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Full Length Research Paper

Genotype by trait relations of yield and yield components in aromatic peppers (*Capsicum annuum)* based on GT biplot

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Drastic changes in random environment and lack of cultivar evaluation and multiple trait assessment across years are major constraints to pepper breeding in derived savanna agro-ecology. Ten genotypes of aromatic pepper grown in randomized complete block design were used to investigate the genotype by trait (GT) biplot analysis and to examine its effectiveness in visualizing fresh fruit yield and yield components relationships and its application in cultivar evaluation, comparison and selection across years. Twenty-two traits including fresh fruit yield were studied using GT biplot analysis. Results of the analysis of variance show signigicant genotypic, year and genotype by year interactions (GEI) for yield and yield components. GT biplot analysis showed that the genotypes were affected diversely by different environmental stresses prevalent in each of the years. G4 (*Shombo*) was outstanding in the first year of assessment having significantly the highest value in eighteen traits including fresh fruit yield, however, in the second year of assessment, G1 (UNS$_2$) and G3 (*Nsky-Ip*), not varying significantly (P = 0.01) from each other, had the highest yield. The combined analysis biplot polygon showed that G4 (*Shombo*) had significantly the highest values in eleven traits. The genotype by year GE biplot show G4 (*Shombe*) as the most outstanding genotype in years 1 and 3 assessment seasons in both fresh fruit yield and major yield components as number of nodes per plant, canopy diameter, number of fruits per plant among other traits as shown in the biplot. G7 (*Tatase*) is the vertex genotype having the highest value in, single fruit weight in all the years of assessment and pericarp thickness in years 2 and 3. Genotype evaluation and selection of parents for high fresh fruit yield and yield components were facilitated by GT biplot, as a result, G4 could be selected as the best genotype for high fresh fruit yield and G7 for high single fruit weight value and pericarp thickness. Equally, selection for number nodes per plant, canopy diameter, number of branches per plant, number of fruits per plant among other traits offers a wide scope for improving fresh fruit yield in *Capsicum annuum*.

Key words: *Capsicum annuum*, genotype by trait, biplot, selection, year.

INTRODUCTION

The importance of peppers in the tropics can not be over emphasized as they are third in importance among cultivated vegetables (Uzo, 1982). Though, primarily grown for their pungency they are also good sources of vitamins A and C especially in fresh state. Their highly cherished flavour and the desirability of the caratenoid pigments in food colouring continually increase consumers demand on them in local and urban markets (Uzo, 1982).

Increased yield has been a major objective of plant breeding programmes. However, yield is a complex polygenic character which is directly or indirectly dependent on a number of traits known as yield components (Ahmed et al., 1997; Elewanya et al., 2005). Wide variations in yield and yield component characters have been observed in aromantic *Capsicum annum*

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genotypes grown in derived Savanna belt of Nigeria (Abu and Uguru, 2006). The sub – components rather than the complex trait *per se* are subjected to selection when identifying parents for hybridization in early generations. The genotype by trait biplot (Yan and Rajcan, 2002; Okoye et al., 2007) facilitates identification of traits that can be used in indirect selection for a target trait and those that may be redundantly measured. A GT biplot can also be used to visualize the merits and shortcomings of individual genotypes which is important for both cultivar evaluation and parent selection (Okoye et al., 2007).

Inconsistencies of genotype performance in different test environments make breeding challenging because no genotype is consistently superior in all test environments (Yan and Kang, 2003). Significant genotype by environment interaction can seriously impair efforts in selecting superior genotypes. Genotype by environmental interactions (GEI) has a negative impact on heritability. Heritability of a trait is a key component in determining genetic advance from selection (Nyguist 1991). As a component of total phenotypic variance (the denominator in any heritability equation), GEI affect heritability negatively, the larger the GEI complement, the smaller the heritability estimate thus progress from selection would be reduced as well (Yan and Kang, 2003).

Allard (1960) reported that genetic and environmental factors and their interactions affect the number of seeds each genotype produces and the proportion of seeds of each genotype that reaches maturity. GEI has been a continuing challenge for breeders and has significant implications in both applied plant and animal breeding programme. The detection of GEI in trials and breeders desire to handle these interactions appropriately has led to the development of procedures that are genetically called stability or consistency analysis (Yan and Kang, 2003). Gauch and Zobel (1997) in explaining GEI reported ‘were there no interactions, the variety trial need to be conducted at only one location to provide universal results’.

