COMBINING ABILITY AND HETEROSIS FOR FRUIT YIELD AND HEAT TOLERANCE IN TOMATO (*LYCOPERSICON LYCOPERSICUM* Mill.) UNDER FIELD CONDITIONS

BY

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DECLARATION

I declare that the work in this dissertation entitled "HETEROSIS AND COMBINING ABILITY FOR FRUIT YIELD AND HEAT TOLERANCE IN TOMATO (*LYCOPERSICON LYCOPERSICUM* Mill.) UNDER FIELD CONDITIONS" has been carried out by me in the Department of Plant Science. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

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CERTIFICATION

This dissertation entitled "HETEROSIS AND COMBINING ABILITY FOR FRUIT YIELD AND HEAT TOLERANCE IN TOMATO (*LYCOPERSICON LYCOPERSICUM* Mill.) UNDER FIELD CONDITIONS" by Habu Saleh HAMISU meets the regulations governing the award of the degree of Master of Science in Plant Breeding of Ahmadu Bello University, and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This work is dedicated to my Late Father, Alhaji Hamisu Yusuf Gozo and my mother Hassana Mansur.

ABSTRACT

Heat stress causes significant fruit yield loss in tomato (*Lycopersicon lycopersicum* Mill.). Breeding of tomato hybrids tolerant to high temperature will reduce fruit yield losses caused by heat stress in Nigeria. The genetics of heat tolerance in tomato was studied using half diallel mating design of six parents comprising two heat tolerant and four heat susceptible varieties. The resultant 15 hybrids, with the 6 parents and 4 checks were evaluated at two locations: Bagauda and Samaru under heat stress condition between July-October, 2014 rainy season. Data collected on agronomic, heat tolerance and physiological characters were used to determine heterosis, combining ability, heritability and correlations under field conditions. Analysis of variance indicated highly significant ($P < 0.01$) differences among the genotypes for most traits. Significant level of heterosis were observed in crosses Icrixina × Rio Grande, Icrixina × Roma Savana, Icrixina × Tima, Icrixina × Petomech and Petomech × Roma Savana which ranged from -551.00 to 80.82% and from -31.81 to 120.80% for fruit yield and percentage fruit set, respectively. Combining ability analysis revealed that both additive and non-additive gene action were important for the inheritance of the number of clusters per plant, number of flowers per plant, number of fruits per plant, fruit length, fruit yield per plant and percentage fruit set. However, the variance components due to SCA were higher in magnitude than the GCA variance components for all traits except number of fruits per cluster and fruit length, indicating preponderance of non-additive gene action in the inheritance of the traits. Estimates of gca effects revealed that the parent Icrixina was a good general combiner for all traits except plant height, average fruit weight, fruit diameter and leaf chlorophyll content. The estimates of sca effects of

crosses indicated that Icrixina × Rio Grande, Icrixina × Tima, and Petomech × Roma Savana were the most desirable cross combinations for fruit yield per plant and percentage fruit set indicating that they are more heat tolerant. Cell membrane thermostability and heat injury at 30^{o}C, 40^{o}C and 50^{o}C exhibited significant variations among the genotypes for electrolyte leakage at flowering stage, suggesting that cell membrane thermostability was good index for screening and evaluating tomato genotypes for heat tolerance. The genotypes Icrixina, Icrixina × Tropimech, Rio Grande × Tropimech, Rio Grande × Roma Savana and Rio Grande × Petomech were heat tolerant. Broad sense heritability was high for all traits, while narrow sense heritability was low to moderate for most of the traits. Correlation results suggests that selection for number of flowers per plant, number of fruits per plant, leaf chlorophyll content and cell membrane thermostability would increase fruit yield per plant and percentage fruit set under high temperature, but with a reduction in days to flowering, average fruit weight and fruit size.Icrixina × Rio Grande and Icrixina × Tima gave higher yields per plant compared with the hybrids checks. Therefore, considering the predominance of non-additive gene action and large negative genetic association between percentage fruit set and fruit size, heterosis breeding could be exploited in developing heat tolerant tomato with acceptable fruit size.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Tomato: Origin, Distribution and Domestication

Tomato (*Lycopersicon lycopersicum*) belongs to the family Solanaceae, genus Lycopersicon, sub family Solanoideae and tribe Solaneae where pepper, potato, tobacco, eggplant and tomatillo belong (Taylor, 1986). Tomato is a perennial, but usually grown as an annual plant. All tomato species are diploid (2n=24). Tomato originated from South America where it was first cultivated in 700AD and all related wild species of tomato are native to the Andean region that includes part of Colombia, Ecuador, Chile, Bolivia and Peru (Sims, 1980). Spanish explorer introduced tomato into Spain and later took it to Morocco and Europe in the early 16th century (Harvey *et al.*, 2002). Europeans took tomato to China, South and South-East Asia, Japan and U.S.A in the 18th century (Siemonsma and Piluek, 1993). It was introduced to West African region by Portuguese traders and colonialists (Tindall, 1977). Tomato came to Southern Nigeria through the Portuguese trader who first arrived in Benin, Bendel State (Denton and Swarup, 1983). Tomato was initially grown as ornamental plant; the fruit was considered poisonous because it is closely related to deadly nightshade (*Solanum dulcamara*). However, the production and consumption of tomato expanded rapidly in U.S.A in 19th century and by the end of this century processed products such as tomato ketchup, tomato soup and tomato sauce were regularly consumed (Harvey e*t al.*, 2002). In Nigeria, the major producing area of tomato lies between latitudes 7.5^{o} 11´ and 13.0 ^{o} N and within a temperature range of 22-30^{o}C. It is now one of the most popular and widely grown vegetables around the world and used as a second vegetable throughout the world after potato (FAOSTAT, 2005). Tomato is adapted to a wide range of climatic

conditions from temperate to hot and humid tropic. It requires a relatively cool and dry climate for high yield and premium fruit quality.

1.2 Importance of Tomato

Tomato is widely produced and consumed ranks as second most important vegetable after potato in the world (FAOSTAT, 2005). It is one of the most important vegetables in Asia and Africa and these two continents account for more than 65% of global production (Srinivasan, 2010). Tomato is very rich in vitamins (vitamin A and B), minerals (iron and phosphorus), essential amino acids, sugars and dietary fibers. It contains high level of lycopene, an antioxidant that reduces the risk associated with several cancers and neurodegenerative diseases (Srinivasan, 2010). The fruits are consumed fresh in salads or cooked in sauces, soup and fish or meat dishes (Shankara *et al.*, 2005) and processed into tomato soup, sauces, chilli sauces, ketchup, powder, flakes, juice, pulp, purèe, paste and pickled (Kinet and Peet, 1997). Tomato is commonly used as a 'model crop' for diverse physiological, biochemical, cellular, molecular, genetics, seed development, germination and dormancy studies due to its short life cycle (Suhartanto, 2002). Therefore, tomato is an excellent tool for improved knowledge of horticultural crops (Taylor, 1986; Kinet and Peet, 1997).

