academicJournals

Vol. 10(30), pp. 2882-2888, 23 July, 2015
DOI: 10.5897/AJAR2014.9196
Article Number: 272705254354
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Prediction model for fresh fruit yield in aromatic peppers (*Capsicum annuum* L.)

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Received 3 October, 2014; Accepted 21 July, 2015

Information on functional relationships among yield components will enhance research efforts in breeding for high yield in aromatic peppers. The aim of this study was to develop models for predicting fresh fruit yield in aromatic *Capsicum annuum* through multiple linear regression analyses. Ten genotypes of aromatic pepper were evaluated for three years in the Faculty of Agriculture farm, University of Nigeria Nsukka in a randomized complete block design (RCBD). Yield components that had strong and significant correlation coefficients were regressed to establish relational functions with fruit yield. The predicted and the actual yield values were tested for significance using t statistic. Fruit yield could be predicted using the combined effects of number of nodes per plant, number of leaves per plant and number of fruits per plant with 87.6% accuracy in the 3 year combined analysis. Linear regression for the single effects of each of the yield components were also used to predict fruit yield. The models developed could predict fruit yield in *C. annuum* with 62.5, 61.7, and 57.2% accuracy using any one of these yield components, number of nodes, number of leaves and number of fruits, respectively. The combined effects gave higher predictive value than the single effects of the traits. The models developed were validated by extrapolating the values and comparing with actual yield data. There were no significant differences between the predicted and actual yield values. Produced model could, therefore, be used in predicting fresh fruit yield in *C. annuum.* Inferences drawn from the functions developed were discussed as they affect breeding for high yield in aromatic peppers.

Key words: Breeding, multiple regressions, predictive value, relational functions, yield components.

INTRODUCTION

Peppers are cherished in many diets of Nigerians. Pepper is the only source of capsaicin, an alkaloid that is a digestive stimulant and important ingredient of daily diet (Bosland and Votava, 2000). The fruit colour is due to the presence of total carotenoid pigments. Consumption of pepper in Nigeria accounts for about 40% of average daily intake either in diets as stimulants due to the presence of the alkaloid capsaicin or as condiments for flavouring and colouring food. Nigeria is the largest producer of pepper in Africa covering about 50% of total Africa production (Adetula and Olakojo, 2006). Nigeria was named as number 12 among top producing countries of dry chillies and peppers – 148508 – 50000 metric tons in 2008 FAO report (Hays, 2009).

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Crop production efforts are directed towards yield optimisation. Optimising yield can either be via agronomic practices and/or breeding. Yield components play important role in many crop research programmes. It is frequently of interest to identify those components which contribute most to the complex trait 'yield' (Piepho, 1995; Baiyeri and Mba, 1997). Information on functional relationship among components of growth and yield will enhance research efforts to breed for high yield in aromatic peppers. It will aid breeders to make both direct and indirect selection for high yield via components that have the strongest bearing on yield. Baiyeri and Mba (1997) reported that knowledge of the strength of the relationship and/or interdependence of yield components will help plant breeders to focus their selection efforts on components that favour faster yield improvements.

Yield improvement programmes of pepper have indicated that some genotypes perform better than others under certain environmental conditions (Mattei et al., 1971). Hays (2009) equally reported that production of pepper is characterised by large fluctuations in the number of fruits and the final fruit yield per genotype over environments. Effects of random environments on *Capsicum annuum* genotypes in relation to yield and its components have also been reported (Abu et al., 2011). There is therefore a need to develop functional relationships with data on yield and yield components in different years of genotypic assessment and in the combined analysis. This will guide both the breeder and the farmer on components to select in order to improve yield. It would equally help in constructive yield prediction even at the vegetative stage of the plants. Estimating the model across years would give insight into the possible effects of the random environment on the accuracy of the prediction. The aim of this work was to develop functional relationship for predicting fresh fruit yield in *C. annuum*.

