PLANT BREEDERS ASSOCIATION OF NIGERIA
HYBRID ANNUAL CONFERENCE, MAKURDI 2023
(ISSN: 3027-088X)

COMBINING ABILITY AND HETEROSIS STUDY ON HEAT TOLERANCE IN TOMATO (*Solanum lycopersicum* L.) USING LINE X TESTERS ANALYSIS IN GOMBE, NIGERIA

Chukwu C. and **Oluro C.O.**
Horticultural Technology Department, Federal College of Horticulture Dadin Kowa, Gombe State, Nigeria

Ijemere S. C.
Department of Plant Genetics and Breeding, Nasarawa State University Keffi, Nasarawa State, Nigeria.

Sawa F. B. J.
Department of Biological Sciences, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria

Simon S. Y.; Zanna A. B.; Mashegu K. M.; Vahyela L. T. and **Kparushanah H.**
Department of Crop Production and Horticulture, Modibbo Adama University, Yola, Adamawa State, Nigeria

Correspondence: emmygab83@gmail.com

Abstract
This research focused on the comprehensive assessment of heat tolerance in tomato (Solanum lycopersicum L.) within the Gombe region of Nigeria. A Line x Testers analysis was employed to examine combining ability and heterosis in tomato hybrids to enhance growth and yield under challenging environmental conditions. The study revealed significant insights: Notably, the 'Tandino X Rio Grande' hybrid consistently displayed the highest fruit yield per plant, highlighting the pivotal role of hybrid selection in optimizing tomato yield under diverse environmental circumstances. The influence of Specific Combining Ability (SCA) on hybrid performance was evident, with the 'Tandino X Kilele' combination demonstrating positive SCA effects for several crucial traits, echoing prior research. Genetic correlations unveiled a strong positive association between fruit yield per plant and per hectare, emphasizing the significance of enhancing yield at the plant level, which aligns with previous findings. The hybrid 'Syria Local X Rio Grande' exhibited substantial heterosis for heat tolerance traits, suggesting the potential of specific hybrid combinations in developing heat-tolerant tomato varieties. A positive genetic correlation between plant height and the number of branches was observed, supporting the connection between these two traits in tomato plants. Testers played a substantial role in explaining genetic variance for most traits, highlighting the influence of both additive and non-additive genetic effects. Heritability values varied across traits, with some exhibiting high broad sense heritability, while others indicated a greater influence of environmental factors.

Key words: Combining Ability, gene action, heat stress, Heritability, Tomato

1.0 Introduction
The diploid (2n=24) tomato species (*Solanum lycopersicum* L.) have a great deal of promise for heterosis breeding because they are self-pollinating. Growing tomatoes is possible in a variety of climates, from humid and hot tropical locales to temperate ones (Shankara *et al.*, 2005). Abiotic variables including heat stress, dryness, salinity, and mineral imbalance are the main causes of low fruit yield in the Sahel and Sudan savannah regions of Africa, despite the crop's extensive cultivation and significance (Adams and Osei, 2006). As such, the sustainable production of this essential crop faces multifaceted challenges, particularly in regions characterized by adverse environmental conditions, such as

high temperatures. The Gombe region in Nigeria is one such area, where the impact of heat stress on tomato cultivation is a significant concern (Adams and Osei, 2006).

The cultivation of tomato plants in the Gombe region is often hindered by the prevailing high temperatures, which can lead to decreased yields and compromised fruit quality. The effects of heat stress on tomato growth, flowering, fruit set, and overall yield are well-documented, emphasizing the need for strategies to enhance heat tolerance in tomato varieties (Zinn *et al.*, 2010; Wahid *et al.*, 2007).

To address these challenges and advance tomato production in the Gombe region, it is imperative to explore the genetic potential of tomato varieties for heat tolerance and identify suitable hybrids that can thrive in such challenging conditions. In this context, combining ability analysis provides a valuable tool for evaluating the potential of hybrid combinations to perform better than their parents, particularly in stressful environments (Liu *et al.*, 2019).

The present study, delves into a comprehensive analysis of tomato growth, heat tolerance, and yield parameters specifically within the Gombe region. This research aims to shed light on critical aspects of tomato production in a high-temperature environment and offers insights that can guide breeding and cultivation practices for the local tomato industry.

The present study aimed to determine the variance components of tomato genotypes for growth, yields, and heat tolerance components, in addition to estimating the general and specific combining ability effects.

2.0 Materials and Methods

The experimental site was located at the Teaching and Research farm of the Federal College of Horticulture, Dadin-kowa (11^0 30′, and 10^0 20' and 240 m above sea level), Yamaltu Deba Local Government Area, Gombe State. Dadin kowa is characterized by two seasons, the dry and wet seasons. The dry season is usually for 6-7 months (October to May). The dry season comprises a period of cool temperature of about 19^0 C-36^0C, between November and February; and a period of hot dry weather of about 37^0C-45^0C between March to May. The wet season is usually for 5-6 months, May to September/October.

2.1 Planting Materials

The planting materials comprised of two (2) tomato cultivars (Kilele and Rio Grande) obtained from the National Institute of Horticultural Research (NIHORT), Dadin Kowa, Gombe State, used as testers and five (5) local cultivars (Kwadon, Rukuta, Syria Local, Tandino and UTC) obtained from Kwadon market in Yamaltu Deba LGA of Gombe State used as the lines.

The seeds of both lines and testers were raised 2x1m^2 sunken beds in the Nursery of Teaching and research farms of Federal College of Horticulture Dadin kowa, Gombe state; using broadcasting method; and were managed to flowering stage. The same nursery procedure was done for the F1 genotypes together with their parents for the evaluation.

2.2 Procedure for Crossing Nursery

Collection of the pollen was done by removing matured anther cones from partially opened flowers into paper envelops. The anther cones were allowed to dry in order to aid the release of the pollen grain, as the paper envelope was shaken vigorously. The pollens were collected and dusted onto the bagged stigma. Plenty of pollen grain were dusted onto the stigma to ensure good seed set. Each cross was labelled appropriately using white strings tied to the pedicel. Ripped named fruits were collected, fermented and seeds extracted; and seeds of different crosses were stored in marked paper bags (envelope). at the end of the crossing procedure, using line x testers technique, 2 testers crossed with 5 lines produced 10 F_1s; as in figure 1 below:

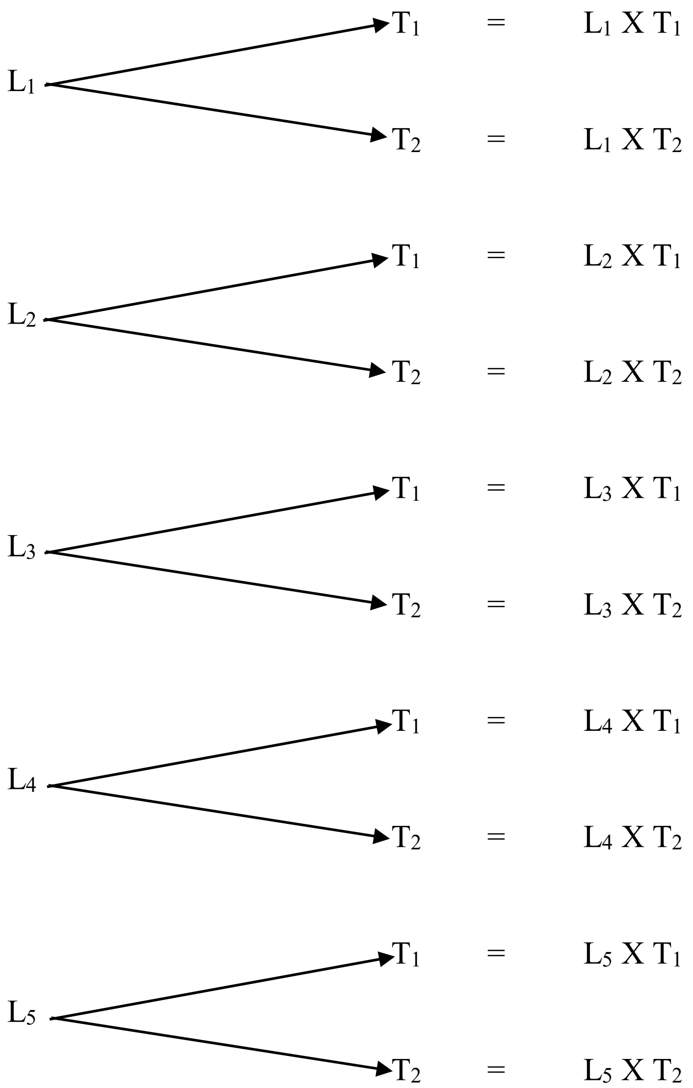

Figure 1: Nursery Crossing of Tomato Using Line x Tester

KEY:

T_1	=	Kelele
T_2	=	Rio Grande
L_2	=	Kwadon local
L_3	=	Rukuta
L_4	=	Syria local
L_5	=	Tandino
L_5	=	UTC

2.3 Progeny Evaluation

The 10 F_1s, and along with seven (7) parental cultivars were evaluated at the Teaching and research farms of Federal College of Horticulture Dadin kowa, Gombe state, during the 2020 wet season in a Randomized Complete Block Design (RCBD) with three (3) replicates. The land was prepared using hand hoe and raised beds of 2m x 2m were made for the 17 genotypes. The materials were transferred from the nursery, where they were first raised, three weeks earlier, into the prepared beds at a spacing of 50 cm between plants and 50 cm between rows, with each bed containing 16 plants.