Genotype and genotype by environment (GGE) biplot based on the principal component analysis (PCA) model, particularly its genotype focused scaling form, provides a superior means for visualizing both mean performance and stability of the tested genotypes. The polygon view of GGE biplot not only shows the best cultivar for each test environment but also divides the test environment into groups (Yan and Kang, 2003). Yan and Rajcan (2002) equally reported that GT biplot can be used to compare genotypes on the basis of multiple traits and identify genotypes that are particularly good in certain aspects and therefore candidates for parents in soybean breeding. Reports on analysis of pepper yield data with genotype and genotype by trait biplot that has a high advantage of showing the best performing genotype at the vertex of the polygon in a particular prevailing environment are rare. Equally pausity of materials exist on characterization of Nigerian genotypes of aromatic pepper across the different environmental stimuli prevalent in different years. Drastic changes in random environment and lack of cultivar evaluation and multiple trait assessment across years are major constraints to pepper breeding in derived savanna agro-ecology.

The objectives of this study were to i) determine pepper yield and yield components relations using GT biplot, ii) show the effectiveness of GT biplot in visualizing the yield and yield components relationships in a polygon pattern, thereby facilitating genotype evaluation, comparison and selection.

MATERIALS AND METHODS

The experimental materials consist of ten aromatic pepper genotypes of which five were obtained from the pepper germplasm of the Department of Crop Science, University of Nigeria Nsukka while the the other five genotypes were bought from the local market. The description of the genotypes can be based on the fruit colour, G1, G3, G5, and G10 are yellow fruited while the rest – G2, G4, G6, G7, G8 and G9 are red fruited genotypes, all of various fruit sizes and shapes. The ten accessions passed through three cycles of selection in the Botanical garden, Department of Botany, University of Nigeria, Nsukka before the commencement of the work. The seedlings for the field work were raised in a nursery inside the Botanical garden. The nursery medium was mixed in the proportion of 3: 2: 1 of top soil, poultry manure and river sand, respectively (Uguru, 1996). The field characterisation of the genotypes was conducted at the research farm of the Department of Crop Science, Faculty of Agriculture, University of Nigeria, Nsukka in a derived Savannah ecology (Latitude 06˚ 52’ N, longitude 07˚ 24’E and altitude 442 m above sea level). The genotypes were assessed for three consecutive years under rain fed conditions in 2002, 2003 and 2004. The experimental design was a randomized complete block design (RCBD) with three replications, each block consisted of ten plots. The seedlings of the different genotypes were transplanted to the field after four weeks.

Data were collected on morphological, agronomic and fruit characters. The analysis of variance (ANOVA) was done using Genstat 5.0, release 4.23DE, discovery edition 1 (Genstat, 2003). Genotypes by trait biplot and stability polygon were done with GGE biplot analysis, a software package by Yan and Kang (2003). The genotypes used in this work were labelled G1 to G10 while the traits were labelled T1 – T22 as in Table 1.

RESULTS

The genotypic effects were highly significant (P = 0.01) in all the traits. The genotype by year (g × y) interactions were highly significant (P = 0.01) for plant height, main stem length, number of nodes on main stem, number of nodes per branch, number of braches per plant and leave area ratio. A non – significant g × y mean square values were estimated for mainstem internode length, canopy diameter, number of nodes per plant and number of leaves per plant (Table 2).

In the combined analysis of variance for fruit and seed characters, significant (P = 0.01) variations were

Table 1. Genotype and trait labels.

Genotypes.	**Traits**
G1 = UNS_2	T6 = Number of leaves/plt
G2 = UNS_3	T7 = Number of nodes on main stem
G3 = *Nsky*-lp	T8 = Number of nodes/branch
G4 = *Shombo*	T9 = Main stem internode lenght
G5 = *Nsky*-se	T10 = Leaf area
G6 = *Tarugu*	T11 = Moisture content (%)
G7 = *Tatase*	T12 = Fruit lenght
G8 = *Dangarawa*	T13 = Fruit diameter
G9 = *Oshosho*	T14 = Pericarp thickness
G10 = *Nsky*-rw	T15 = Number seeds/fruit
	T16 = Seed weight/fruit
Traits	T17 = Fruit stalk lenght
T1 = Plant height	T18 = Number of fruits/plt
T2 = Main stem lenght	T19 = Weight of fruits/plt
T3 = Number of branches/plt	T20 = Single fruit weight
T4 = Number of nodes/plt	T21 = Dry weight of fruits/plt
T5 = Canopy diameter	T22 = Yield (T/ha)

Table 2. Combined analysis of variance for morphological and agronomic characters showing only the degrees of freedom and mean square values.