MATERIALS AND METHODS

Ten aromatic pepper genotypes were used in this study; five were obtained from the pepper germplasm of the Department of Crop Science, University of Nigeria Nsukka while the other five genotypes were bought from the open market. All genotypes were grown for 3 cycles in the Botanical garden before the onset of the experiment. These genotypes were evaluated in the field under rain fed conditions for 3 years in the Faculty of Agriculture Research Farm, University of Nigeria, Nsukka. Nsukka lies within latitude of 06° 51' N, longitude 07° 29' E and an altitude of 400 m above sea level. Randomized Complete Block Design (RCBD) of three replications was used. Each block was divided into ten plots measuring 2.9 m x 2 m (5.8 m^2). The seeds of different genotypes were raised in nursery baskets before transplanting to the field. The nursery medium was a 3:2:1 mixture of top soil, poultry manure and river sand, respectively (Uguru, 1996). Transplanting was done at four weeks and the plant spacing was 45 cm x 60 cm intra - and inter – row spacing, respectively (Bosland and Votatava, 2000). The seeds collected after each year's sowing were used for the following year's planting. Data were collected on morphological and agronomic characters for each of the three years. The data collected on yield components; viz number of nodes per plant, number of leaves per plant and number of fruits per plant together with the combined effects of the three traits, were regressed with fruit yield in each of the years, and then in the combined analysis of the three years data. Prediction models were developed for each of the years and the 3 year combined analysis. The predicted model was used to estimate the predicted yield in tonnes per hectare. The estimated yield based on the developed model was plotted against the actual yield for each of the years and the 3 year combined analysis.

Statistical analysis: The data collected on the growth parameters and fruit yield were subjected to analysis of variance (ANOVA) for each of the years of evaluation and the means for each of the three years were used in 3 years combined analysis. The effects of treatment on the above parameters (yield components and fruit yield) were tested for significance using Fisher's Least Significant Difference (F-LSD) at 5% probability level (Obi, 2002). The predicted and actual yield values were tested for significance using t-test procedures as outlined by Jones et al. (2007). The statistical package used for the analyses of variance and regression was Genstat release 7.22 DE (GENSTAT, 2009).

RESULTS AND DISCUSSION

Regression models were developed to predict the effects of yield components on fresh fruit yield. By using these models, fruit yield could be successfully predicted at onset of flowering via the number of nodes and number of leaves per plant. Significant (P = 0.001) simple and multiple regression existed among yield components – number of nodes, number of leaves and the number of fruits, with fresh fruit yield. The functional equations developed are shown on Table 1. The level of significance of the regression and the standard error of estimation (SEE) support their usefulness for prediction. Pepper plants inherently keep growing and flowering at the nodal regions with a consequent increase in nodal and leave formation even at fruiting. Yield prediction using the number of nodes and number leaves could serve as pre-flowering index in predicting fruit yield; this could guide the breeder/farmer on whether to increase inputs on agronomic practises in order to improve the yield.

Number of nodes per plant (NP) versus fruit yield (FY)

Predictions for the fresh fruit yield using linear regression across the 3 years of genotypic evaluation and in the combined analysis for the number of nodes per plant showed the following functions FY = -1.53 + 0.035NP, FY = 0.66 + 0.016NP, FY = 0.271 + 0.025NP, FY = -2.244 + 0.032NP (Table 1). The fitted equation explained 90.4, 10.8, 81.5 and 62.5% of the fruit yield using the number of nodes for each of the three years and in the 3 years combined analysis (Table 1). Note that year 2 was not significant; however, the high r^2 values obtained in other years could be used to predict fruit yield at the vegetative stage of the crop when agronomic inputs can still be applied to increase expected yield. The significant

Table 1. Predictive functions, correlation, coefficients of determination and standard error of estimates (SEE) of yield components of *C.annuum* across the years of genotypic evaluation and the three year combined analysis.