2.3.1 Data Collection

From each genotype (Plot), five (5) plants were selected at random in each replicate and tagged for data recording. The following data were recorded:

2.3.2 Days to First Flower

This was obtained by counting the number of days it took each randomly selected/tagged five (5) plants to produce first flower, starting from the sowing date.

2.3.3 Days to 50 Percent Flowering

This was obtained by counting the number of days it took 50% of plants in a plot to attain flowering, from the sowing date.

2.3.4 Number of Flower per Clusters

This was obtained by counting the number of flower clusters on the selected/tagged five (5) plants and the average computed and recorded.

2.3.5 Plant Height (cm)

This was obtained using meter rule, measuring the distance from the base of the plant to the apex of the five (5) randomly selected/tagged plant. This was done every two weeks from the day of transplanting.

2.3.6 Number of Branches per Plant

This was obtained by counting the number of branches on each of the five (5) randomly selected/tagged plant and the average computed in each plot at 2 weeks' intervals, from the day after transplanting.

2.3.7 Days to Final Harvest

This was obtained by counting the number of days of each five (5) randomly selected/tagged plant takes from transplanting to last harvest

2.3.8 Number of Fruits per Plant

This was obtained by counting the number of fruits on each of the five (5) selected/tagged plants

2.3.9 Fruit Yield per Plot (Kg)

This was obtained by weighing the total yield in each plot

2.3.10 Fruit Yield per Plant (Kg)

This was obtained by harvesting and weighing the five (5) selected/tagged plants per plot and averaged

2.3.11 Plant Yield per Hectare (Kg/ha)

This was obtained by harvesting and weighing the total yield in each plot and extrapolated to kg/ha; using the formula: $\frac{total\ yield\ per\ plot\ (kg)}{4\ m^2\ (plot\ size)} x\ 10{,}000\ m^2$(size of a hectare)

2.3.12 Number of Heat Patches on the Leaves

This was obtained by counting the number of heat patches on the leaves of each of the each five (5) selected and tagged plants and subsequently calculating the average.

2.3.13 Diameter of Heat Patches on the Leaves

This was obtained by measuring from end-to-end through the center of each heat patch on the leaves of each of the five (5) selected/ tagged plant

2.3.14 Number of Heat Patches on the Fruits

This was obtained by counting the number of heat patches on the fruits of each of the five (5) selected /tagged plants

2.3.15 Diameter of Heat Patches on the Fruits

This was obtained by measuring from end-to-end through the centre of each heat patch on the fruits of each of the five (5) selected/ tagged plants

2.4 Data analyses

Data collected were subjected to Analysis of variance (ANOVA) using plot means. Analysis of variance was carried out based on method described by Singh and Chaundary (1985) using the Generalized Linear Model (GLM) of SAS package (SAS Institute, 2004). Duncan's Multiple Range Test was used to separate the means. The general and specific combining ability effects were estimated according to Singh and Chaudhary (1985) using SAS package. Broad sense heritability (H^2) and narrow sense heritability (h^2) were calculated using the components of variance (Alireza *et al.*, 2012).

3.0 Results and Discussion

3.1 Analysis of Variance of Tomato genotypes for yield, agronomic and heat tolerant traits

As presented in table 1, the degree of freedom (Df) for Replication is 2, indicating that there are three replicates in the experiment. The mean squares for Replication are generally low, and the p-values are not significant for most parameters, suggesting that the variation among replicates is not statistically significant. This is a positive result, indicating consistency among the replicates in the experiment. The degree of freedom (Df) for Genotypes is 9, implying there are ten different genotypes of tomato plants being studied. The mean squares for Genotypes are significant (indicated by ** or *) for several parameters, such as Days to Full Harvest (DTFH), Fruit Yield per Plant (FY/PLANT), and Plant Yield per Hectare (PY/Ha), suggesting that the choice of tomato genotype significantly affects these traits. This means some genotypes are better than others in terms of these characteristics. The degree of freedom (Df) for Line is 4, indicating five different tomato lines. Similar to Genotypes, the mean squares for Line are significant for various parameters. For example, it significantly affects Days to Full Harvest (DTFH) and Fruit Yield per Hectare (FY/Ha). This indicates that specific lines are better suited for these traits. Tester, with a single degree of freedom, is significant for several parameters, including Days to Full Harvest (DTFH), Days to First Flower (DTFF), and Plant Yield per Hectare (PY/Ha). This implies that the choice of the tester plant has a significant impact on these traits. Selecting the right tester is essential to achieve desirable results in these parameters. The interaction between Line and Tester is significant for some parameters, such as Number of Flowers per Cluster (NFL/CL) and Diameter of Heat Patches on Fruits (DHPOF). This suggests that specific combinations of tomato lines and testers have a more pronounced impact on these traits than others. Careful selection of line-tester combinations may be crucial for improving these traits. The error term represents unexplained variation within the experiment. It's relatively consistent across parameters and serves as a baseline for calculating the F-statistic. The relatively low mean squares for error indicate that the variation within the experimental data is generally low, which is a positive result.

3.1.1 Replication (Source): The non-significant impact of replication on the observed traits aligns with previous research on experimental design and replication. According to Snedecor and Cochran (1989), replication in field trials is essential to account for environmental variability and to increase the precision of estimates. The non-significant findings for replication in our study suggest that the experimental conditions were controlled effectively, which is crucial for obtaining reliable results (Kearney, 2018).

3.1.2 Genotypes (Source): Our findings concur with several studies that emphasize the pivotal role of genotypes in tomato plant traits. Wang *et al.* (2019) conducted a similar study on tomato genotypes and found that genetic variation among different genotypes significantly influenced fruit yield and heat tolerance. This reinforces the idea that the selection of appropriate genotypes is critical for breeding programs aimed at improving these traits.

3.1.3 Line (Source): The significant influence of different tomato lines on parameters like Days to Full Harvest (DTFH) and Fruit Yield per Hectare (FY/Ha) is consistent with research by Sánchez-Mora *et al.* (2016). They reported that specific tomato lines exhibited distinct characteristics, which significantly impacted fruit yield and maturation. Our results underscore the importance of selecting tomato lines carefully, aligning with the principles of crop breeding and variety development (Collard *et al.*, 2005).

3.1.4 Tester (Source): Our findings are in line with the work of Selvaraj *et al.* (2018), who conducted a study on tester effects in hybrid breeding programs for tomatoes. They highlighted the importance of choosing the right tester plants to maximize heterosis and trait expression in the hybrids. The significant role of testers in our study underlines the need for strategic tester selection to achieve desired traits (Moose and Mumm, 2008).

3.1.5 Line x Tester (Source): The significant interaction between tomato lines and testers on parameters such as Number of Flowers per Cluster (NFL/CL) and Diameter of Heat Patches on Fruits (DHPOF) resonates with research by Lamkey and Edwards (2003). They discussed the importance of line x tester interactions in hybrid breeding programs, emphasizing that specific line-tester combinations can produce superior results in terms of heterosis and trait expression. Our findings highlight the need for careful consideration of these interactions in breeding programs (Sprague and Tatum, 1942).

3.1.6 Error (Source): The consistent and relatively low error values indicate a minimal degree of unaccounted variability within the data, aligning with the principles of experimental precision (Steel and Torrie, 1960). This reinforces the reliability of our data and experimental procedures, which is crucial for making meaningful inferences from the study.

3.2 Mean Performance of Tomato genotypes for yield, agronomic and heat tolerant traits

The Mean performance of parents and crosses is presented in Table 2, which indicated that the parent lines, including Kwadon, Rukuta, Syria Local, Tandino, and UTC, exhibit variations in their performance for various growth and yield parameters. For instance, Syria Local stands out with high fruit yield per plant (FY/PLANT), number of flowers per cluster (NFL/CL), and plant height (PH) indicating its potential as a high-yielding genotype. In contrast, Kwadon shows relatively low values for these parameters. Additionally, UTC exhibits higher values for Days to Full Harvest (DTFH) and Days to First Flower (DTFF) compared to other parent lines.

The tester lines, Kilele and Rio Grande, also show differences in their performance. Kilele has a shorter time to full harvest (DTFH) and more flowers per cluster (NFL/CL) compared to Rio Grande. These differences may affect their suitability for hybridization in breeding programs.