Sources of variation	Df	Plant height	Main stem length	Main stem internode length	No. of nodes on main stem	No. of nodes/ branch	Canopy spread	No. branches/ plant	No. of nodes/ plant	No. of leaves/ plant	Leave area
Block	2	5.30	43.83	0.04	15.373	17.162	3.26	1532.8	6977	134501	1.03
Year	2	4879.47**	540.55**	0.3**	843.517**	543.60**	5933.8**	94889.4**	387900**	179013.2**	633.44**
Genotype	9	440.37**	132.24**	0.72**	59.422**	41.114**	118.0**	5163.1**	30814**	9996.4**	140.32**
Genotype x year	18	56.79**	41.53**	0.0146	40.673**	28.183**	37.70	2549.0**	4395$^{n.s}$	1303.6	48578**
Error	58	18.38	6.803	0.0284	4.414	4.964	32.35	775.9	3342	679.4	9.012
Total	89										

**Significant at 0.01 probability level.

observed among the genotypes. The g × y mean square values were not significant in fruit stalk length, number of seeds per fruit and dry seed weight per fruit, however, g × y variance ratio were highly significant (P = 0.01) in number of fruits per plant, fresh fruit weight, fruit diameter, fruit length, fruit wall thickness, single fruit weight per plant, fruit dry weight and fresh fruit yield (Table 3).

The GT biplot among the ten genotypes

Table 3. Combined analysis of variance for fruit and seed characters showing only the degrees of freedom and mean square values.

Sources of variation	df	No. of fruits/ plant	Fresh fruit wt/plant	Fruit diameter	Fruit length	Fruit stallk length	Fruit wall thickness	Single fruit Weight	Fruit dry weight	No. of seeds/ fruit	Seed wt/ /fruit	Fresh fruit yield/ha (T/ha)
Block	2	256.5	2167.0	0.0903	0.0696	0.1562	0.02755	0.2574	104.05	542.9	0.0238	2.411
Year	2	9953.5**	102673.0**	9.3446**	0.3922	0.1899	0.4069**	17.3236**	5127.14**	47.4	0.02454	113.594**
Genotype	9	2467.4**	2352.0**	1.6278**	38.0403**	3.4503**	1.8681**	48.7415**	1374.83**	29979.8**	0.7352**	25.897**
Genotype x year	18	74.8**	12023.0**	0.5847**	0.9606**	0.03211	0.56701**	7.8246**	653.02**	273.1	0.0097	13.357**
Error	58	105.4	2010	0.0364	0.1201	0.08779	0.05474	0.4236	59.17	334.6	0.00906	.231
Total	89											

**Significant at 0.01 probability level.

(G1 – G10) for twenty two traits labelled T1 – T22 for 2002, 2003 and 2004 assessments were effective in showing the inter relationship between genotypes and traits (Figures 1 - 3). The variation due to GT as explained by the biplot are indicated at the upper left corner of the biplot. These variations expressed in percentage are 70.7, 65.9, 70.7 and 75.3% for 2002, 2003, 2004 and combined analysis, respectively.

In 2002 GT biplot, the genotype G4 (*Shombo*) being the vertex genotype had significantly (P = 0.01) the highest values in eighteen out of twenty two traits evaluated. G4 was not however significantly different from G9 in the expression of these eighteen traits. The yield components associated with these two genotypes that had significantly (P = 0.01) the highest fresh fruit yield are plant height, number of branches per plant, number of nodes per plant, canopy diameter, leaf area ratio, number of fruits per plant, dry weight of fruits per plant among others (Figure 1). The genotype G7 (*Tatase*) occupied a section of the polygon, having significantly (P = 0.01) the highest values in three traits, namely moisture content, number of seeds per fruit and single fruit weight. The interactive effects between the genotype and environmental components shown by significant g × y (P = 0.01) effects (Tables 2 and 3) portrayed a different shape in the GT biplot polygon in 2002 (Figure 2).

G4 (*Shombo*) and G9 (*Oshosho*) were not significantly different from each other in the expression of traits, however they had significantly (P = 0.01) highest values in only eight characters excluding the fresh fruit yield. G2 which is significantly (P = 0.01) similar with G1 and G3 genotypes had significantly (P = 0.01) the highest values in ten characters comprising the fresh fruit yield and major yield components as number of branches per plant, number of nodes per plant, canopy diameter, leaf area, number of fruits per plant, and dry weight of fuits per plant. G7 (*Tatase)* had the highest values in pericarp thickness and single fruit weight. G1 (UNS_{2}), G2 (UNS_3) and G3 (*Nsky – lp*) had highest values in nine traits.