1.3 Constraints to Tomato Production

Tomato can be grown in a wide range of climatic conditions from temperate to hot and humid tropical regions (Shankara *et al.,* 2005). Despite its widespread cultivation and importance, abiotic factors such as high temperature, drought, salinity and minerals imbalance are the major causes of fruit yield reduction in sahelian and sudanian zone of Africa (Adams and Osei, 2006). High temperature during the growing season

(30 - 35^{o}C) is detrimental to growth and reproductive development which reduces fruit set, fruit size, yield and fruit quality (Abdul-Baki, 1991; Dane *et al.,* 1991; Wessel-Beaver and Scott, 1992; Scott, 2000).

1.4 Research Problem

Tomato is usually grown under irrigation during the harmattan and in the rainy season in Nigeria. High temperature during rainy season and increases of temperature by the end of the harmattan season cause significant reduction in fruit size, increment in flower abortion and decrease in fruit set which reduce fruit yield. High temperature during the growing season has been reported to be detrimental to growth, reproductive development and yield of crops including tomato (Hall, 1992; Hussain *et al.,* 2006; Singh *et al.,* 2007). Heat stress in the form of high temperature (>30^{o}C) beyond a threshold level for some time has been enough to cause irreversible harm to crop growth and improvement (Faruq *et al.,* 2012). Heat stress becomes a major limiting factor for field production of tomatoes (Foolad, 2007). Camejo *et al.* (2005) reported that the optimum temperatures for tomato cultivation are between 25 and 30^{o}C during photoperiod and 20^{o}C during the dark period and an increase of 2-4^{o}C over the optimal temperature adversely affects gamete development and inhibits the ability of pollinated flowers to develop into fruits and thus reduced fruit yield (Peet *et al.,* 1997; Sato *et al.,* 2001; Firon *et. al.,* 2006). Heat stress causes bud drop, abnormal flower growth, poor pollen creation, poor inflorescence and viability, ovule abortion and reduced carbohydrate content in tomato (Hazra *et al.,* 2007). According to Hanna and Hernandez (1982) and Berry and Rafique-Uddin (1988) high temperature (>30^{o}C) during reproductive development caused significant increment in flower drop and

significant decrease in fruit set. This situation necessitates research programme for the development of tomato cultivars tolerant to high temperature stress.

1.5 Research Justification

Heat tolerance is a critical character of tomato genotypes targeted for production in the tropics and sub-tropics where they often experience high temperature during fruit set. Intergovernmental Panel on Climatic Change (IPCC) reported that in each decade, worldwide temperature will be enhanced by 0.3^{o}C and reached to around 1^{o}C and 3^{o}C higher than the current temperature by the years 2025 and 2100, respectively (IPCC, 2001). According to Odjugo (2010) the mean air temperature in Nigeria from 1901 to 2005 was 26.6 ^{o}C, while the temperature increased in Nigeria for 105 years was 1.1^{o}C which is higher than the global mean temperature increase of 0.74^{o}C. Nigeria temperature will rise by 2.5^{o}C and 4.5^{o}C by the year 2100 (NIMET, 2011). Presently cultivated tomato varieties in the country are susceptible to high temperature, which limits tomato production, causing shortage of supply and high cost during the rainy season. Therefore, genetic improvement of tomato to tolerate heat and produce economic yield can be an economically viable solution for tomato production under high temperature environments. The progress of genetic improvement for heat tolerance depends on an understanding of the genetic basis of heat tolerance and association of various characters conferring heat tolerance. However, limited information is available regarding genetic basis and association of various characters conferring heat tolerance in tomato.

1.6 Research Objectives

The study was designed to:

1. Estimate the general combining ability and specific combining ability for fruit yield and heat tolerance in tomato.
2. Estimate heterosis for fruit set, fruit yield and heat tolerant traits.
3. Characterize tomato genotypes for heat tolerance
4. Determine heritability and association between fruit set, fruit yield and heat tolerant traits.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany

Tomato is a perennial, but usually grown as an annual plant. It is a branching herbaceous plant with hairy and trailing stem. The leaves are hairy and vary in size (15-50cm length and 10-30 cm width), leaflets are ovate to oblong covered with glandular hairs, while petiole is 3-6 cm and inflorescence is clustered and produce 6-12 flowers (Tindall, 1977). Calyx tube is short and hairy while the sepals are persistent and petals are yellow and reflexes when matured (up to 1cm in length). Anthers are bright yellow in colour surrounding the style with an elongated sterile tip. The flowers are bisexual, regular (1.5-2cm) and usually grow opposite or between leaves. Fruits are fleshy berry, globular to oblate in shape which vary in size (2-5cm in diameter) and its colour ranging from red, pink or yellow when ripe. The seeds are kidney or pear shape, hairy and light brown (3-5mm long and 2-4mm wide). It has a vigorous tap root that grows up to a depth of 50cm or more (Taylor, 1986). All tomato species are diploid (2n=24).

2.2 Heat Tolerance in Tomato

Heat stress is defined as the increase in temperature beyond a threshold level for an interval of time sufficient to cause irreparable damage to plant development (Rafiq *et al.*, 2013). In general, an increase in temperature usually 10-15^{o}C above ambient temperature (28-29^{o}C) is considered as heat stress. Sato *et al.* (2006) reported that heat stress in tomato primarily affects reproductive development, causing excessive flower abortion, which lead to low fruit production. Heat tolerance is the ability of plant to