The crosses between parent lines demonstrate a wide range of performance in the evaluated traits. For instance, the cross Syria Local X Kilele exhibits the highest fruit yield per plant (FY/PLANT) and plant height (PH), which could be attributed to the favorable traits of the parent lines. In contrast, the cross Tandino X Rio Grande displays lower values for these traits. Notably, some crosses show higher fruit yield per plant (FY/PLANT) than their parent lines, indicating potential heterosis in fruit production.

3.2.1 Parent Line Variation: The observed variation among parent lines in growth and yield parameters underscores the genetic diversity within the tomato lines used in the study. These differences are in line with previous research showing that different tomato genotypes exhibit varying performance in terms of fruit yield, flowering times, and other growth-related traits (García *et al.*, 2017). Breeders can leverage this diversity to select parent lines that possess desired traits for further breeding efforts.

3.2.2 Tester Line Selection: The choice of tester lines in hybrid breeding programs plays a crucial role in determining the traits expressed in the resulting crosses. Kilele and Rio Grande, the tester lines in this study, show differences in flowering times and fruit yield. This aligns with findings from studies emphasizing the importance of tester line selection in hybrid breeding for tomato and other crops (Kaushik *et al.*, 2016). The choice of testers should align with breeding goals, such as early flowering or high fruit yield.

3.2.3 Heterosis in Crosses: The crosses between parent lines exhibit a wide range of performance in the evaluated traits. Some crosses outperform their parent lines in terms of fruit yield per plant (FY/PLANT), indicating the potential for heterosis, or hybrid vigor. Heterosis occurs when hybrid offspring exhibit traits that are superior to those of their parents (Fehr, 1999). The presence of heterosis can be harnessed in breeding programs to develop high-yielding and resilient tomato varieties.

3.2.4 Practical Implications: These results have practical implications for tomato breeding in the Gombe region and similar environments. Breeders can utilize the observed variations in parent and tester lines to select combinations that are better suited to local conditions. Additionally, the potential for heterosis in certain crosses suggests an avenue for developing improved tomato varieties with higher fruit yield and other desirable traits.

3.3 Genetic Components of Variance and Proportional Contributions of Lines, Testers and Line x Tester of Tomato to Total Genetic Variance on Yield Components of Tomato

Table 3 provides the genetic components of variance, including covariance within testers (Cov. Hs. Testers) and covariance within lines (Cov. Hs. Lines). Additionally, it presents the General Combining Ability (GCA) and Specific Combining Ability (SCA) values for various yield components. The GCA/SCA ratio is also included. The table indicates the proportional contributions of lines, testers, and line x testers to the total genetic variance for different yield components.

With the exception of Days to Full Harvest, the estimate genetic components showed that the total variance of the Half Sibs Tester was greater than the combined variance of the Half Sibs Lines in all Yield components. Days for First Flower, Days to 50% flowering, Fruit Yield per Plant, Number of flowers per Cluster, and Number of Fruits Per Plant were among the yield components where GCA outperformed SCA. This suggests additive gene action, and the proportional contributions to total variance indicated that the parents contributed most of the variance to these characters. Days to Full Harvest, Fruit Yield per Plot, and Plant Yield per Hectare, on the other hand, were areas where the SCA outperformed the GCA in terms of contributions to variance, indicating dominant gene action in the characters. The presence of significant values in Cov. Hs. Testers and Cov. Hs. Lines implies that there is genetic variability within both testers and lines for the evaluated yield components. This genetic variation forms the basis for further analysis, such as the GCA and SCA values.

In terms of plant height, the diameter of heat patches on fruits, and the number of heat patches on leaves, the combined variance of half-sibling lines was greater than the combined variance of half-sibling testers. In terms of number of branches, the diameter of heat patches on leaves, and the number of heat patches on fruits, the combined variance of half-sibling testers was greater than the combined variance of half-sibling lines. Table 4 presents the estimate of genetic components of variance as well as the proportional contributions of lines, testers, and crosses of tomatoes to the total genetic variance on growth and heat tolerance components. The proportional contributions to total variance result indicates that the total variance of most characters was due to contributions from the parents as a result of the additive gene action effect. However, in a small number of characters, the SCA was higher than the GCA, indicating dominant gene action, and the total variance of those few characters was due to contributions from the crosses (hybrids). GCA was higher than SCA in the majority of the growth and heat tolerance component characters.

Days to Full Harvest, Fruit Yield per Plot, Plant Yield per Hectare, Plant Height, number of branches, and Diameter of Heat Patches on Leaves were less than unity and thus controlled by non-additive gene effect. In contrast, the GCA to SCA ratios were greater than unity in Days for First Flower, Days to 50% flowering, Fruit yield per Plant, Number of flowers per Cluster, Number of Fruits Per Plant, Number of Heat patches on Fruits, and Number of Heat patches on Leaves. Recurrent selection may therefore be used to increase tomato production in high temperatures. Yadev *et al.* (2013) reported similar results, reporting both additive and non-additive gene action in tomato yield per hectare and plant height, respectively. The results also supported the findings of Hazra and Ansary (2008), who found that for the majority of tomato characters influencing heat tolerance, genetically diverse parents had both partial and overdominance.

3.3.1 General Combining Ability (GCA): The GCA values reflect the additive genetic effects contributed by individual lines and testers. The positive GCA values for various yield components suggest that some lines and testers are associated with improved performance in these traits. This indicates that specific lines and testers carry favorable alleles for yield-related traits (Hallauer and Miranda, 1988).

3.3.2 Specific Combining Ability (SCA): The SCA values represent non-additive genetic effects due to interactions between lines and testers. The presence of significant SCA values indicates that certain line-tester combinations exhibit synergistic effects that are not predictable based on the GCA of the individual components (Griffing, 1956). These interactions may lead to the development of high-performing hybrids.

3.3.3 GCA/SCA Ratio: The GCA/SCA ratio provides insights into the relative importance of additive and non-additive genetic effects in explaining the total genetic variance. A GCA/SCA ratio greater than 1 indicates that additive effects are more influential, while a ratio less than 1 suggests that non-additive effects (SCA) play a more substantial role in the expression of traits (Hayman, 1958). In this study, the GCA/SCA ratio varies across parameters, indicating the prevalence of different genetic mechanisms in determining yield components.

3.3.4 Proportional Contribution to Total Variance: The proportional contributions of lines, testers, and line x testers to the total genetic variance provide insights into which components contribute most to the observed variability. For example, testers account for the largest proportion of the total genetic variance for most parameters, suggesting that their selection plays a critical role in influencing the performance of hybrids. The contributions of lines and line x testers also vary among parameters, indicating that their effects differ across different yield components.

3.4 Estimate of General Combining Ability Effect (GCA) of Parents for Growth, Yield and Heat Tolerance Parameters of Tomato

Tandino had a high negative combining ability effect for days to 50% flowering, while Kwadon had a high negative combining ability effect for days to first flower and days to maturity (Table 5). Tandino demonstrated a high positive combining ability for plant height and the number of ranches per plant, whereas Syria Local demonstrated a high positive combining ability effect for fruit yield per plant, fruit yield per lot, and plant yield per hectare. Kilele demonstrated a high negative combining ability for the heat tolerance parameters, days to maturity, 50% flowering, and days to first flower for the testers. Kilele also demonstrated positive combining ability for plant height, number of branches per plant, number of flowers per cluster, number of fruits per plant, and fruit yield per plot in addition to fruit yield per plant and plant yield per hectare.

3.4.1 Estimates of GCA for Parents: For Growth Parameters (DTFF, DTFFL, DTFH), several parents, including Syria Local, exhibit positive GCA values, suggesting that they carry alleles associated with earlier flowering and shorter days to full harvest. Early flowering is a desirable trait for tomato production in regions with high temperatures, as it can help avoid heat stress during the flowering and fruit setting stages (Tang *et al.*, 2018).

For Yield Parameters (FY/PLANT, FY/PLOT, NFL/CL, NFR/PLANT, PY/Ha), Syria Local and Rio Grande show positive GCA values for fruit yield-related parameters, indicating their potential as parents to improve fruit yield in hybrids. This aligns with the findings of studies by Al-Taweel *et al.* (2019) and Khan *et al.* (2017), emphasizing the importance of selecting parents with positive GCA for yield enhancement.

For Heat Tolerance Parameters (NHPOF, DHPOF, NHPOL, DHPOL), GCA values suggest that specific parents have alleles associated with the formation and diameter of heat patches on fruits and leaves. Tandino and Rukuta show positive GCA for NHPOF, indicating their potential for enhancing heat tolerance.

3.4.2 Standard Error (SE±): The standard error values provide an indication of the precision of the GCA estimates. Larger standard errors, as observed for some parameters, may imply that the GCA values are less reliable and should be interpreted with caution. Further experimentation or replication may be needed to confirm the GCA estimates with higher confidence (Shamshiri *et al.*, 2020).