The GT biplot graphically displayed the interrelation among the twenty two traits and the genotypes in 2004 evaluation season (Figure 3). G4 and G9 diversified in their manifestation of traits. G4 (*Shombo*) was highly outstanding as significantly (P = 0.01) the best genotype in character manifestation under the prevailing environmental conditions of 2004 assessment seasons, this genotype had the highest values in eleven out of the twenty two traits studied, these traits comprise fresh fruit yield and major yield components as plant height, number of branches per plant, number of nodes per plant, canopy diameter, number of leaves per plant, leaf area ratio, number of fruits per plant, dry weight of fruits per plant among others while G9 had highest values in three traits, viz number of seeds per fruit, seed weight(g) per fruit and fruit stalk length. G7 maintained significantly (P = 0.05) the highest values in pericarp thickness and single fruit weight similar to the values in 2003. G5, G2 and G10 did not vary significantly (P = 0.01) from each other in four traits.

The results of the GT biplot using the grand mean values from the combined analysis evidently show G4 (*Shombo*) excelling in vigour and yield as it had significantly (P = 0.01) the highest values in eleven traits (Figure 4). These traits include fresh fruit yield and major yield components. It is important to note that G7 (*Tatase*) still maintained the vertex cultivar having significantly (P = 0.01) the highest values in pericarp thickness, number of seeds per fruit and single fruit weight. Using the fresh fruit yield data in plotting the stability biplot across the three

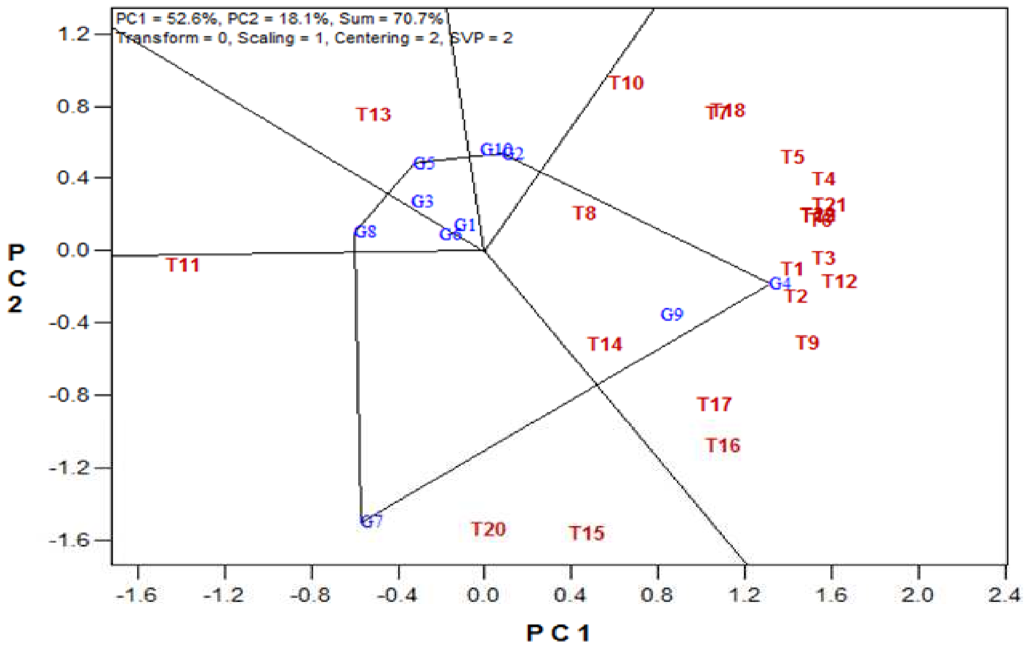

Figure 1. Year 2002 genotype by trait biplots.