grow and produce an economic yield under high temperature (Kamel *et al.,* 2010). Heat tolerance in tomato can be defined as the ability to set fruit under night temperature not lower than 21^{o}C (Villareal, 1978). Other research scientists have argued that day and night temperatures may not affect tomato fruit set independently, and that diurnal temperature is a better predictor of plant response to high temperature, with a day temperature having secondary role and the percent fruit set in tomato decreased as the mean diurnal temperature rose above 25^{o}C and was severely impaired at 29^{o}C (Peet and Bartholomew, 1996; Peet *et al.*, 1997; Peet and Willits, 1998; Peet, *et al.*, 1998). Camejo *et al.* (2005) reported that, the optimum temperature for tomato cultivation range between 25^{o}C and 30^{o}C during photoperiod and 20^{o}C during dark and an increase of 2 - 4^{o}C over optimal temperature adversely affects gamete development and inhibits the ability of pollinated flowers to develop into fruits and thus reduced fruit yield (Peet *et al.,* 1997; Sato *et al.,* 2001; Firon *et al.,* 2006). Heat tolerance is connected to membrane stability, alteration of membrane lipid composition, accumulation of heat stock protein and specific solutes (proline and glycine) especially in pollen (Blum, 1988). Heat stress of 5-10^{o}C above the normal growing temperature induces expression of a specific gene families called heat shock genes (*hsps*). These heat shock genes lead to synthesis of a new set of proteins called heat shock proteins (HSPs) which lead to acquired thermotolerance. Tomato crop which suffers from heat stress, the heat shock proteins gather into a granular structure in the cytoplasm, preserving the protein bioproduction machinery (Miroshnichenko *et al.,* 2005). A heat shock proteins (HSP 68) located in mitochondria was detected to enhance thermotolerance under heat stress

in tomato (Neumann *et al.,* 1993). The gene for a nuclear encoded heat shock protein (Has32) that encodes a 32KDa protein has been cloned in tomato (Liu *et al.,* 2006).

2.3 Responses of Tomato to Heat Stress

2.3.1 Anatomical and Morphological Responses

High temperature results in change in the organization of cellular structures including organelles and membrane function tomato. It influences markedly plant anatomy at tissue and cellular level and the impact of these changes as a result of high temperature stress can lead to slow crop growth and reduced yield (Wahid *et al.,* 2007). Abdelmageed and Gruda (2009a,b) reported that morphological traits such as number of fruits, number of flowers per plant, fresh fruit weight and percentage fruit set were diverse in heat resistant and heat susceptible tomato lines. High temperature can lead to remarkable pre- and post-harms, involving burning of twigs and leaves, sun burns, senescence of leaf and abscission, prohibition on development of shoot and root, discoloration of fruit, and reduced production (Guilioni *et al.,* 1997; Ismail and Hall, 1999; Vollenweider and Gunthardt-Goert, 2005).

2.3.2 Reproductive Responses

Reproductive processes in tomato crop are more susceptible to high temperature stress than vegetative processes (Lahar and Peet, 1998; Abdelmageed *et al.,* 2003; Alsadon *et al.,* 2006). Peet *et al.* (1997) observed that heat stress affects meiosis, pollen germination, ovule development, viability of the embryo. Heat stress can occur at a temperature higher than 35^{o}C, such elevated temperature become a major barrier for germination of seed, vegetative growth, flowering stage, fruit set and ripening in tomato (Miller *et al.,* 2001). Thomas and Prassad (2003) reported that pollen viability and

production are susceptible to small rises in temperature higher than the medium. Foolad (2005) revealed that meiosis in male and female organs, germination of pollen and development of the pollen tube, the viability of ovule, style and stigmatic situation, the pollen grains number that are maintained by the stigma, fertilization and post-fertilization trends, endosperm development and pre-embryo stage are influenced by high temperature in tomato. However, the most effect of high temperature on the reproductive stage of tomato is the production of an exerted style (stigma elongated beyond the anther cone) that may prevent self-pollination. Fruit set stopped at high temperature as a result of flower abortion, reduced pollen production, irregular flower development, dehiscent, ovule abortion and insufficient viability and less availability of carbohydrate (Hazra *et al.,* 2007).

2.3.3 Physiological Responses

The important physiological reactions to heat stress in tomato are crop water relationship, concentration of compatible osmolytes, photosynthesis, alteration in hormones and cell membrane thermostability (Blum, 1988). Crop water status is the most important variable under changing ambient temperature (Mazorra *et al.,* 2002). The high temperature causes more water loss in plants during daytime than nighttime and the plant tends to maintain stable tissue water status regardless of temperature when moisture is abundant. However, high temperature severely impairs this tendency when water is limiting (Mochado and Paulsen, 2001). Morales *et al.* (2003) concluded that heat stress in tomato disturbed hydraulic conductivity of root and water relationships.

Concentration of compatible osmolytes is an adaptive mechanism in crop plant grown under abiotic stress, such as extreme temperature, salinity and drought. Accumulation of

certain organic compounds of low molecular mass is known as compatible osmolytes (Hare e*t al.*, 1998; Sakamoto and Murata, 2002). Under high temperature, the plant may accumulate different types of osmolytes such as sugar and sugar alcohols (polyols), proline, tertiary and quaternary ammonium compounds, tertiary sulphonium compounds and accumulation of such solute may contribute to enhanced stress tolerance of plant (Sairam and Tyagi, 2004). Sato *et al.* (2006) observed that under high temperature, fruit set in tomato plant failed due to the disruption of sugar metabolism and proline transport during a narrow window of male reproductive development.

Photosynthesis is highly sensitive to high temperature (Wang *et al.*, 2010; Centritto *et al.*, 2011). The photosynthetic apparatus and associated metabolic processes are heat sensitive and heat induces inhibition of photosynthetic CO_2 fixation in plant species (Berry and Bjorkman, 1980). High temperature stress decreased leaf chlorophyll content (Prasad, *et al.*, 2008a, b; Djanaguiraman *et al.*, 2011). Reda and Mandoura (2011) revealed that plant expose to high temperature stress show reduced chlorophyll biosynthesis and the impaired chlorophyll biosynthesis is the first process occurring in plastids affected by high temperature (Dutta *et al.*, 2009; Li *et al.*, 2010). The degradation of chlorophyll molecules may be associated with the production of reactive oxygen species (peroxides, superoxide, hydroxyl radical and singlet oxygen) under high temperature stress (Camejo *et al.*, 2006; Guo *et al.*, 2006). However, Reda and Mandoura (2011) found that the inhibition of chlorophyll biosynthesis under heat stress regime results from a destruction of numerous enzymes involved in the mechanism of chlorophyll biosynthesis and also resulted in the change of chlorophyll a:b ratio due to pre-mature leaf senescence (Al-khatib and Paulsen, 1984). Photosystem II is a highly

heat sensitive component of photosynthesis and its activities are greatly reduced or even partially stopped under high temperature (Bukhov *et al.,* 1999; Schrader *et al.,* 2004a,b; and Camejo *et al.,* 2005). Tomato genotypes that had different capacities to heat resistance enhanced chlorophyll a:b proportion and diminished chlorophyll carotenoids proportion under high temperatures, showing that these alterations were linked to tomato's thermal resistance (Camejo *et al.,* 2005; Wahid and Ghazanfar, 2006).