Traits	Functions **YEAR 1**	R	R^2(%)	SEE
No of nodes/plt	FY = -1.53 + 0.035NNP	0.95	90.4	0.66
No of leaves/plt	FY = -1.031 + 0.068NLP	0.92	83.9	0.86
No of fruits/plt	FY = 0.058 + 0.145NFP	0.79	62.0	1.32
Combined effects of the traits	FY = -1.452 + 0.018NNP + 0.022NLP + 0.044NFP	0.96	92.3	0.69
	YEAR 2			
No of nodes/plt	FY = 0.66 + 0.016NNP	0.33	10.8	2.95
No of leaves/plt	FY = 4.96 + 0.005NLP	0.06	0.4	3.12
No of fruits/plt	FY = 1.81 + 0.096NFP	0.89	75.5	1.45
Combined effects of the traits	FY = -0.4 + 0.01NNP – 0.005NLP + 0.09NFP	0.9	81.5	1.56
	YEAR 3			
No of nodes/plt	FY = 0.271 + 0.025NNP	0.903	81.5	1.0
No of leaves/plt	FY = 0.216 + 0.043NLP	0.908	82.5	0.97
No of fruits/plt	FY = 2.313 + 0.067NFP	0.728	53	1.59
Combined effects of the traits	FY = -0.153 – 0.005NNP + 0.042NLP + 0.031NFP	0.941	88.6	0.91
	Combined analysis of 3 years data (Mean of means)			
No of nodes/plt	FY = -2.244 + 0.032NNP	0.79	62.5	1.09
No of leaves/plt	FY = -0.36 + 0.04NLP	0.79	61.7	1.11
No of fruits/plt	FY = 1.92 + 0.077NFP	0.76	57.2	1.17
Combined effects of the traits	FY = -1.237 + 0.001NNP + 0.029NLP + 0.055NFP	0.94	87.6	0.73

NNP = Number of Nodes/plantt, NLP = Number of Leaves/plant, NFP = Number of Fruits/plant, FY = Fruit Yield.

influence of the number of nodes on fruit yield could be positively exploited. Nodes are the flowering points in *C. annum* peppers. This implies that selection for high nodal formation in a breeding programme targeted to increase fruit yield would be advantageous. Equally, the breeder/farmer could adopt agronomic practices that would increase high nodal formation before and during flowering. Number of nodes among other traits has been reported to be of great economic importance in pepper production (Nandadevi and Hosamani, 2003).

Number of leaves per plant (LP) versus fruit yield (FY)

Functions developed using the number of leaves per plant for each year and the combined analysis are as stated:

FY = -1.031 + 0.068 LP (r^2 = 83.9 %), FY = 4.96 + 0.005LP (r^2 = 0.4%), FY = 0.216 + 0.043 LP (r^2 = 82.5 %), FY = -0.36 + 0.04LP (r^2 = 61.7 %)

The above functions showed that fruit yield was 83.9, 82.5 and 61.7% dependent on the number leaves per plant in year 1, 3 and combined analysis, respectively (Table 1). The model was not significant in year 2 (r^2 = 0.4%); hence, the high values of SEE (Table 1 year 2). Vegetative parameters as number of nodes and leaves per plant could serve as pre-fruiting prediction index in *C. annum*. The number of leaves being the photosynthetic source is vital to fruit setting, development and maturity. These vegetative parameters could serve as indices for pre-fruiting prediction. The early predictions could enable the breeder/farmer to increase agronomic practices that would cause increased luxuriant growth via these two parameters and indirectly improve the yield.

Number of fruits per plant (FP) versus fruit yield (FY)

The coefficient of determination across the years for number fruits seems weak, though significant. The fitted equations could explain fruit yield via the number fruits per plant by 62, 75.5, 53 and 57.2%, across the 3 years and in the combined analysis, respectively. The weak expression could possibly be that the number of fruits per plant affects fruit yield via itself and individual fruit size – single fruit weight. The developed equations, coefficients of determination and SEE are shown on Table 1. Based