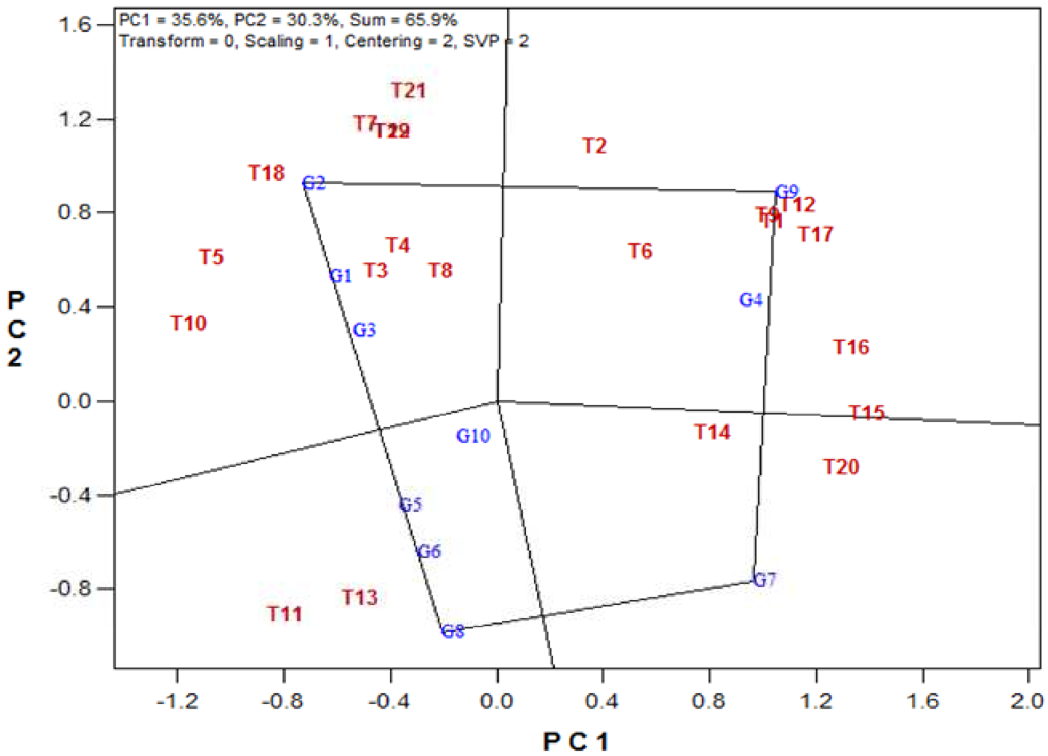

Figure 2. Year 2003 genotype by trait biplots.

years, the genotype by year GY biplot explained 97.7% (52.1% + 45.6%) of the total variation due to genotype and genotype by year (Figure 5). This value is indicated at the upper left corner of the biplot. The GY biplot shows

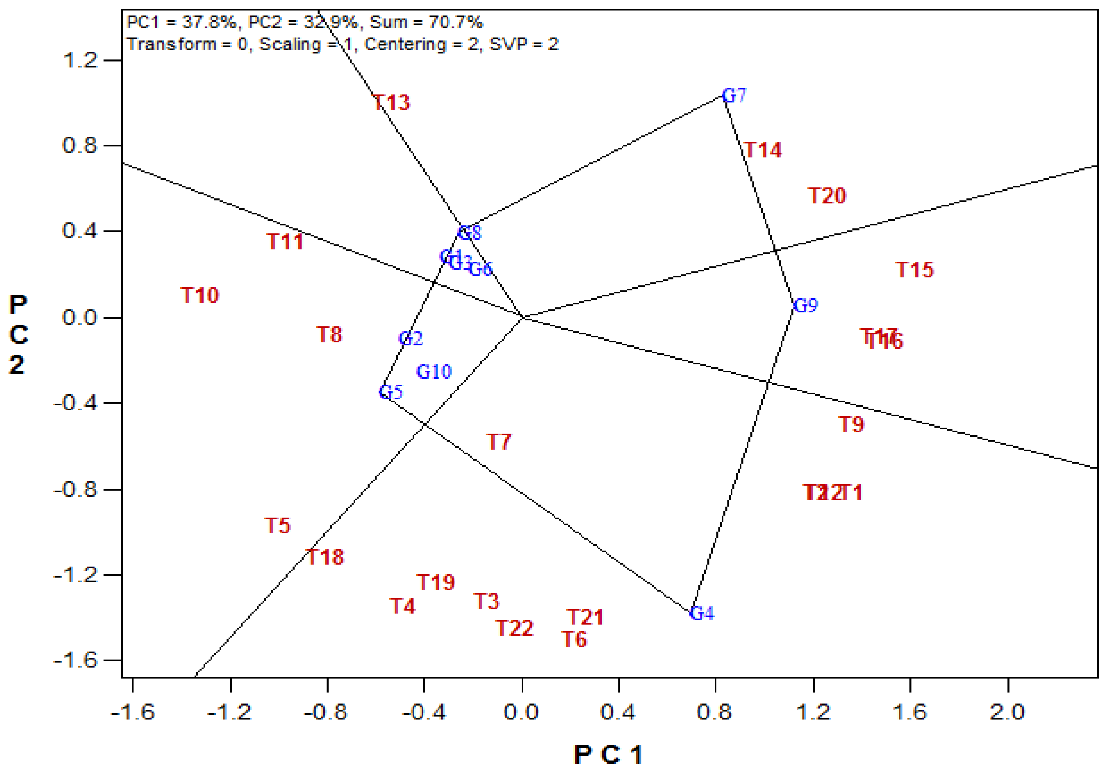

Figure 3. Year 2004 genotype by trait biplots.