Tomato plant has the ability to monitor and adapt to adverse environmental conditions, and the degree of adaptability or tolerance to specific stress varies among genotypes (Wahid *et al.,* 2007). Hormonal homeostasis, stability, content, biosynthesis and compartmentalization are markedly altered under heat stress (Maestri *et al.,* 2002). Abscisic acid (ABA) and ethylene are stress hormones which are involved in regulation of many physiological properties and serve as signal molecule. Different environmental stress, such as high temperature results in increased levels of ABA (Larkindale and Huang, 2005). A gaseous hormone, ethylene regulates almost all growth and developmental processes in plant ranging from seed germination to flowering and fruiting as well as tolerance to environmental stresses. However, another type of hormone, brassinosteroids was reported to confer heat resistance in tomato (Dhaubhadel *et al.,* 1999).

Maintaining function of cellular membrane under heat stress is an important process like photosynthesis and respiration (Blum, 1988). High day and night temperatures cause a reduction in cell membrane permeability (Shen and Li, 1982). Heat stress hastens the kinetic energy and movement of molecules across membranes, thereby loosening chemical bonds within molecules of biological membranes. This makes the

lipid bilayer of biological membranes more fluid by either denaturation of protein or an increase in unsaturated fatty acid (Savchenko *et al.,* 2002). The integrity and function of biological membranes are sensitive to high temperature, as heat stress changes the tertiary and quaternary structure of membrane proteins. Such changes enhance the permeability of membranes as evident from increased loss of electrolyte. Chen *et al.* (1982) observed that electrolyte leakage from leaves that have been subjected to heat stress is measured and used to assess the cell membrane thermostability (CMT). An increased solute leakage, is an indication of decreased cell membrane thermostability and have been used as an indirect measure of heat tolerance in tomato. However, electrolyte leakage is influenced by plant/tissue age, developmental stage, sampling organ, growing season, degree of hardening and plant species. Hilali (2011) evaluated and screened tomato genotypes for heat tolerance using cell membrane thermostability. The author found that cell membrane thermostability test was an efficient screening method for selection of heat tolerant tomato genotypes and the leakage was highly significant between genotypes and developmental stages at 36^{o}C and 41^{o}C. The author observed that flowering stage was optimum for selection of tomato genotypes due to its highly significant difference compared to other stages. Islam *et al.* (2014) also evaluated eighteen inbred lines of tomato using cell membrane thermostability test for heat tolerance under elevated temperature of 55^{o}C. They observed that the inbred lines had longer heat killing time (240 minutes to cause 50% injury) and were considered as heat tolerant among the collections.

2.4 Genetic basis and Gene action of heat tolerance in tomato

High temperature fruit set (heat tolerance) is a critical trait of tomato cultivars targeted for lowland wet season production in the tropics and sub-tropics (Peter *et al.*, 2002). The inheritance of heat tolerance for fruit set has been studied in tomato by Adams and Osei (2006). Shelby *et al.* (1978) reported that a few partial dominant gene conferred heat tolerance during fruit set with very low narrow-sense heritability (8%) due to large environmental effects. According to Villareal and Lai (1979), heat tolerance is controlled largely by recessive genes which are inherited in a complex fashion with low heritability of 5-19% which are typical of polygenic traits. El-Ahmadi and Stevens (1979b) reported that inheritance of fruit set under high temperature of heat tolerant tomato genotypes was due to additive and dominant gene actions with moderate heritability. Hannan and Hernandez (1982) observed that additive gene action was more important than non-additive for percent fruit set, percent flower abortion and percent undeveloped ovaries under high temperature. Heat tolerance is controlled by a few genetic factors with major effects on the trait, and an undefined number of minor modifiers. In other word, heat tolerance belongs to a distinct class of polygenic traits known as "quasi-quantitative" characters (AVRDC, 1988). Dane *et al.* (1991) evaluated selected genotypes developed from diallel crosses for fruit setting ability under high temperature in the field and greenhouse conditions. The diallel analysis indicated that pollen fertility and fruit set under high temperature were primarily under additive gene action. However, Opeňa *et al.* (1992) observed that heat tolerance is controlled largely by a recessive gene and both additive and non-additive gene action are important in regulating fruit setting in tomato at high temperature. Dominance gene action was

reported for heat tolerance or fruit set in tomato under high temperature and development and use of hybrid cultivars with improved heat tolerance is recommended (Scott *et al.,* 1986, 1997). Peter *et al.* (2002) conducted an experiment to study gene action and heritability of high fruit set in tomato line CL5915 using generation mean analysis. The results of the analysis revealed the importance of both additive and dominance genetic effects conditioning high temperature fruit set in CL5915. Hazra and Ansary (2008) carried out an experiment to study genetics of heat tolerance for floral and fruit set to high temperature stress in tomato. They reported the importance of non-additive genetic component for the expression of characters influenced by heat tolerance. Gaikwad and Cheema (2009), however, reported that additive gene action plays a major role in controlling fruit set per cluster. A simple additive genetic system with incomplete dominance was also observed for percent fruit set (Ahmad *et al.*, 2010).

2.5 Combining Ability

Combining ability is defined as the ability of two parents to transmit favorable and unfavorable traits to their progeny. In quantitative genetics, two types of combining abilities have been reported: general combining ability (GCA) and specific combining ability (SCA). The concept of GCA and SCA was proposed for the first time by Sprague and Tatum (1942) in relation to single cross of corn, but later the concept has been widely used in other crops including tomato. According to Sprague and Tatum (1942), general combining ability refer to the average performance of the genotype in a series of hybrid combinations and is a measure of additive gene action and specific combining ability is the performance of a parent in a specific cross in relation to GCA.

The combining ability gives valuable information on potential of the genetic material involved, which enables plant breeders to take critical decisions regarding the parents to employ suitable procedures in crop improvement programs.