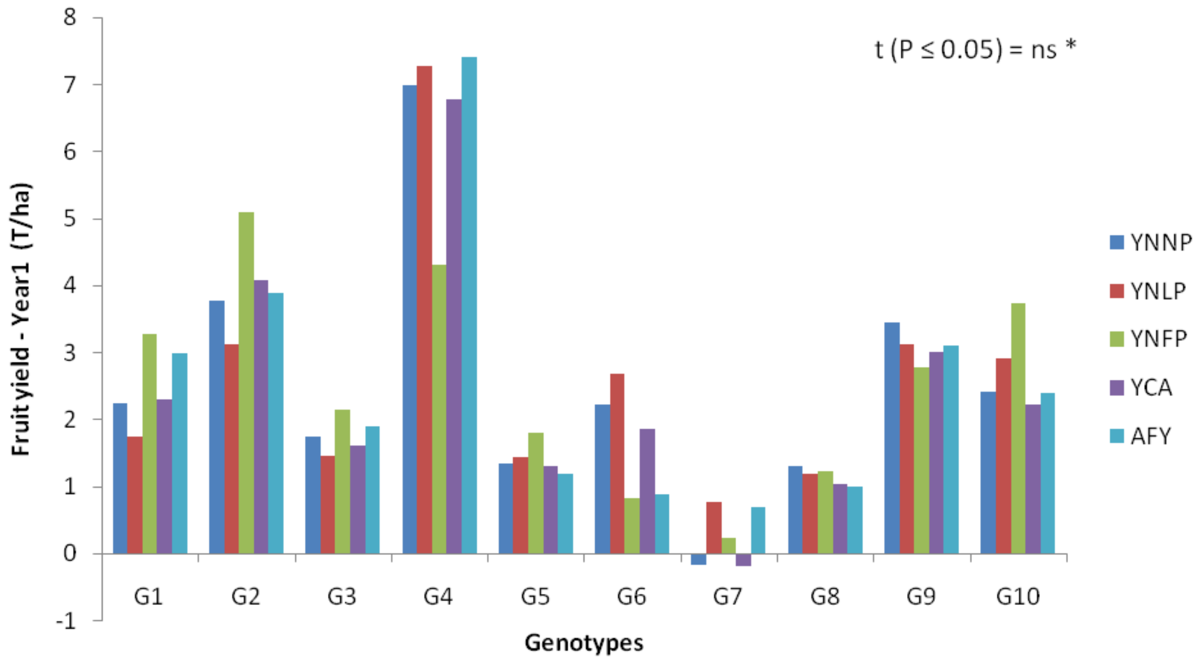

Figure 1. Actual and predicted yield across genotypes in year 1. Chart legend: NNP = Number of Nodes/plant, NLP = Number of Leaves/plant, NFP = Number of Fruits/plant, YCA = yield prediction from the combined analysis of NNP, NLP, NFP, AFY = Actual Fruit Yield.*Estimated t ($P \leq 0.05$) for NNP vs AFY = 0.011, NLP vs AFY = 0.07, NFP vs AFY = 0.005, YCA vs AFY = 0.26. Tabulated t ($P \leq 0.05$) = 2.12.

on similar observed correlations, Lahbib et al. (2012) reported the number of fruits as one of the characters that were effective on yield.

Combined effects of the three traits on fruit yield

The developed functions for the fruit yield using the combined effects of the three traits, viz: number of nodes per plant. Number of leaves per plant and number of fruits per plant in each of the years and the combined analysis are stated in the following regression equations: FY = -1.452 + 0.018NP + 0.022LP + 0.044FP (r^2 = 92.3 %), FY = -0.4 + 0.01NP – 0.005LP + 0.09FP (r^2 = 81.5 %), FY = -0.153 – 0.005NP + 0.042LP + 0.031FP (r^2 = 88.6 %), FY = -1.237 + 0.001NP + 0.029LP + 0.055FP (r^2 = 87.6 %). The multiple regression equations of the joint effect of the three yield components showed that fruit yield is 81.5 to 92.3% dependent on the collective effects of these three traits across the years and in the combined analysis. In all the years of genotype evaluation and the combined analysis of 3 years data, the combined effects of the three traits viz: number of nodes per plant, number of leaves per plant and number of fruits per plant gave higher predictive values than individual traits. This implies that breeding efforts based on the joint effects of these 3 traits would produce a shift in mean value under selection faster than that focused on individual traits. The estimates from the 3 years data analysis were significant, having a range of probability level from 0.004 – 0.01. The single effects could explain fruit yield by 62.5, 61.7 and 57.2% while the combined effects of the 3 traits explained 87.6% of the fruits yield in the combined analysis of the 3 years (Table 1). The model developed from the joint effects of the traits in the 3 years combined analysis is as follows:

FY = -1.237 + 0.001NP + 0.029LP + 0.055FP

The actual yield values plotted against the predicted yield based on the models developed are shown in Figures 1 to 4. The yield values predicted from the joint effects of the 3 traits across the years had closer relationship with the actual yield due to their higher coefficients of determination. The extrapolated chart of the actual and predicted yield (Figure 3) gave a sharper figure as the components explained high predictive values except the number of fruits per plant that was relatively low (53 %). The actual and predicted yield in the combined analysis (Figure 4) showed closer relationship than the ones developed using the single traits. This closer relationship could be explained by the higher values of the coefficients estimated using the three traits. The estimated values of Student's t statistic (two-tailed tests) for predicted versus actual yield values in comparison with the tabulated t- values are indicated below the charts (Figures 1 to 4). The estimated t- values were not significant across all the predicted versus actual yield