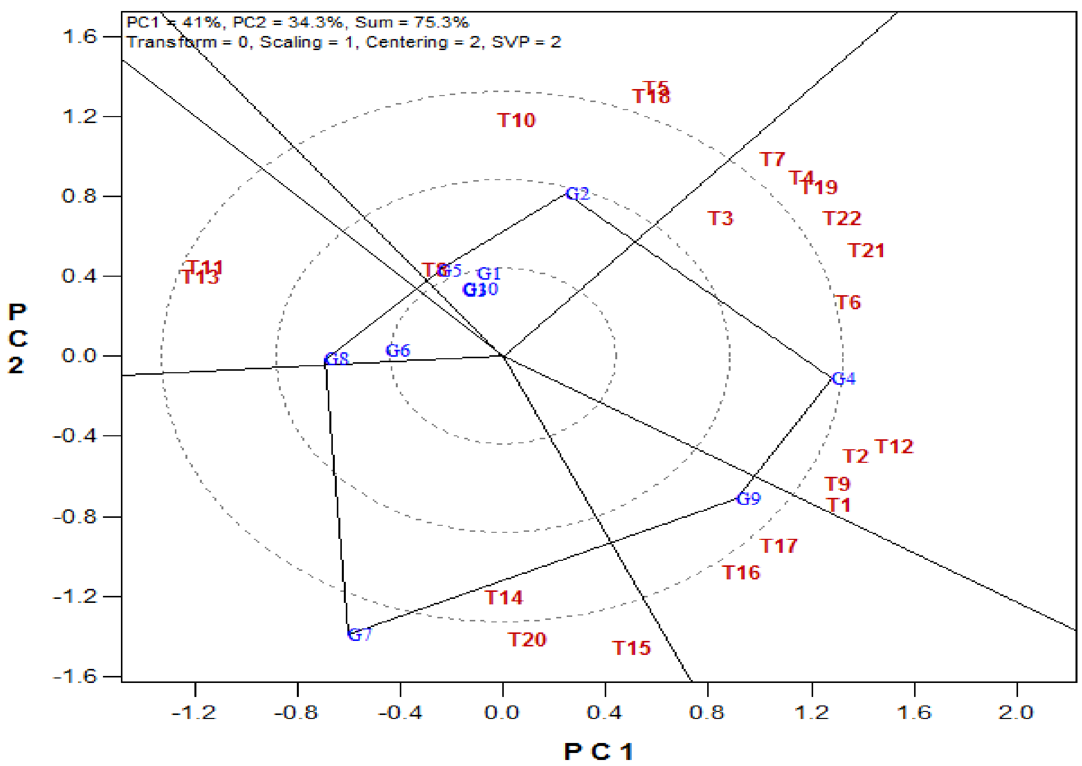

Figure 4. Three year (grand) mean genotype by trait biplots.