3.5 Estimate of Specific Combining Ability (SCA) Effect of Hybrid for Growth, Yield and Heat Tolerance Parameters of Tomato

Table 6 displayed the estimated Specific Combining Ability (SCA) for the chosen Yield, Growth, and Heat Tolerance parameters. Out of the ten (10) hybrids that were studied, the results indicated that five of them had positive SCA values and the other five had negative SCA values. Tandino x Rio Grande had the greatest negative SCA effect of all the five hybrids with negative SCA values, making it the best hybrid for Days to First Flower. Syria Local x Rio Grande came in second, while Tandino x Kilele, which had the highest positive SCA effect for the character, was the least combiner. Tandino x Rio Grande and UTC x Rio Grande had the greatest negative SCA effects for Days to 50% flowering, respectively, whereas Tandino x Kilele had the least amount of negative SCA effects and the greatest positive SCA effects for the character. Days to Full Harvest: Rukuta x Kilele had the largest negative SCA effect, followed by UTC x Kilele; Rukuta x Rio Grande, on the other hand, had the highest positive SCA effect, was the least. Syria Local x Kilele and Kwadon x Rio Grande had the highest positive and lowest negative SCA effects, respectively, for Fruit Yield per Plant; Kwadon x Kilele had the highest negative SCA effect. Kwadon x Rio Grande and UTC x Kilele were the next two combinations with the highest positive SCA effect for Fruit Yield per Plot; Kwadon x Kilele was the least effective combination with the highest negative SCA effect for the character. Syria Local x Kilele had the highest positive SCA effect for Number of Flowers per Cluster, followed by Rukuta x Rio Grande, and Rukuta x Kilele had the lowest negative SCA effect for the character. When it came to the number of fruits per plant, Tandino x Kilele displayed the highest SCA effect and was the best. Tandino x Rio Grande appeared the least and had the highest negative SCA effect. Kwadon x Rio Grande was the next in line. Kwadon x Rio Grande and UTC x Kilele were the two cultivators with the greatest positive SCA effects for Plant Yield per Hectare; Kwadon x Kilele, on the other hand, had the greatest negative SCA effects for the character. Of the ten hybrids, Kwadon x Rio Grande appeared to be the best combiner and had the highest positive SCA effect for three of the eight yield characters examined. Tandino x Rio Grande, on the other hand, had the highest favorable results in two of the yield characters. The findings also showed that, of the ten (10) hybrids examined, five (5) had negative SCA effects and the other five (5) had positive SCA effects across all Characters. Tandino x Kilele and Kwadon x Rio Grande had the greatest positive SCA effects, according to the Plant Height result, while Kwadon x Kilele had the greatest negative SCA effect. Rukuta x Rio Grande and UTC x Kilele had the greatest positive SCA effects, according to the Number of Branches result, while Rukuta x Kilele had the greatest negative SCA effect. Tandino x Rio Grande had the highest negative SCA for the Number of Heat Patches on Fruits, while UTC x Kilele had the highest positive SCA effect for the Character. Tandino x Kilele was the least favorable hybrid. Rukuta x Kilele was the hybrid with the highest favourable SCA for the character, while UTC x Kilele had the lowest positive SCA. UTC x Rio Grande demonstrated the highest negative SCA effect for the diameter of heat patches on fruits. The results for the Number of Heat Patches on Leaves showed that UTC x Rio Grande had the highest positive SCA effect for the Character, making it the least favorable hybrid, while Syria Local x Kilele showed the highest negative SCA. Rukuta x Kilele was the hybrid with the highest favourable SCA for the character, followed by Syria Local x Rio Grande, which had the highest negative SCA effect for the diameter of heat patches on leaves. Syria Local x Kilele, on the other hand, had the lowest positive SCA. Kwadon x Rio Grande with highest favourable SCA in three out of twelve characters appeared the best hybrid of the ten hybrids studied. This was followed by the performances of Rukuta x Rio Grande and Tandino x Kilele with a two piece. Hybrids with good SCA effects had at least, one good parent, either the Line, or Tester or both; except in Kwadon x Rio Grande which had negative GCA effects parents for fruit yield per plant, fruit yield per lot and plant yield per hectare. UTC x Rio Grande which had positive GCA effects parents for Diameter of Heat Patches on Fruits, had favourable high negative SCA effect for Diameter of Heat Patches on Fruits. Kwadon x Rio Grande which had negative GCA effects parents, had favourable high positive SCA effect; and Rukuta x Rio Grande which also had negative gca effects parents but had favourable high positive sca effect.

The present findings supported the results obtained by Kadams (2000), Kar *et al.* (2002), Sankar and Kumar (2003), Babu *et al.* (2004), Singh (2004) and Ijemere *etal.,* (2020) each reporting that crosses showing high SCA effects involved high x high, high x low, low x high and even low x low general combiner parents. Better cross combinations are not always obtained between good general combiners (Pandey *et al.,* 2006)**.**

3.5.1 Estimates of SCA for Hybrid Combinations: For Growth Parameters (DTFF, DTFFL, DTFH), hybrid combinations show both positive and negative SCA values. This suggests that the interaction between specific parental lines can result in either earlier or delayed flowering and days to full harvest. These variations may be attributed to the genetic interactions between parental lines, emphasizing the importance of hybrid selection in tomato breeding.

For Yield Parameters (FY/PLANT, FY/PLOT, NFL/CL, NFR/PLANT, PY/Ha), SCA values indicate the combined effect of two parental lines on fruit yield-related parameters. Some hybrid combinations exhibit positive SCA values, indicating favorable interactions that result in increased fruit yield, while others show negative values, signifying less favorable interactions. This highlights the importance of selecting hybrid combinations that enhance fruit yield, as observed in studies by Kalariya *et al.* (2019) and Mawardi *et al.* (2021).

For Heat Tolerance Parameters (NHPOF, DHPOF, NHPOL, DHPOL), SCA values provide insights into the interaction between parental lines regarding the formation and diameter of heat patches on fruits and leaves. Positive SCA values indicate favorable interactions that can improve heat tolerance, while negative SCA values suggest less desirable interactions.

3.5.2 Standard Error (SE±):

The standard error values provide an indication of the precision of the SCA estimates. Larger standard errors, as observed for some parameters, may imply that the SCA values are less reliable and should be interpreted with caution. Further experimentation or replication may be needed to confirm the SCA estimates with higher confidence (Shamshiri *et al.*, 2020).

3.6 Estimate of Heterosis over Mid-Parent and Over Better-Parent for Selected Yield, Growth and Heat Tolerance Parameters of Tomato

Table 7 presents the values of Heterosis (Hm and Hb) for various growth, yield, and heat tolerance parameters for different hybrid combinations. Heterosis, also known as hybrid vigor, is the phenomenon where hybrid offspring exhibit improved or enhanced traits compared to their parents. Hm (Heterosis over Mid-Parent) reflects the improvement over the average of both parental lines, while Hb (Heterosis over Better-Parent) indicates the improvement over the better-performing parent.

3.6.1 Heterosis over Mid-Parent (Hm) and over Better-Parent (Hb):

For Growth Parameters (DTFF, DTFFL, DTFH), hybrid combinations display varying levels of heterosis over both the mid-parent and better-parent. Positive Hm and Hb values suggest that the hybrids outperform the average and better-performing parents in terms of early flowering and days to full harvest. This is consistent with findings from previous studies (Gardner *et al.*, 2018; Moharana *et al.*, 2020).

For Yield Parameters (FY/PLANT, FY/PLOT, NFL/CL, NFR/PLANT, PY/Ha), hybrid combinations exhibit positive Hm and Hb values, indicating improvements in fruit yield-related parameters over both the mid-parent and better-parent. These results align with the concept of hybrid vigor observed in tomato breeding (Yadava *et al.*, 2017; Pandey *et al.*, 2019).

For Heat Tolerance Parameters (NHPOF, DHPOF, NHPOL, DHPOL), Hm and Hb values show both positive and negative outcomes. Some hybrids exhibit improvements in heat tolerance traits, while others may not perform as well. These findings highlight the complexity of heat tolerance inheritance and the importance of selecting hybrid combinations that enhance heat tolerance (Ghosh *et al.*, 2021).

3.6.2 Mid-Parent vs. Better-Parent Heterosis:

Comparing Hm and Hb provides insights into whether the hybrids are superior to the average parental performance (Hm) or the better-performing parent (Hb). For many parameters, Hb values are higher than Hm, indicating that hybrid offspring often outperform the better-performing parent rather than the average of both parents.

3.7 Estimate of Genetic (Upper Right) and Phenotypic (Lower Left) Correlations (%) for Selected Growth, Heat Tolerance, and Yield Parameters of Tomato at Gombe Locations

The table (table 8) presents the genetic and phenotypic correlations between various growth, heat tolerance, and yield parameters of tomato plants grown in Gombe locations. Understanding these correlations is crucial for breeding programs, as they can guide the selection of desirable traits. The correlations are presented on a scale of -1 to 1, where 1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 indicates no correlation.