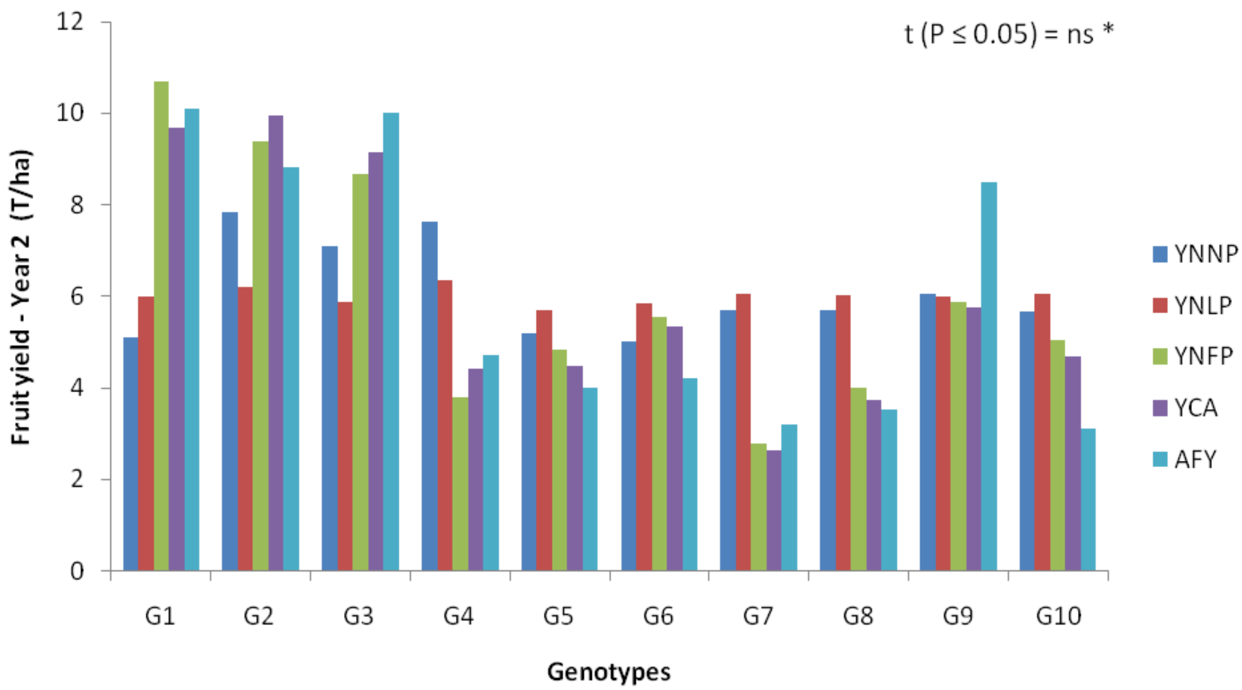

Figure 2. Actual and predicted yield across genotypes in year 2. Chart legend: NNP = Number of Nodes/plant, NLP = Number of Leaves/plant, NFP = Number of Fruits/plant, YCA = yield prediction from the combined analysis of NNP, NLP, NFP, AFY = Actual Fruit Yield.*Estimated t ($P \leq 0.05$) for NNP vs AFY = 0.08, NLP vs AFY = 0.013, NFP vs AFY = -0.033, YCA vs AFY = 0.023. Tabulated t ($P \leq 0.05$) = 2.12.