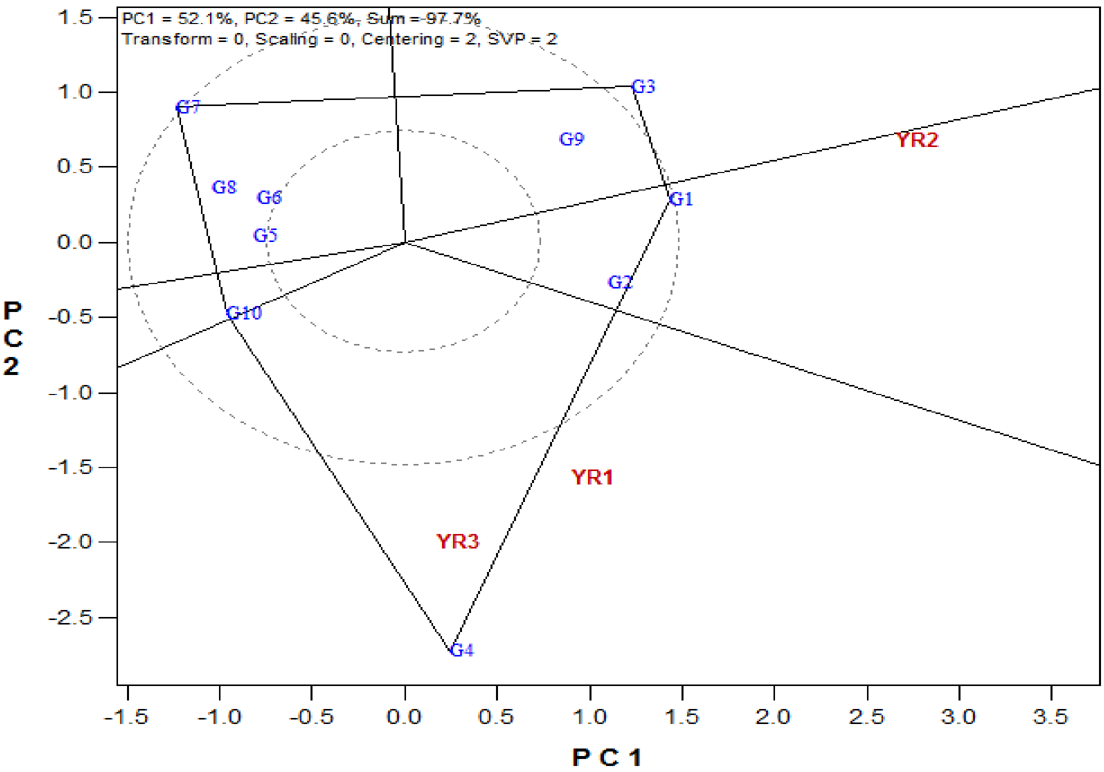

Figure 5. Stability / Adaptation (GY) biplot using fresh fruit yield values (T/ha) across the three years.

G4 (*Shombo*) as the vertex cultivar in years 2002 and 2004. This genotype is significantly the best in both yield and yield components traits within the two environments covered. While G1, G2, G3, and G9 thrives best under the prevailing environmental conditions of 2003 assessment season.

DISCUSSION

Studies on variations in quantititative characters based on wide genetic base have been reported to vary tremendously in several species (Elewanya et al., 2005). The highly significant levels obtained for different traits across genotypes indicate that the genotypes performed differently within and across the years of assessment, this could be attributed to diverse genetic background of the varieties studied. The significance of years of assessment is a pointer to significant effects of prevailing environmental components perculiar to each of the years on the expression of traits among the genotypes. Kang and Gauch (1996) reported that genetic variation exists for plant responses to many stress factors, differential response of genotypes to these stresses could be a cause for genotype by environment interaction. Our results show that, the genotype by year interactions were very highly significant for most of the traits. This seems to suggest that there was no better year / season for all the genotypes in the manifestation of these traits rather they reacted differently to different environmental signals prevalent in the different years. This observation is similar to a previous report that no genotype is consistently superior in all test environments (Yan and Kang, 2003). Busey (1983) and Eisemann et al. (1990) equally reported lack of consistency in genotype performance across environments, these researchers however opined that this could be exploited as they provide additional information for the breeder.

In discussing the effects of random environment, Akcura et al. (2005) reported that the partitioning of variance components revealed that environmental factors both predictable (locations) and unpredictable (year) were important sources of variation. Futhermore, the authors stated that when GEI results from variations in unpredictable environmental factors such as year to year variation in rainfall distribution, the breeder needs to develop stable genotypes that can perform reasonably well under a range of conditions. The genotypes used in this work showed variations in character manifestation in different years of assessment, these variations can easily be visualized in the genotype by trait biplot. The polygon view of the biplot that showed cultivar yield potentials in a particular environment indicates that the vertex cultivar is the highest cultivar in all the traits within each sector.

Yan and Kang (2003) reported that within a sector, the genotype at the vertex of the polygon is the winner in all environments or traits falling in the sector, thus, regardless of the shape of the biplots, all the biplots indicate the same ‘which - won – where’ pattern. In 2002, G4 (*Shombo*) was prominently the best performing genotype in the combinations of the prevailing environmental conditions of that year. This genotype was not previously grown in this agro-ecological zone but predominantly out yielded all the other genotypes including the land races. However, the combinations of environmental stimuli in 2003 might have put this genotype under stress as there were decreased values in both yield and yield component characters. Baker (1988b) reported that any environmental condition other than optimal represents stress to a test organism. G9 (*Oshosho*) which was not significantly different from G4 was at the vertex of the polygon, as the best performing genotype in eight traits. These eight traits did not include fresh fruit yield and yield components that have high correlations with fruit yield (Abu, 2009). G2 (*UNS3*), a genotype from the Department of Crop Science gene bank, occupied the opposite vertex, being probably advantaged by the combinations of the prevailing environmental stimuli of this year, was the best genotype in nine traits which includes fresh fruit yield.

The 2004 assessment season, marked a separation in character expression of G4 and G9, it could probably be that, having been grown for two seasons in this agro-ecological belt, these genotypes are adapting to the prevailing environmental signals. This is in line with an earlier report that plants that have incorporated a variety of environmental signals into their developmental pathways possess a wide range of adaptive capacities (Scandalios, 1990). G4 stood out prominently as the superior genotype in the expression of twelve traits including fresh fruit yield.

