environments for %CAFF and was stable. Genotypes TRFK 303/577 (3) and SFS150 (5) were good and stable for %EGCG and %ECG, while TRIT 201/43 (2) was good and stable for %TC.

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