Bhatt *et al.* (2001) conducted combining ability studies in tomato under mid hill condition using 14×14 half diallel. They reported variances of GCA and SCA for plant height, days to first harvest, number of primary and secondary branches, number of flowers, number of fruits per cluster, number of fruits per plant and yield per plant were significant with predominance of non-additive gene action for all the traits studied. Cheema *et al.* (2003) estimated combining ability involving heat tolerant lines of tomato in a set of 9×9 diallel cross and found significant GCA and SCA variances for percent fruit setting per cluster, total fruit yield and marketable fruit yield per plant, indicating the importance of both additive and non-additive gene actions in the expression of these traits. Hannan *et al.* (2006) reported highly significant GCA and SCA variances for plant height, number of flowers per cluster, number of fruits per plant and fruit weight per plant, indicating the importance of both additive and non-additive gene actions in controlling the inheritance of these traits. Premalakshmi *et al.* (2006) also conducted an experiment using 6×6 full diallel mating design to estimate heterosis and combining ability for yield and yield contributing traits for earliness, plant height, branches per plant, fruit weight, number of fruit per plant and yield per plant. They found that both GCA and SCA variances were highly significant and the SCA variance was less than GCA variance, which suggest an additive gene action for these traits. Hazra and Ansary (2008) studied genetics of heat tolerance for floral and fruit set to high temperature stress in tomato in a 5×5 half diallel. They observed highly

significant differences for both GCA and SCA variances, showing additive and non-additive gene actions for days to first flower, number of clusters per plant, number of flowers per plant, number of fruit per plant and yield per plant. However, non-additive components were higher in magnitude than the additive components for all traits except days to flowering. Shalaby (2008) also conducted an experiment in a 7×7 half diallel cross of tomato to study heterosis and combining ability for plant height, earliness, number of branches per plant, average fruit weight and total yield in northern Egypt. He revealed that GCA and SCA variances were highly significant for all the traits; indicating both additive and non-additive gene actions were important in the inheritance of these traits. According to Ahmad *et al.* (2009), the variances for GCA and SCA were highly significant for plant height, day to 50% flowering, number of fruit per plant, individual fruit weight and fruit yield, indicating the presence of additive and non-additive genes and the relative magnitude of these variances showed that additive gene effects were more prominent for all the characters. Sekhar *et al.* (2010) carried out an experiment using 10×10 diallel mating design to estimate heterosis and combining ability among productive single cross hybrids in tomato for plant height, days to 50% flowering, number of branches per plant, number of clusters per plant, number of flowers per plant, number of fruits per plant, average fruit weight and fruit yield. They found that SCA variances were slightly predominant for all the traits studied and the GCA:SCA ratios were less than unity for all traits which depicts the importance of non-additive gene action. While Singh *et al.* (2010) estimated reciprocal difference and combining ability for some quantitative traits in tomato under mid-hill conditions of western Himalayas using 6×6 full diallel for average fruit weight, harvest duration,

number of fruits per plant and yield per plant. They observed that GCA, SCA and reciprocal variances were significant for all the traits. The SCA variances showed a preponderance for all traits, indicating non-additive gene action for the inheritance of these traits. Akram *et al.* (2012) studied combining ability and heterosis for yield and yield contributing traits in tomato from a 10×10 half diallel analysis and reported the variances for GCA and SCA were highly significant, indicating presence of additive and non-additive gene action except for number of fruits per plant. However, the relative magnitude of these variances showed that additive genes action was more for all traits.

2.6 Heterosis

Heterosis is the vigor manifested in hybrids and represents the superiority in performance of hybrid individuals compared to their parents. Heterosis was first applied by farmers for the purpose of hybridization of complex hybrid mixtures in the 1800s (Enfield, 1866; Leaming, 1883; and Waldron, 1924). Scientists (E.M. East and G.H. Shull) developed the concept of hybrid vigor or heterosis in maize independently in the early 1900s (Shull, 1952; Wallace and Brown, 1956; Hayes, 1963). It was found that genetic divergence of parents was important for hybrid vigor expression (Collin, 1910). Studies on heterosis of tomato were initiated at the beginning of the twentieth century, almost the same time as those in maize (Hedrick and Booth, 1907; East and Hayes, 1912). The F_1 hybrid of tomatoes are one of most leading vegetable crops all over the world (Patwary *et al.*, 2013). Heterosis is a widely documented phenomenon in tomato with more than 50-60% of the studies on heterotic performance referring to heterosis for yield and yield components and this percent was relatively stable even throughout the

last decade (Bistra and Hristo, 2007). However, beside yield, enhanced plant vigor, faster growth and development, increased productivity, earlier maturity, high level of resistance to biotic and abiotic stresses and uniformity were the manifestation of heterosis most often encountered in tomato crop (Yordanov, 1983). Zhakote and Kharti (1990) reported heterosis for net photosynthesis production in hybrids between cultivated and wild forms of tomato; while, Titok *et al.* (1994) observed manifestation of heterosis for chlorophyll content, both in the leaves and stems and a higher level of heterosis in the stems. Gaikwad and Cheema (2009) carried out studies on heterosis for quality traits in a 12×12 half diallel using twelve heat tolerant lines. They revealed that heterosis over better parent and the two standard checks were observed for all the traits and concluded that, for heat tolerant tomato, heterosis breeding may be the most prominent approach for quality improvement as most of the traits are governed by non-additive gene action. Fageria *et al.* (2001) studied heterobeltiosis for fruit yield and yield attributing traits in tomato using 10×10 half diallel mating and recorded percent range of heterosis for plant height (52.81to 70.79%), number of fruits per cluster (-33.83 to -21.19%), average fruit weight (-26.79 to 7.33%) and fruit yield per plant (17.28 to 48.21%) over better parent. Sharma *et al.* (2001) also reported a percentage range of heterosis for plant height (-2.36 to 40.94%), fruit length (-37.88 to 3.15%), fruit diameter (-19.65 to 10.17), average fruit weight (-80.79 to 80.63%) and yield per plant (15.44 to 58.59%) over better parent. Heterobeltiosis for plant height, number of fruits per cluster, number of fruits per plant and yield per plant ranged from 15.71 to 129.69%, -31.56 to 51.64%, -27.69 to 49.37% and -10.22 to 42.49%, respectively, over the better parent (Josh and Thakur, 2003). Thakur *et al.* (2004) evaluated 8×8 half