The major advantage of this genotype by trait biplot is that the largest value can easily be visualized in a dataset. The biplot of the grand mean reveal G4 (*Shombo*) as the best genotype in twelve out of twenty-two characters studied. Among these twelve traits were fruit weight per plant, dry weight of fruits per plant and fresh fruit yield in tons per hectare in addition to other major yield component characters as number of branches per plant and number of nodes per plant. The G4 (*Shombo*) genotype equally maintained a consistent high value for plant height, thereby placing this genotype at an advantaged position in hand harvesting. Selection for a high yielding genotype in *C. annuum* could be by indirectly selecting yield components that are related to yield as shown by the biplot. G4 was significantly the most outstanding in fresh fruit yield in the first and third years, and in the combined analysis. The major yield components that are consistently associated with the highest yielding cultivar in any of the years are plant height, number of branches per plant, number of nodes per plant, canopy diameter, number of leaves per plant, leaf area ratio, number of fruits per plant, fresh and dry weight of fruits per plant. These yield components that are consistently related with fresh fruit yield should form part of target traits for selection of superior genotypes in breeding programmes aimed at high fresh fruit yield under savanna agro-ecology.

G7 (*Tatase*) had the highest mean performance in three major and unique traits. These include pericarp thickness, number of seeds and single fruit weight. Fruit wall (pericarp) thickness is an important quality trait for puree industries. Galmarini (1997) reported that fruit wall thickness together with flavour and colour have been targets of breeding programmes in Argentina. Fruit wall thickness in addition to the redness of colour of this genotype increased its potential as colourant in food, puree and drug industries. Nandadevi and Hosamani (2003) had reported that number of fruits per plant was a major character contributing to yield, however, single fruit weight has been observed to be of great importance based on consumers’ choice. G7 (*Tatase)* is a mild genotype as regards hotness and consumers demand of this genotype is based on fruit size (high single fruit weight). Todorova et al. (2003) having observed a similar trend, reported that the breeder or the farmer should strike a balance between number of fruits per plant leading to increased fresh fruit yield and single fruit weight depending on prevailing conditions of the local and urban market based on consumers choice and market demand. The high number of seeds in this genotype is not advantageous to consumers since the fresh fruits (pericarp only) are used predominantly as vegetable and sources of carotenoids, however, they confer some advantages to farmers and seed producing and distribution agencies.

Plants respond to a host of environmental signals which results in genotype by environment interactions. The GEI has equally led to the concept of stability or consistency of performance. Smith (1990) reported that the extent of an individual’s adaptability to environmental conditions reflects the extent and sophistication of the controls over the synthesis and action of specific proteins. The yield stability biplot showed G4 (*Shombo*) as the best genotype in year one and three, however G1, G3 and G9 occupy an angle of the polygon as having uniform performance that did not differ significantly from each other in year two. G7 (*Tatase*) with the highest mean single fruit weight had the lowest mean fresh fruit yield and is positioned at the left end of the vertex from the biplot origin. The breeder is in a strait, not being sure of the next season’s prevailing conditions and which genotypes would yield better, however, earlier researchers have suggested a way forward for breeders.

Evans (1993) suggested that breeders should select a fairly stable or consistent genotype from year to year. In consideration of this suggestion and the report of Akcura et al. (2005), that breeders need to develop stable genotypes that can perform reasonably well under a range of conditions, selection among the genotypes used in this work could be aproached in two ways depending on the the farmers objective and the prevailing conditions in the local market. G7 (*Tatase*) could be recommended based on it's consistency in having high values in single fruit weight and pericarp thickness. However, this genotype consistently had low yield performance and significantly the lowest mean yield in derived savanna ecology. G4 (*Shombo*) had the highest mean fresh fruit yield and had an outstanding performance across the years, this genotype could be recommended for high fresh fruit yield while G7 (*Tatase*) could be recommended if consumers preference in the local market is on single fruit weight or high pericarp thickness. The yield of G4 (*Shombo*) even at its season of lowest yield, was higher than that of the average yielding genotype and some other genotypes that may be considered as land races.

Based on the report that superior cultivars must be evaluated on the basis of multiple environmental trials (MET) and multiple traits to ensure that the selected cultivar have acceptable performance in variable environments within the target region and to meet many facet of the demand from the producers, processors and the consumers (Yan and Rajcan, 2002) the summaries of this study are as follows; the indirect traits that could be selected for yield improvement of aromatic peppers in derived savanna agro-ecology include canopy diameter, number of branches per plant, number of leaves per plant, number of nodes per plant, plant height, leaf area ratio number of fruits per plant and weight of fruits per plant. Using the statistic of mean yield – the most common description of a genotype's performance, in the combined analysis, *Shombo* (G4), a red fruited genotype, would be recommended to farmers and breeders whose aim is high fresh fruit yield output under rain fed conditions in derived savanna agro-ecology of Nigeria. *Tatase* (G7), also a red fruited genotype has high potential for puree industries in having high pericarp thickness in addition to high single fruit weight.

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