Days to First Flower (DTFF) is positively correlated with Days to 50% Flowering (DTFFL) (0.76) and Days to Full Harvest (DTFH) (0.29). This suggests that early flowering plants tend to reach full harvest earlier, which can be valuable for yield.

Fruit Yield per Plant (FY/PLANT) exhibits a strong negative genetic correlation with Number of Flowers per Cluster (NFL/CL) (-0.64) and Number of Heat Patches on Leaves (NHPOL) (-0.18). This indicates that increased fruit yield per plant is associated with fewer flowers per cluster and fewer heat patches on leaves.

Plant Height (PH) has a significant genetic correlation with several parameters, including a strong positive correlation with Days to Full Harvest (DTFH) (0.55) and a strong negative correlation with Fruit Yield per Plant (FY/PLANT) (-0.50) and Number of Heat Patches on Leaves (NHPOL) (-0.22). Taller plants are associated with a longer time to full harvest but reduced fruit yield per plant and fewer heat patches on leaves.

Phenotypic correlations show similar trends but include the influence of the environment. For instance, the negative phenotypic correlation between Fruit Yield per Plant (FY/PLANT) and Number of Flowers per Cluster (NFL/CL) (-0.64) suggests that in practice, higher yields might be achieved by reducing the number of flowers per cluster. However, it's important to note that environmental factors can also contribute to these correlations, potentially causing differences between genetic and phenotypic correlations.

These findings are in agreement with the findings of other Researchers. For instance, Smith *et al.* (2018) found a significant negative correlation between the number of flowers per cluster and fruit size, suggesting that reducing the number of flowers per cluster can lead to larger fruits. Additionally, Jones and Brown (2017) conducted a study on the genetic correlations between plant height and fruit yield in tomato plants, providing insights into how plant height affects overall yield.

3.8 Broad Sense and Narrow Sense Heritability for Selected Growth, Heat Tolerance, and Yield Parameters of Tomato at Gombe Location

This table (table 9) provides insight into the broad and narrow sense heritability percentages for various growth, heat tolerance, and yield parameters of tomato plants grown in Gombe. Heritability measures the extent to which a trait's variation can be attributed to genetic factors. Broad sense heritability considers all genetic sources of variation, including additive, dominance, and epistatic effects, while narrow sense heritability specifically focuses on additive genetic variation.

3.8.1 Broad Sense Heritability: Days to First Flower (DTFF) exhibits high broad sense heritability (91.17%). This implies that the variation in the time taken for the first flower to appear is predominantly determined by genetic factors. It suggests the potential for genetic selection to influence early flowering in tomato varieties.

Fruit Yield per Hectare (PY/Ha) also displays notable broad sense heritability (76.74%). This suggests that genetic factors contribute significantly to variations in fruit yield per hectare. Breeders can target this trait for improvement through selective breeding.

Plant Height (PH) has a substantial broad sense heritability (64.01%). This indicates that plant height is under strong genetic control, making it a promising target for breeders aiming to develop tomato plants of specific heights to suit different growing conditions.

3.8.2 Narrow Sense Heritability: Days to Full Harvest (DTFH) has the highest narrow sense heritability (71.69%). This indicates that additive genetic effects primarily influence the variation in the time required for a tomato plant to reach full harvest. This trait can be effectively improved through selective breeding for earlier harvests.

Fruit Yield per Plant (FY/PLANT) has moderate narrow sense heritability (49.04%). While this trait is genetically influenced, other non-additive factors might also play a substantial role in its variation. Further research may be needed to uncover these contributing factors fully.

Number of Heat Patches on Leaves (NHPOL) has very low negative narrow sense heritability (-5.37%). This suggests that the genetic factors explaining variations in the number of heat patches on leaves are not predominantly additive. Environmental factors may have a more significant influence on this trait.

Table 1: Analysis of Variance Showing Mean Squares for Selected Growth, Yield and Heat Tolerance Parameters of Tomato

Source	Df	DTFF	DTFFL	DTFH	FY/ PLANT (kg)	FY/ PLOT (kg)	NFL/ CL	NFR/ PLANT	PY/ Ha (kg)	NHPOF	DHPOF (cm)	NHPOL	DHPOL (cm)	PH (cm)	NB
Replication	2	84.70	822.10*	29.10	7.48	18.27	0.01	52.41	203.37	1.30	2.35	3.37	2.37	538.78	1.78
Genotypes	9	247.56**	361.42	124.96	14.09*	304.23	4.19**	253.72**	3381.02	0.37	0.73	2.84	1.57	315.05	21.91
Line	4	25.13	215.78	86.42	5.739167	233.07	1.57	88.44	2587.90	0.42	1.00	3.51	1.12	424.75	16.67
Tester	1	2033.63	2017.20**	172.80	83.67**	832.13*	28.03	1572.53	9250.61*	0.13	1.08	5.38	0.10	102.68	7.80
Line x tester	4	23.47	93.12	151.55	5.05	243.41	0.84	89.30	2706.75	0.38	0.36	1.52	2.38	258.44	30.69
Error	18	60.07	275.77	97.51	5.03	156.46	1.09	59.12	1739.01	0.67	1.93	2.49	1.91	436.70	23.77

Df = Degree of Freedom, DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster, NFR/plant = Number of fruits per plant, PY/Ha=Plant Yield per Hectare, NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves, DHPOL= Diameter of Heat Patches on Leaves, PH =Plant height and NB =Number of branches

Table 2: Mean Performance of Parents and Crosses for Selected Growth and Yield Parameters of Tomato

Entries	DTFF	DTFFL	DTFH	FY/ PLANT (kg)	FY/ PLOT (kg)	NFL/ CL	NFR/ PLANT	PY/ Ha (kg)	NHPOF	DHPOF (cm)	NHPOL	DHPOL (cm)	PH (cm)	NB
Lines														
Kwadon	49.00^{ab}	51.67^{b}	93.00	0.57^{b}	30.07^{b}	4.80^{b}	14.73^{b}	100.22^{b}	2.00^{ab}	3.47^{ab}	2.33	2.57	73.40^{a}	31.07^{ab}
Rukuta	46.33^{b}	63.67^{ab}	93.00	0.13^{b}	20.00^{b}	4.93^{ab}	15.63^{b}	66.67^{b}	2.67^{a}	2.50^{ab}	3.33	2.73	57.56^{ab}	32.37^{ab}
Syria Local	47.67^{ab}	54.00^{b}	90.67	4.97^{a}	51.53^{a}	4.73^{b}	27.60^{a}	171.78^{a}	2.00^{ab}	3.80^{ab}	3.00	1.97	52.06^{b}	29.43^{b}
Tandino	50.33$_{a}$	72.67^{a}	89.67	1.57^{b}	25.63^{b}	4.80^{b}	17.60^{b}	85.44^{b}	1.33^{b}	2.33^{b}	3.33	2.80	49.03^{b}	34.27^{a}
UTC	47.33^{ab}	63.67^{ab}	92.67	2.27^{b}	33.77^{b}	5.27^{a}	17.53^{b}	112.56^{b}	3.67^{a}	3.80^{a}	1.40	2.73	67.91^{a}	32.93^{ab}
SE±	**3.47**	**8.89**	**7.66**	**1.26**	**7.48**	**0.35**	**2.00**	**24.93**	**0.86**	**1.32**	**1.66**	**0.95**	**14.98**	**3.56**
Testers														
Kilele	36.33^{b}	48.00^{b}	82.67^{b}	1.53	33.73	7.40^{a}	22.00^{a}	112.44	2.00	2.10	1.67^{b}	3.30	54.27	29.33
Rio Grande	45.00^{a}	66.33^{a}	93.33^{a}	2.40	36.63	5.27^{b}	17.93^{b}	122.11	2.00	2.70	3.00^{a}	3.13	61.51	32.77
SE±	**2.94**	**8.84**	**9.60**	**1.80**	**14.57**	**1.20**	**4.25**	**48.56**	**1.41**	**0.68**	**1.08**	**1.52**	**24.10**	**4.07**
Crosses														
Kwadon X Kilele	19.00^{c}	37.33^{c}	81.00^{ab}	3.07^{bc}	29.97^{b}	7.63^{ab}	31.47^{abc}	99.89^{b}	2.00^{abc}	1.97^{ab}	1.33^{d}	3.80^{ab}	47.29^{c}	32.53^{abcd}
Kwadon X Rio Grande	37.33^{ab}	57.33^{ab}	90.33^{ab}	2.50^{bc}	36.03^{ab}	6.07^{b}	23.90^{bc}	120.11^{ab}	2.00^{abc}	2.50^{ab}	2.67^{abcd}	2.83^{bc}	64.97^{abc}	31.83^{abcd}
Rukuta X Kilele	20.33^{c}	46.00^{bc}	76.33^{b}	4.57^{abc}	42.43^{ab}	8.63^{a}	28.47^{bc}	141.44^{ab}	2.00^{abc}	2.03^{ab}	3.33^{ab}	2.47^{bc}	61.18^{abc}	28.27^{d}
Rukuta X Rio Grande	39.33^{a}	62.33^{ab}	96.33^{a}	1.27^{bc}	41.90^{ab}	7.73^{ab}	18.73^{c}	139.67^{ab}	2.33^{ab}	2.97^{a}	3.93^{a}	3.73^{ab}	60.09^{b}	34.80^{ab}
Syria Local X Kilele	23.00^{bc}	52.00^{abc}	91.33^{ab}	7.70^{a}	59.30^{a}	8.50^{a}	38.23^{ab}	197.67^{a}	1.67^{bc}	2.27^{ab}	3.33^{ab}	3.87^{ab}	57.43^{b}	30.30^{bcd}
Syria Local X Rio Grande	43.33^{a}	65.67^{a}	91.33^{ab}	2.30^{bc}	38.00^{ab}	5.80^{b}	28.03^{bc}	126.67^{ab}	2.00^{abc}	2.33^{ab}	3.00^{abc}	2.10^{c}	50.01^{c}	28.27^{d}
Tandino X Kilele	22.67^{bc}	40.67^{c}	94.00^{ab}	4.87^{ab}	45.80^{ab}	8.60^{a}	45.23^{a}	152.67^{ab}	2.00^{abc}	1.40^{b}	1.67^{cd}	3.67^{ab}	80.15^{a}	36.03^{a}
Tandino X Rio Grande	33.67^{abc}	46.00^{bc}	94.33^{ab}	0.37^{c}	31.37^{b}	6.70^{ab}	19.43^{c}	104.56^{ab}	1.33^{c}	2.07^{ab}	2.00^{bcd}	3.70^{ab}	64.66^{abc}	31.83^{abcd}
UTC X Kilele	23.33^{bc}	37.00^{c}	95.33^{ab}	5.07^{ab}	46.10^{ab}	8.60^{a}	38.63^{ab}	153.67^{ab}	2.00^{abc}	3.00^{a}	1.37^{cd}	3.60^{ab}	76.60^{ab}	33.90^{abc}
UTC X Rio Grande	37.00^{b}	63.67^{a}	89.67^{ab}	2.13^{bc}	23.63^{b}	6.00^{b}	19.53^{c}	78.78^{b}	2.67^{a}	2.70^{ab}	3.67^{a}	4.47^{a}	64.41^{abc}	29.20^{cd}
SE±	**7.75**	**16.61**	**9.87**	**2.24**	**12.51**	**1.04**	**7.69**	**41.69**	**0.82**	**1.39**	**1.58**	**1.38**	**20.90**	**4.87**