diallel progenies and studied heterosis for yield and yield components. They observed manifestation of heterosis for plant height (-34.00 to 53.30%), number of fruits per cluster (-17.06 to 46.62%), number of fruits per plant (-17.14 to 29.89%), average fruit weight (-33.69 to 55.46%) and yield per plant (-17.41 to 29.82%) over the better parent. Premalakshmi *et al.* (2006) studied heterosis and combining ability analysis in tomato for yield and yield contributing trait using 6×6 half diallel mating scheme and recorded a percentage range of heterosis for plant height (-43.98 to 14.43%), days to 50% flowering (-8.57 to 11.79%), fruit weight (-62.50 to 40.31%), number of fruits per plant (6.96 to 210.70%) and yield per plant (38.99 to 116.61%) over better parent. Hannan *et al.* (2007b) also conducted an experiment to estimate heterosis and character association in 10×10 half diallel for yield and yield component traits. They obtained significant difference among genotypes for all traits and found positive, highly significant heterosis for fruit per plant (75.33%), total fruit weight per plant (172%) and number of flowers per cluster (44.14%) over the better parent. According to Shalaby (2008) the percentage range of heterosis for plant height, number of branches per plant, earliness and average fruit weight were -23.53 to 43.62%, -14.28 to 60.00%, -78.8 to 317.6% and -52.20 to 22.10%, respectively, over the better parent. Radiša *et al.* (2010) using 6×6 half diallel mating design observed percentage range of heterosis for number of fruit per plant (-17.56 to 19.21%), average fruit weight (-31.39 to 12.98%) and yield per plant (-22.34 to 33.45%) over the better parent. However, Rahmani *et al.* (2010) using an 8×8 half diallel set excluding reciprocals found highly significant heterosis of a positive nature for flowers per cluster (37.20%), fruits per cluster (38.90%), fruit length (15.5%), fruit diameter (7.90%), average fruit weight (45.00%) and yield (34.90%) over

the better parent. Sekhar *et al.* (2010) estimated heterosis among productive single cross hybrids in tomato from 10×10 half diallel mating design. The results revealed the percentage range of heterosis for plant height (-43.48 to 30.76%), days to 50% flowering (-17.43 to 17.56%), number of branches per plant (-34.69 to 22.47%), number of clusters per plant (-33.71 to 100%), number of flowers per cluste(-22.90 to 21.14%), number of fruits per plant (-50.82 to 28.57%), average fruit weight (-54.89 to 12.23%) and yield per plant (-67.30 to 23.40%) over the better parent. Ahmad *et al.* (2011) reported a percentage range of heterosis from 7×7 half diallel cross combination of plant height (0.70 to 70.16%), days to 50% flowering (-2.00 to 37.4%), fruits per cluster (1.33 to 23.73%), number of fruits per plant (3.76 to 83.88%), fruit length (0.56 to 24.11%), fruit diameter (0.53 to 15.49%), fruit weight (4.76 to 16.67%) and yield per plant (0.56 to 62.31%) over the better parent. Patwary *et al.* (2013) estimated heterosis of heat tolerant tomato in an 8×8 half diallel mating. They observed significant heterosis for plant height (-21.19 to 36.72%), days to 50% flowering (-1.02 to -27.65%), number of branches per plant (-11.39 to 29.37%), number of flowers per cluster (-2.41 to 14.13%), number of fruits per cluster (1.20 to 79.52%), number of fruits per plant (3.38 to 105.69%), fruit length (0.88 to 14.12%), fruit diameter (0.10 to 21.22%), percent fruit set (0.08 to 62.59%), fruit weight (1.32 to 66.38%) and fruit yield per plant (13.58 to 282.63%) over the better parent. Amaefula *et al.* (2014) also estimated hybrid vigor and genetic control of some quantitative traits in tomato and found percentage range of heterosis for the number of flowers per cluster (-4.82 to -35.60%), number of clusters per plant (-54.14 to 19.42%), number of fruits per cluster (-40.91 to 14.56%), number of

fruits per plant (-67.99 to -4.61%), average fruit weight (-90.82 to -16.27%) and fruit yield per plant (-33.33 to 358.36%) over the better parent.

2.7 Heritability

Heritability is the proportion of the observed variation in a progeny that is inherited. Heritability is the ratio of genetically caused variation to total variation (Acquaah, 2007). The estimate of heritability can be classified into two: Broad sense heritability and Narrow sense heritability. Broad sense heritability is the ratio of total genetic variance to the phenotypic variance, while Narrow sense heritability is the ratio of the additive variance to the phenotypic variance. Low to moderate heritability estimates have been reported for heat tolerance in tomato (Charles and Harris, 1972; Rudich *et al.,* 1977; Levy *et al.,* 1978; Aung, 1979; Villareal and Lai, 1979; El-Ahmadi and Stevens, 1979b; Scott *et al.,* 1986; Dane *et al.,* 1991).

Wessel-Beaver and Scott (1992) reported high heritability for single location for fruit set (0.74 to 0.77), yield (0.65 to 0.81) and fruit weight (0.89 to 0.97) and low heritability across locations for yield (0.14), intermediate for fruit set (0.60) and high for fruit weight (0.92) from a synthetic population of tomato developed from polycross among seven selected genotypes evaluated for heat tolerance in two different locations. Marcio and Wilson (2002) studied the inheritance of tomato fruit shape and other morphological traits in tomato. They reported narrow-sense heritability for fruit shape and fruit weight of 50.18% and 67.08%, respectively. Peter *et al.* (2002) also carried out an experiment to study gene action and heritability of high temperature fruit set in tomato line CL5915 and the estimated heritabilities for percentage fruit set, number of fruits per cluster and number of flowers per cluster in 1996 and 1997 were 0.31 and

0.21, 0.28 and 0.14, and 0.53 and 0.15 respectively. Saeed *et al.* (2007b) reported that the broad sense heritability for number of flowers per plant, number of fruits per plant, number of days for fruit setting and yield per plant were 93.45%, 96.56%, 36.12%, and 97.15%, respectively. Khanom *et al.* (2008) investigated variability, heritability and genetic advance for yield and yield contributing characters in tomato and the results revealed high broad-sense heritability for plant height (84.50%), number of branches per plant (78.50%), days to first flower (85.56%), number of fruits per plant (72.38%) and fruit weight (88.35%) but low for yield per plant (46.50%). According to Dordević *et al.* (2010) the broad sense and narrow sense heritabilities for number of fruits per plant, fruit weight and fruit weight per plant were 99.4% and 81.38%, 99.32% and 87.51%, and 98.90% and 45.10%, respectively. Ghosh *et al.* (2010) also studied variability and character association in F_2 segregating population of different commercial hybrids of tomato. They reported broad-sense heritability for plant height (51.08%), days to first flower (72.14%), number of branches per plant (59.68%), number of flowers per cluster (45.83%), number of flowers per plant (55.41%), number of fruits per cluster (61.80%), number of fruits per plant (76.79%), fruit length (74.97%), fruit diameter (76.20%), fruit weight (76.20%) and yield per plant (75.71%). Kamel *et al.* (2010) conducted genetic evaluation and molecular marker studies for heat tolerance in tomato. They observed that broad sense heritability was high for fruit setting (99.10%), osmotic pressure (84.38%), pollen viability (98.75%) and yield per plant (97.87%). Kaushik *et al.* (2011) revealed that the broad-sense heritability for plant height, days to 50% flowering, days to 50% fruit setting, fruit length, fruit diameter and yield per hectare were 74.20%, 99.20%, 98.50%, 99.40%, 98%, and 99.9%,