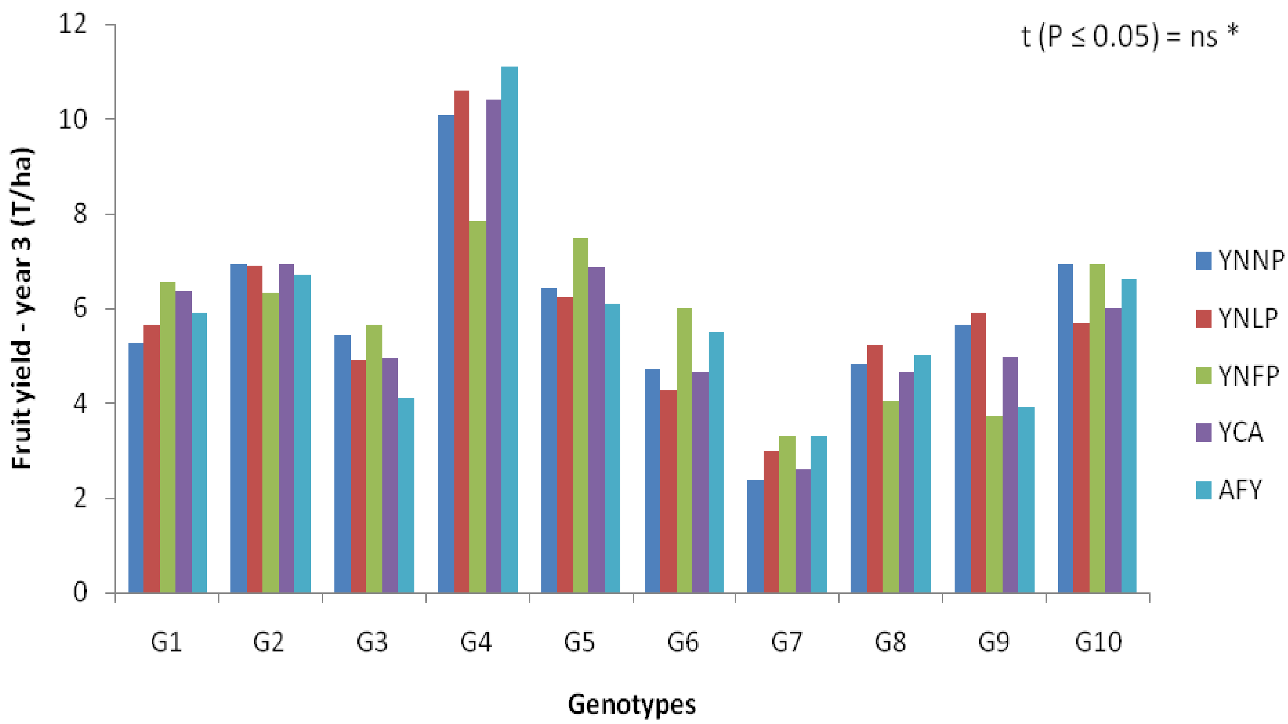

Figure 3. Actual and predicted yield across genotypes in year 3. Chart legend: NNP = Number of Nodes/plant, NLP = Number of Leaves/plant, NFP = Number of Fruits/plant, YCA = yield prediction from the combined analysis of NNP, NLP, NFP, AFY = Actual Fruit Yield. *Estimated t ($P \leq 0.05$) for NNP vs AFY = 0.11, NLP vs AFY = 0.133, NFP vs AFY = 0.19, YCA vs AFY = 0.13. Tabulated t ($P \leq 0.05$) = 2.12.