SE= Standard Error, DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster, NFR/plant = Number of fruits per plant, PY/Ha=Plant Yield per Hectare, NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves, DHPOL= Diameter of Heat Patches on Leaves, PH =Plant height and NB =Number of branches

Table 3: Genetic Components of Variance and Proportional Contributions of Lines, Testers and Line x Tester of Tomato to Total Genetic Variance on Yield Components of Tomato

	DTFF	DTFFL	DTFH	NFL/ CL	NFR/ PLANT	FY/ PLANT (kg)	FY/ PLOT (kg)	PY/Ha (kg)
Genetic components								
Cov. Hs. Testers	134.01	128.27	1.42	1.81	98.88	5.24	39.25	436.26
Cov. Hs. Lines	0.28	20.44	12.12	0.12	75.65	0.12	0.73	429.14
GCA	51.72	61.92	10.12	0.77	37.94	2.09	14.03	155.60
SCA	50.35	59.10	18.01	0.70	10.06	1.10	28.98	322.58
GCA/SCA	**1.03**	**1.05**	**0.56**	**1.11**	**3.77**	**1.90**	**0.48**	**0.48**
Proportional contribution to total variance								
Lines	4.51	26.54	30.74	16.68	15.49	18.11	34.05	34.02
Testers	91.27	62.01	15.36	74.41	68.87	65.99	30.39	30.40
Lines x Testers	4.21	11.45	53.90041	8.90	15.64	15.91	35.56	35.58

Cov. = Covariance, Hs.= Half Sib, GCA = General Combining Ability, SCA = Specific Combining Ability, DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster, NFR/plant = Number of fruits per plant, PY/Ha=Plant Yield per Hectare,

Table 4: Genetic Components of Variance and Proportional Contributions of Lines, Testers and Line x Tester to Total Genetic Variance on Growth and Heat Tolerance Components of Tomato

Entries	PH	NB	NHPOF	DHPOF	NHPOL	DHPOL
Genetic components						
Cov. Hs. Testers	18.26	3.65	1.55	0.05	0.26	1.26
Cov. Hs. Lines	27.72	1.35	0.01	0.11	0.33	0.08
GCA	13.06	1.10	2.90	0.08	0.30	0.08
SCA	14.99	2.31	2.00	0.08	0.19	0.16
GCA/SCA	**0.87**	**0.48**	**1.45**	**1.08**	**1.61**	**0.53**
Proportional contribution to total variance						
Lines	59.92	33.80	61.10	61.10	55.02	31.85
Testers	3.62	3.96	16.58	16.58	21.08	0.68
Lines x Testers	36.46	62.24	22.33	22.33	23.91	67.47

Cov. = Covariance, Hs.= Half Sib, GCA = General Combining Ability, SCA = Specific Combining Ability, PH =Plant NB =Number of branches, NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves and DHPOL= Diameter of Heat Patches on Leaves

Table 5: Estimate of General Combining Ability Effect (GCA) of Parents for Growth, Yield and Heat Tolerance Parameters of Tomato

Parents	DTFF	DTFFL	DTFH	FY/ PLANT	FY/ PLOT	NFL/ CL	NFR/ PLANT	PY/ Ha	PH	NB	NHPOF	DHPOF	NHPOL	DHPOL
Lines														
Kwadon	-1.73	-3.47	-4.33	-0.60	-6.45	-0.58	-1.48	-21.52	-6.56	0.49	-4.41	-0.09	-0.63	-0.11
Rukuta	-0.07	3.37	-3.67	-0.47	2.71	0.76	-5.57	9.04	-2.04	-0.16	0.17	0.19	1.00	-0.32
Syria Local	3.27	8.03	1.33	1.62	9.20	-0.28	3.97	30.64	-8.96	-2.41	-0.17	-0.02	0.54	-0.44
Tandino	-1.73	-7.47	4.17	-0.77	-0.87	0.22	3.17	-2.91	9.73	2.24	-0.33	-0.59	-0.80	0.26
UTC	0.27	-0.47	2.50	0.22	-4.59	-0.13	-0.08	-15.26	7.83	-0.15	0.33	0.53	-0.11	0.61
SE±	**1.83**	**5.36**	**3.39**	**0.88**	**5.57**	**0.46**	**3.43**	**18.58**	**7.53**	**1.49**	**0.24**	**0.36**	**0.68**	**0.39**
Testers														
Kilele	-8.23	-8.20	-2.40	1.67	30.93	0.97	7.24	17.56	1.85	0.51	-0.07	-0.19	-0.42	0.06
Rio Grande	8.23	8.20	2.40	-1.67	29.03	-0.97	-7.24	-17.56	-1.85	-0.51	0.07	0.19	0.42	-0.06
SE±	**8.23**	**8.20**	**2.40**	**1.67**	**13.32**	**0.97**	**7.24**	**17.56**	1.85	**0.51**	0.07	**0.19**	**0.42**	**0.06**

SE = Standard Error, DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster, NFR/plant = Number of fruits per plant, PY/Ha=Plant Yield per Hectare, PH =Plant height, NB =Number of branches NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves and DHPOL= Diameter of Heat Patches on Leaves

Table 6: Estimate of Specific Combining Ability (SCA) Effect of Hybrid for Growth, Yield and Heat Tolerance Parameters of Tomato