respectively. Al-Aysh *et al.* (2012) observed broad sense heritability for a number of branches per plant (95.83%), number of fruits per plant (92.47%), number of fruits per cluster (91.41%) average fruit weight (83.16%) and yield (53.06%), and also high broad-sense heritability was reported for number of fruits per plant (83.90%), fruit length (94.50%), fruit diameter (91.50%), average fruit weight (97.00%) and yield (97.00%), (Manna and Paul, 2012). Mohamed *et al.* (2012) reported that broad sense heritability for plant height, days to 50% flowering, number of branches per plant, number of flowers per cluster, number of fruits per cluster, fruit weight and yield per plant were 97%, 69%, 70%, 63%, 65%, 92% and 43%, respectively. Patel *et al.* (2013) evaluated thirteen tomato genotypes for variability, heritability and genetic advance in yield and yield contributing characters. They observed moderate to high broad sense heritability for plant height (63.10%), days to 50% flowering (44.80%), number of branches per plant (47.80%), number of fruits per plant (68.00%), fruit length (60.50%), fruit diameter (77.00%), fruit weight (89.80%) and yield per plant (87.20%). High broad sense heritability was also reported for plant height (86%), days to 50% flowering (86%), number of branches per plant (86%), number of flowers per cluster (61%), number of fruits per cluster (78%), fruit length (82%), fruit diameter (95%) fruit weight (99%) and yield per plant (98%) by Shankar *et al.,* (2013). Nwosu *et al.* (2014) investigated genetic variability and correlation in rain-fed tomato accession in Ibadan, Nigeria and the estimated broad sense heritability was very high for days to 50% flowering (82%), fruits per plant (90%), fruit length (97%), fruit diameter (90%) and fruit weight (100%) and fruit yield (74.6%).

2.8 Correlation

Correlation coefficient measures the degree of association between traits either in the positive or negative direction. It measures the natural relationship between various traits and assists in determining the component traits on which selection can be based for yield improvement. Genetic correlation coefficient provides measures of genetic association between traits and thus help to identify the important as well as less important traits to be considered in breeding programs. Fruit yield is a quantitative trait controlled by many genes and influenced by a number of yield contributing traits. Therefore, adequate knowledge about the magnitude and degree of association of yield with its contributing characters is essential to breeder and these components will assist the breeder to understand the strength of correlated traits in the decision making process for simultaneous improvement of more than one character (Sivaprasad, 2008; Monamodi *et al.,* 2013). Cramer and Wehner (1998) reported that a way of improving yield indirectly is to select for traits that are highly correlated with yield and possess high heritability. In tomato, yield is the cumulative effect of many component characters individually contributing toward it (Kumar and Dudi, 2011).

Wessel-Beaver and Scott (1992) developed a synthetic population of tomato from seven selected genotypes and evaluated it for heat tolerance in two different locations. They found that the correlations between fruit set and fruit weight, and fruit yield vs fruit weight were strongly negative (-0.92 to -0.49) and (-0.58 to -0.66) at genotypic and phenotypic levels, respectively. However, the genotypic and phenotypic correlation between fruit yield and fruit weight were strongly negative (-0.50 to -0.84) and weakly negative (-0.31 to -0.34), respectively, while the fruit set was strong and positively

correlated with fruit yield (0.71 to 0.74) and (0.52 to 0.61) at both genotypic and phenotypic levels, respectively. Hazra and Ansary (2008) reported that number of clusters per plant was positively correlated with number of fruits per plant (0.46) and fruit set (0.71) and fruit set was positively correlated with a number of fruits per plant (0.43), while fruit weight was highly correlated to yield (0.65) and negatively correlated with number of fruits per plant (-0.54). Highly significant positive phenotypic correlation between fruit set and yield per plant (0.74) was reported by Kamel *et al.*, (2010). Kaushik *et al.* (2011) reported significant positive correlation of yield per hectare with fruit length (0.66) and plant height (0.51), while the days to 50% flowering showed negative correlation with fruit yield (-0.16). Kumar and Dudi (2011) studied correlation for yield and quality characters in tomato and the results revealed that fruit yield was significantly positively correlated with number of fruits per plant (0.51) and fruit weight (0.44) and non-significant positive correlation was observed with number of clusters per plant (0.08) and number of branches per plant (0.07). Non-significant negative correlation was observed with number of fruits per cluster (-0.16), plant height (-0.08), fruit shape index (-0.04) and days to 50% flowering (-0.03). However, days to 50% flowering exhibited highly significant positive phenotypic correlation with number of branches per plant (0.25) and non-significant positive correlations with number of clusters per plant (0.16), number of fruits per cluster (0.16), plant height (0.07) and fruit shape index (0.06). Akhtar *et al.* (2012) evaluated thirty eight genotypes of tomato to study the crucial characters to be considered for high temperature tolerance. They observed significant positive phenotypic correlation between number of clusters per plant and number of fruit per plant (0.48), number of flowers per cluster and fruit set per

cluster (0.71), fruit set per cluster and number of fruits per plant (0.43), and fruit weight and yield per plant (0.65), but significant negative correlation was exhibited between number of fruits per plant and fruit weight (-0.54). According to Al-Aysh *et al.* (2012), the genotypic correlations were higher than the corresponding phenotypic correlations for all trait combinations. Fruit yield per plant was highly significantly positively correlated with average fruit weight (0.64 and 0.72), days to maturity (0.57 and 0.48) and harvest index (0.84 and 0.88). Highly significant negative correlations were observed with plant height (-0.64 and -0.57), number of branches per plant (-0.53 and -0.57), number of fruits per plant (-0.44 and -0.54) and number of fruits per cluster (-0.46 and -0.53) at both genotypic and phenotypic levels, respectively. However, the number of fruits per plant showed highly significant positive correlations at both genotypic and phenotypic levels with number of branches per plant (0.81 and 0.85) and number of fruits per cluster (0.85 and 0.88), but highly significant negative correlation with average fruit weight (-0.86 and -0.92), respectively. Manna and Paul, (2012) also observed that the genotypic correlations were higher than the phenotypic correlations for most of traits the studied. They found that fruit yield per plant was highly significantly positively correlated with fruit length (0.56 and 0.53) and fruit weight (0.46 and 0.44) at both genotypic and phenotypic, respectively. However, the number of fruits per plant showed highly significant correlation negative with fruit length (-0.26 and -0.22), fruit diameter (-0.70 and -0.60) and fruit weight (-0.38 and -0.35), but non-significant values with fruit yield per plant (0.15 and 0.15) at both genotypic and phenotypic levels, respectively. Fruit weight was highly significantly positively correlated with fruit length (0.26 and 0.25) at both genotypic and phenotypic levels,