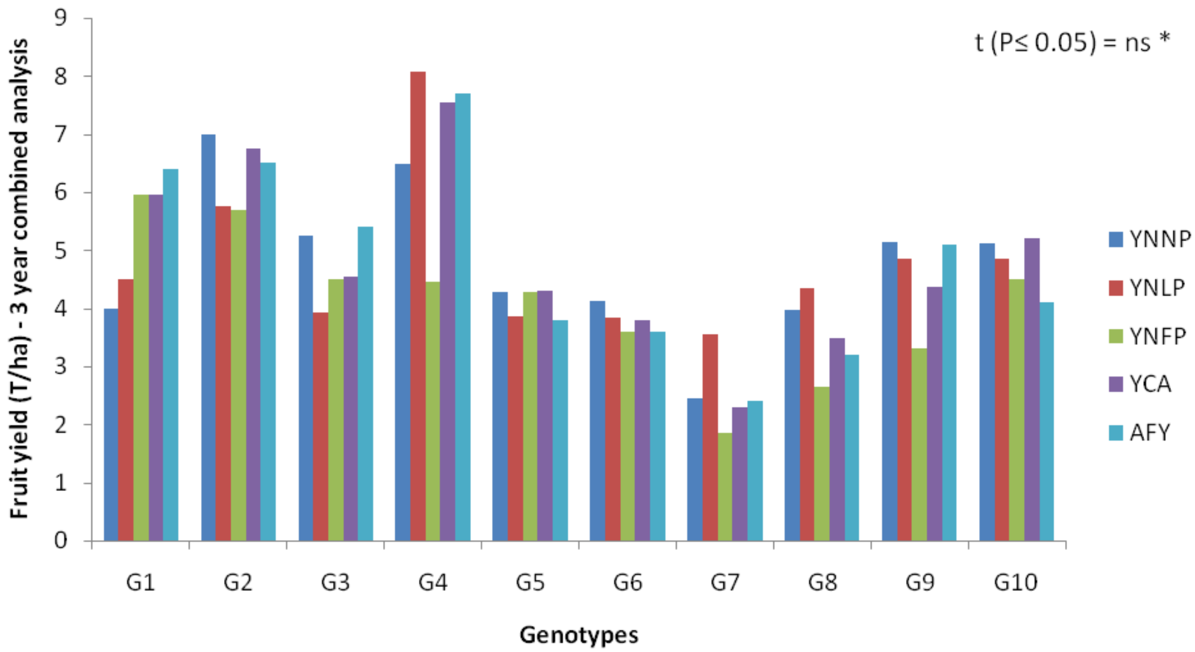

Figure 4. Actual and predicted yield across genotypes in the 3 year combined analysis. Chart legend: NNP = Number of Nodes/plant, NLP = Number of Leaves/plant, NFP = Number of Fruits/plant, YCA = yield prediction from the combined analysis of NNP, NLP, NFP, AFY = Actual Fruit Yield. *Estimated t ($P \leq 0.05$) for NNP vs AFY = 0.029, NLP vs AFY = 0.047, NFP vs AFY = 0.55, YCA vs AFY = 0.003. Tabulated t ($P \leq 0.05$) = 2.12.

values. This indicates that the predicted and actual yield values were not statistically different, thus suggesting that the models could accurately predict fruit yield in *C. annuum* for either agronomic production or breeding programmes.

Year effects on prediction models

The combined effects of the three yield components in year 2 explained the fitted equation as high as 81.5% even when two out the three traits were not significant when considered alone. The bars of actual yield in relation to predicted yield showed wider disparity than the other two years especially with number of nodes and number of leaves that had a non significant coefficient of determination (Figure 2). Kumar and Dubey (2001) reported that correlation coefficients are specific to the material and environmental conditions, emphasizing that associations between quantitative traits are subject to environemntal fluctuatations.

The estimation of the model for each year and in the combined analysis offered the opportunity of checking the accuracy of the prediction across the random environment of the three years. The linear regressions of year 1 and 3 were significant with high predictive accuracy, while the year 2 was not significant for number of leaves and number of nodes. The observed random environment of the second year seemed to be unfavourable and this may have affected genotypic expression and association link between traits. Drastic variation in the random environment could bring variation in the expected validity of the model. This seems to suggest that models are different or inaccurate when environmental conditions are not met. Where there are erratic weather conditions which differed widely from that of the preceding years, prediction may not be sufficiently accurate due to the major influence of the environment on the gene expression. The wide variations exhibited by *C. annum* genotypes in character manifestation across the random environment of derived savannah ecology have been sufficiently discussed (Abu et al., 2011). Marcelis and Gijzen (1998) reported that the accuracy of prediction of cucumber yields depends on accuracy of whether prediction. Crop yield is the result of complex interaction among factors of soil, atmosphere, plant genotypes and management practices adopted (Sehgal, 2013). Costa and Coelho (2009) reported that agriculture is an economic activity that strongly depends on climate and weather information. The complex interaction of crop with various factors and of the factors among themselves make crop yield modelling a difficult task (Sehgal, 2013). These are all suggestive of the fact that developed functions are subject to influence by other factors or information outside the conditions for the experiment where they were developed. The year 2 distribution chart showed wider disparity than the other years and the combined analysis; this is also a pointer to the inability of the genotypes to fully express inherent ability due to weather conditions.

Conclusion

Fruit yield could be accurately predicted – above 80% accuracy, via the combined effects of number of nodes per plant, number of leaves per plant and number of fruits per plant. Yield improvement programme based on the selection of these 3 traits would increase fruit yield. Adopting agronomic practices that would encourage luxuriant growth – more number of nodes, leaves and invariably number of fruits, could significantly increase fruit yield in aromatic peppers. Fluctuations in random environment could affect the validity of the predictions via its effect on yield components; however, accuracy of predictions could be maintained by a combination of these three traits in estimating the coefficient of determination rather than the use of individual traits in linear regression analysis.

Conflict of Interest

The authors have not declared any conflict of interest.

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