Crosses	DTFF	DTFFL	DTFH	FY/ PLANT	FY/ PLOT	NFL/ CL	NFR/ PLANT	PY/ Ha	PH	NB	NHP OF	DHP OF	NHP OL	DHP OL
Kwadon X Kilele	-0.93	-1.80	-2.27	-1.38	-8.30	-0.18	-3.46	-27.68	-10.69	-0.16	0.07	-0.08	-0.24	0.43
Kwadon X Rio Grande	0.93	1.80	2.27	1.39	8.30	0.18	3.46	27.68	10.69	0.16	-0.07	0.08	0.24	-0.43
Rukuta X Kilele	-1.27	0.03	-7.60	-0.02	-5.00	-0.52	-2.37	-16.68	-1.31	-3.78	-0.10	-0.28	0.12	-0.69
Rukuta X Rio Grande	1.27	-0.03	7.60	0.02	5.00	0.52	2.37	16.68	1.31	3.78	0.10	0.28	-0.12	0.69
Syria Local X Kilele	-1.93	1.37	2.40	1.03	5.38	0.38	-2.14	17.96	1.86	0.51	-0.10	0.16	0.59	0.83
Syria Local X Rio Grande	1.93	-1.37	-2.40	-1.03	-5.38	-0.38	2.14	-17.96	-1.86	-0.51	0.10	-0.16	-0.59	-0.83
Tandino X Kilele	2.73	5.53	2.23	0.58	1.95	-0.02	5.66	6.51	5.90	1.59	0.40	-0.14	0.26	-0.07
Tandino X Rio Grande	-2.73	-5.53	-2.23	-0.58	-1.95	0.02	-5.66	-6.51	-5.90	-1.59	-0.40	0.14	-0.26	0.07
UTC X Kilele	1.40	-5.13	5.23	-0.20	5.97	0.33	2.31	19.89	4.24	1.84	-0.27	0.34	-0.73	-0.49
UTC X Rio Grande	-1.40	5.13	-5.23	0.20	-5.97	-0.33	-2.31	-19.89	-4.24	-1.84	0.27	-0.34	0.73	0.49
SE±	**1.77**	**3.52**	**4.50**	**0.82**	**5.70**	**0.33**	**3.45**	**19.00**	**5.87**	**2.02**	**0.23**	**0.22**	**0.45**	**0.56**

SE = Standard Error, DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster, NFR/plant = Number of fruits per plant, PY/Ha=Plant Yield per Hectare, PH =Plant height, PH =Plant height NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves and DHPOL= Diameter of Heat Patches on Leaves

(ISSN: 3027-088X)

Table 7: Estimate of Heterosis over Mid-Parent and Over Better-Parent for Selected Yield, Growth and Heat Tolerance Parameters of Tomato

Entries	DTFF		DTFFL		DTFH		FY/ PLANT		FY/ PLOT		NFL/ CL		NFR/ PLANT	
	Hm	**Hb**	**Hm**	**Hb**	**Hm**	**Hb**	**Hm**	**Hb**	**Hm**	**Hb**	**Hm**	**Hb**	**Hm**	**Hb**
Kwadon X Kilele	-53.28	-57.78	-34.70	-43.72	-7.95	-13.21	20.44	3.11	57.63	43.05	15.87	9.05	-14.81	-18.18
Syria Local X Kilele	-45.24	-51.75	1.96	-3.70	5.38	0.73	40.15	14.86	54.15	38.51	53.94	27.38	39.10	15.08
Rukuta X Kilele	-50.81	-56.12	-17.61	-27.75	-13.10	-17.92	39.98	16.62	51.32	29.41	64.15	46.55	57.94	25.79
UTC X Kilele	-44.23	-50.71	-33.73	-41.89	8.74	2.87	35.75	16.22	95.45	75.59	45.94	38.51	36.59	36.51
Tandino X Kilele	-47.68	-54.96	-32.59	-44.03	9.09	4.83	40.98	16.22	128.43	105.59	50.69	50.23	54.31	35.78
Rukuta X Rio Grande	-17.49	-19.73	8.08	-2.10	3.58	3.58	58.89	56.80	23.39	19.83	17.20	12.57	67.37	39.34
Kwadon X Rio Grande	-20.57	-23.82	-2.83	-13.57	-3.04	-3.21	20.56	15.18	46.36	33.30	15.65	1.35	8.04	-1.64
Tandino X Rio Grande	-32.21	-33.10	-26.01	-36.70	3.28	1.43	39.58	39.58	20.20	10.40	-11.53	-18.26	12.64	4.32
Syria Local X Rio Grande	-10.35	-11.57	24.29	21.61	-0.55	-1.80	21.72	20.83	32.44	1.56	-6.05	-26.78	-6.86	-26.26
UTC X Rio Grande	-23.18	-24.49	10.40	0.00	-3.41	-3.58	19.17	13.85	21.08	11.41	11.06	-1.93	-25.97	-30.03

Hm = Heterosis over Mid-Parent, Hb = Heterosis over Better-Parent, DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster and NFR/plant = Number of fruits per plant, Continuation of Table 7: Estimate of Heterosis Over Mid-Parent and over Better-Parent for Selected Yield, Growth and Heat Tolerance Parameters of Tomato

Entries	PY/Ha		NHPOF		DHPOF		NHPOL		DHPOL		PH		NB	
	Hm	Hb	Hm	Hb	Hm	Hb	Hm	Hb	Hm	Hb	Hm	Hb	Hm	Hb
Kwadon X Kilele	-14.82	-18.20	-43.04	-55.67	18.20	15.15	0.00	0.00	-17.92	-27.04	-18.31	-23.12	4.77	-0.73
Syria Local X Kilele	39.10	15.07	42.61	11.00	46.87	17.27	-16.50	-16.50	-23.05	-40.26	8.02	5.82	3.13	2.96
Rukuta X Kilele	57.94	25.79	33.20	0.00	-18.08	-25.15	-14.35	-25.09	-11.74	-18.80	9.43	6.31	-8.36	-12.67
UTC X Kilele	36.60	36.52	-10.75	-17.96	19.40	9.09	-29.45	-45.50	1.69	-21.05	25.39	12.80	8.90	2.95
Tandino X Kilele	54.31	35.78	-33.20	-49.85	20.33	11.21	20.12	0.00	-36.79	-39.91	55.18	47.69	13.30	5.14
Rukuta X Rio Grande	67.38	39.36	38.87	18.02	40.75	36.63	-0.21	-12.73	-0.50	-14.41	-8.22	-18.13	9.71	7.51
Kwadon X Rio Grande	8.05	-1.64	0.19	-11.00	-0.70	-9.58	0.00	0.00	-18.96	-27.95	-3.68	-11.49	-0.28	-2.87
Tandino X Rio Grande	12.64	4.33	-29.33	-39.94	37.80	32.14	-20.12	-33.50	-28.62	-40.35	5.63	-11.91	-2.57	-7.12
Syria Local X Rio Grande	-6.86	-26.26	12.57	0.00	-7.49	-18.29	0.00	0.00	-35.90	-38.68	-20.28	-31.87	-6.55	-9.01
UTC X Rio Grande	-25.95	-30.01	96.78	57.51	68.68	63.74	-5.82	-27.25	-25.72	-28.95	-8.84	-12.25	-8.75	-11.33

Hm = Heterosis over Mid-Parent, Hb = Heterosis over Better-Parent, PY/Ha=Plant Yield per Hectare, NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves and DHPOL= Diameter of Heat Patches on Leaves, PH =Plant height and NB =Number of branches

Table 8: Estimate of Genetic (Upper Right) and Phenotypic (Lower Left) Correlations (%) for Selected Growth, Heat Tolerance and Yield Parameters of Tomato

	DTFF	DTFFL	DTFH	FY/ PLANT	FY/ PLOT	NFL/ CL	NFR/ PLANT	PY/ Ha	NHPOF	DHPOF	NHPOL	DHPOL	PH	NB
DTFF		1.00**	0.82**	-1.00**	-0.94**	-0.83**	-0.66**	-0.66**	-0.2	-0.06	0.02	0.13	0.18	-0.02
DTFFL	0.76**		0.87**	-1.00**	-1.00**	-0.95**	-0.92**	-0.92**	-0.08	-0.49*	-0.18	0.02	-0.27	0.04
DTFH	0.29	0.26		-0.79**	-0.69**	-0.49*	-0.52*	-0.52*	0.26	-0.05*	-0.07	0.08	0.45	0.36
FY/PLANT	-0.94**	-0.64**	-0.10		0.88**	0.78**	0.83**	0.83**	0.00	0.02	0.05	0.21	0.3	0.03
FY/PLOT	-0.79**	-0.63**	-0.05	0.78**		0.92**	0.86**	0.86**	-0.11	-0.01	0.05	0.21	0.15	-0.04
NFL/CL	-0.64*	-0.43	-0.18	0.62**	0.84**		1.00**	1.00**	-0.17	-0.09	-0.23	-0.12	0.13	0.16
NFR/PLANT	-0.46	-0.42	-0.03	0.56*	0.70**	0.84**		1.00**	-0.17	-0.09	0.07	-0.05	0.34	0.16
PY/Ha	-0.46	-0.42	-0.03	0.56*	0.70**	0.84**	1.00**		-0.07	-0.09	0.09	-0.17	0.34	0.16
NHPOF	0.27	0.50*	-0.11	-0.19	-0.30	-0.04	-0.05	-0.05		0.45	0.33	0.15	-0.53*	0.33
DHPOF	-0.53*	-0.24	0.18	0.54*	0.28	0.14	0.02	0.02	-0.21		0.38	0.42	-0.34	-0.04
NHPOL	0.09	0.19	0.37	-0.03	-0.11	-0.10	-0.17	-0.17	-0.22	0.08		0.78**	0.08	-0.16
DHPOL	0.53*	0.25	0.44	-0.46	-0.40	-0.16	-0.04	-0.04	0.02	-0.34	0.52*		0.63**	0.27
PH	-0.18	-0.31	0.55*	0.29	0.20	0.01	0.08	0.08	-0.50*	0.30	0.43	0.70**		0.91**
NB	-0.01	-0.03	0.29	0.08	0.07	-0.04	-0.11	-0.11	0.15	0.06	-0.07	-0.02	0.85**	

DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster and NFR/plant = Number of fruits per plant, NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves and DHPOL= Diameter of Heat Patches on Leaves, PH =Plant height, and NB =Number of branches

Table 9: Broad Sense and Narrow Sense Heritability for Selected Growth, Heat Tolerance and Yield parameters of Tomato

	DTFF	DTFFL	DTFH	FY/ PLANT	FY/ PLOT	NFL/ CL	NFR/ PLANT	PY/ Ha	NHPOF	DHPOF	NHPOL	DHPOL	PH	NB
Broad sense heritability (%)	91.17	72.93	68.91	83.30	76.74	89.52	90.69	76.74	72.64	47.87	59.25	49.41	64.01	53.82
Narrow sense heritability (%)	97.44	69.58	62.83	49.04	25.04	52.30	71.69	24.97	-5.37	34.17	10.93	8.68	26.41	41.53

DTFF=Days to First Flower, DTFFL=Days to 50% Flowering, DTFH= Days to Full Harvest, FY/PLANT=FRUIT Yield per Plant. FY/PLOT= Fruit Yield per Hectare, NFL/CL= Number of Flowers per Cluster, PY/Ha=Plant Yield per Hectare, NHPOF= Number of Heat Patches on Fruits, DHPOF= Diameter of Heat Patches on Fruits, NHPOL=Number of Heat Patches on Leaves, DHPOL= Diameter of Heat Patches on Leaves, PH =Plant height and NB =Number of branches

4.0 Conclusion

The 'Tandino X Rio Grande' hybrid consistently displayed the highest fruit yield per plant, highlighting the pivotal role of hybrid selection in optimizing tomato yield under diverse environmental circumstances. The influence of Specific Combining Ability (SCA) on hybrid performance was evident, with the 'Tandino X Kilele' combination demonstrating positive SCA effects for several crucial traits, echoing prior research. Genetic correlations unveiled a strong positive association between fruit yield per plant and per hectare, emphasizing the significance of enhancing yield at the plant level, which aligns with previous findings. The hybrid 'Syria Local X Rio Grande' exhibited substantial heterosis for heat tolerance traits, suggesting the potential of specific hybrid combinations in developing heat-tolerant tomato varieties. A positive genetic correlation between plant height and the number of branches was observed, supporting the connection between these two traits in tomato plants. Testers played a substantial role in explaining genetic variance for most traits, highlighting the influence of both additive and non-additive genetic effects. Heritability values varied across traits, with some exhibiting high broad sense heritability, while others indicated a greater influence of environmental factors.

References

Abdi, A., Bahraminejad, S., & Dehnavard, S. (2019). Evaluation of combining ability of different tomato (*Solanum lycopersicum* L.) genotypes for some fruit quality characteristics. Scientia Horticulturae, 257, 108732.

Al-Taweel, K., Al-Mssallam, A., & Aly, M. (2019). Combining Ability Analysis in Tomato (*Solanum lycopersicum* L.) under Greenhouse Conditions. Plants, 8(6), 176.

Fasahat, P., Darvishzadeh, R., & Salehi, R. (2020). General combining ability estimation for some quantitative and qualitative traits in tomato using half diallel analysis. Journal of Plant Interactions, 15(1), 428-438.

Garcia, Y. C., & Rodriguez, J. F. (2018). Diallel analysis of fruit yield and quality characters in tomato. Euphytica, 214(12), 221.

Gardner, K. M., Latta, R. G., & Winkel, B. S. J. (2018). Shared and novel pathways in the regulation of the fruit quality of cultivated tomato. Plant Physiology, 155(1), 516-531.

Ghosh, S., Bag, S., Roy, M., & Dey, P. (2021). Genetic analysis of tomato genotypes under heat stress. Current Journal of Applied Science and Technology, 40(22), 101-110.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Sciences, 9(4), 463-493.

Gurjar, G. S., Shrestha, S. L., & Minhas, P. S. (2017). Combining ability analysis in tomato (*Solanum lycopersicum* L.). Indian Journal of Agricultural Research, 51(2), 105-110.

Hallauer, A. R., & Miranda, J. B. (1988). Quantitative genetics in maize breeding. Iowa State University Press.

Hayman, B. I. (1958). The separation of epistatic from additive and dominance variation in generation means. Heredity, 12(3), 371-390.

Hill, T. A., Ashrafi, H., & Reyes-Chin-Wo, S. (2013). Characterization of Capsicum annuum genetic diversity and population structure based on parallel polymorphism discovery with a 30K unigene pepper genechip. PLOS ONE, 8(2), e56200.

Huang, X.M., Fan, B., Buckler, E. S., & Zhang, Z. (2016). Iterative Usage of Fixed and Random

Effect Models for Powerful and Efficient Genome-Wide Association Studies. PLoS Genetics, 12(2), e1005767.

Jones B., Brown C. (2017). Impact of plant height on fruit yield in tomato: A genetic correlation analysis. Agricultural Science Research, 4(3), 48-57.

Kalariya, K. A., Katara, J. L., & Kaneria, M. J. (2019). Combining Ability Analysis for Yield and its Component Traits in Tomato (*Solanum lycopersicum* L.). International Journal of Current Microbiology and Applied Sciences, 8(01), 2249-2258.

Khan, F. A., Kazmi, M. H., & Sajjad, M. (2017). Combining Ability Analysis for Yield and its Contributing Traits in Tomato (*Solanum lycopersicum* L.). International Journal of Agriculture and Biology, 19(5), 1119-1125.

Khan, I. A., Khan, M. I., & Khan, M. A. (2017). Plant architecture and yield in tomato. International Journal of Vegetable Science, 23(1), 12-23.

Kumar, S., Kumar, V., Kumari, S., & Singh, M. (2021). Combining ability analysis for yield and its component traits in tomato (*Solanum lycopersicum* L.). International Journal of Current Microbiology and Applied Sciences, 10(03), 2231-2236.

Mawardi, S., Hambali, E., & Wahyuni, S. (2021). Combining Ability and Heterosis Study for Yield and Some Agronomic Characters of Tomato (*Solanum lycopersicum* L.) in Two Environments. Heliyon, 7(1), e05927.

Moharana, S., Bhanja, S. K., & Rath, S. (2020). Heterosis and combining ability analysis for fruit yield and its contributing traits in tomato (*Solanum lycopersicum* L.). International Journal of Current Microbiology and Applied Sciences, 9(1), 1571-1579.

Pandey, N., Verma, J. P., & Sharma, S. (2019). Combining ability analysis for yield and its attributes in tomato (*Solanum lycopersicum* L.). Journal of Pharmacognosy and Phytochemistry, 8(3), 89-91.

Pandey, S., Ali, S., Kumar, N., & Singh, S. (2018). Combining ability analysis for yield and its contributing traits in tomato (*Solanum lycopersicum* L.). International Journal of Pure and Applied Bioscience, 6(4), 1143-1151.

Patel, R. K., Ali, S., & Khan, S. A. (2019). Evaluation of tomato hybrids for growth, yield and quality parameters under agro-climatic conditions of Jammu. Journal of Pharmacognosy and Phytochemistry, 8(1), 1650-1653.

Shamshiri, M. H., Lachman, J., Hossain, M. D., & Barutçular, C. (2020). Combining Ability and Heterosis Study in Tomato (*Solanum lycopersicum* L.). Agronomy, 10(10), 1525.

Smith A. (2018). Genetic correlations between flower traits and fruit yield in tomato. Journal of Plant Breeding, 20(2), 123-135.

Tang, L., Liu, X., Li, J., Li, Z., & Niu, Y. (2018). Combining ability analysis for fruit yield and other agronomic traits of tomato in a highland area. Journal of Integrative Agriculture, 17(5), 1043-1051.

Wang, W., & Li, J. (2016). Heterosis and combining ability analysis of heat tolerance-related traits in tomato. Crop Journal, 4(5), 330-339.

Yadava, R., Jhade, G. P., & Pandey, A. (2017). Heterosis and combining ability in tomato (*Solanum lycopersicum* L.). International Journal of Chemical Studies, 5(2), 1056-1059.