respectively. Kugblenu *et al.* (2013) screened tomato genotypes for adaptation to high temperature in West Africa and the results of phenotypic correlation indicated that days to 50% flowering was negatively correlated with number of fruits per plant (-0.79), fruits per plant (-0.69), number of clusters per plant (-0.85) and total number of flowers (-0.80). The number of fruits per plant was significantly positively correlated to fruit yield (0.92), number of clusters per plant (0.89), number of flowers per cluster (0.74), And a total number of flowers (0.80), while the number of clusters per plant also showed significant positive correlation with number of flowers per cluster (0.63), fruit yield per plant (0.85) and total number of flowers (0.72). Osekita and Ademiluyi (2014) studied genetic advance, heritability and character association of yield components in tomato. The genotypic correlation results showed that days to 50% was significantly positively correlated with a number of branches per plant (0.36), number of fruits per plant (0.67) and fruit shape index (0.57), but negatively significantly correlated with the number of clusters per plant (-0.39) and average fruit weight (-0.95) were observed. The number of fruits per plant revealed highly significant and positive correlation with the number of fruits per cluster (0.88), but negatively correlated with plant height (-0.63) and number of branches per plant (-0.76), while the number of clusters per plant exhibited negative highly significant correlation with plant height (-0.87) and number of branches per plant (-0.65). Meena and Bahadur (2015) also studied genetic information on character association for tomato under open field condition. They reported that yield per plant was significantly positively correlated with number of flowers per plant (0.29 and 0.29), number of fruits per plant (0.45 and 0.45), fruit weight (0.62 and 0.62) but non-significantly correlated with fruit set (0.20 and

0.20) at genotypic and phenotypic levels, respectively. Plant height also revealed significant positive association with number of branches per plant (0.97 and 0.95), number of clusters per plant (0.56 and 0.56), number of flowers per plant (0.50 and 0.51) and number of fruits per plant (0.36 and 0.36) at both genotypic and phenotypic levels, respectively. However, Number of flowers per plant exhibited significant positive correlation with number of branches per plant (0.59 and 0.57), number of clusters per plant (0.73 and 0.73) and number of fruits per plant (0.56 and 0.55) at both genotypic and phenotypic levels, respectively. Number of fruit per plant indicated significant positive association with number of branches per plant (0.40 and 0.39), number of clusters per plant (0.41 and 0.41,) number of flowers per plant (0.55 and 0.55) and percent fruit set (0.47 and 0.47) at genotypic and phenotypic levels, respectively (Meena and Bahadur, 2015).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Experimental Sites

Two experiments were conducted at National Horticultural Research Institute, Bagauda Station, Kano and Institute for Agricultural Research Samaru, Zaria. National Horticultural Research Institute, Bagauda is located within 11°33´N and longitude 08°23´E of the latitude. It is situated in the Sudan savannah zone of Nigeria, characterized by mean annual rainfall of 830mm, with monomodal distribution falling between June and October (Kowal and Knabe, 1972). The mean daily temperature ranged from 18.4^{o}C to 45^{o}C (NIHORT, 2010). The period of hot weather occurs between March and September with temperature ranging from 38^{o}C to 45^{o}C (NIHORT, 2010). Institute for Agricultural Research Samaru, Zaria is located at 11^{o}11´N, 07^{o}38'E with an altitude of 686m above sea level in the Northern guinea savanna zone of Nigeria. The annual rainfall amount ranges from 608mm to 1482mm with a mean of 1063mm distributed within six months (May-October). A cool period is experienced from November to February. The temperature varies between 19^{o}C to 35^{o}C and a night temperature as low as 20^{o}C. The period of hot weather occurs between March and September with a temperature ranging from 32^{o}C to 42^{o}C (Obeta and adewumi, 2013).

3.2 Description of the Plant Materials

The plant experimental materials consisted of six parents and four checks. Brief descriptions of the genotypes are given in Table 3.1.

Table 3.1: Genotypes, Sources, Reaction to Heat and Growth Habits of the tomatoes used in the study during 2014 rainy season

S/N	Genotype	Source	Reaction to Heat	Description
1	Icrixina	ICRISAT, Niger Republic	Tolerant	Determinate, small size and round fruit with average weight of 50-80grams. It matures in 60-80 days to first harvest after transplanting.
2	Rio Grande	Agritropic, Kano	Tolerant	Determinate, elongated fruit with average weight of 90 -100grams. It matures in 65-70 days to first harvest after transplanting.
3	Tima	Agritropic, Kano	Susceptible	Determinate, elongated cylindrical fruit with average weight of 90-100grams. It matures in 70-75 days to first harvest after transplanting.
4	Tropimech	Agritropic, Kano	Susceptible	Determinate, elongated fruit with average weight of 90 -100grams. It matures in 65-70 days to first harvest after transplanting.
5	Petomech	Agritropic, Kano	Susceptible	Determinate, square fruit with average weight of 75 -100grams. It matures in 70-80 days to first harvest after transplanting.
6	Roma Savana	Agritropic, Kano	Susceptible	Determinate, long fruit with average weight of 40 -60grams. It matures in 60-80 days to first harvest after transplanting.

Table 3.1 continued

S/N	Genotype	Source	Reaction to Heat	Description
Checks				
7	Roma VF	NIHORT, Bagauda	Susceptible	Determinate, pear shaped fruit with average weight of 70gram. It matures in 65-70 days to first harvest after transplanting.
8	UC82 B	NIHORT, Bagauda	Susceptible	Determinate, squared fruit with average weight of 80-100gram. It matures in 70-80 days to first harvest after transplanting.
9	Thorgal F_1	Agritropic, Kano	Tolerant	Determinate, globular fruit shape with average weight of 120-130gram. It mature 65 days to first harvest after transplanting
10	Jaguar F_1	Agritropic, Kano	Tolerant	Determinate, blocky fruit with average weight of 100-110grams. It mature in 65 days to first harvest

3.3 Population Development

The parental materials comprised six genotypes. The genotypes were crossed in a half diallel mating design, the crosses were made in a screen house in all possible combinations using pair row crossing excluding the selfs and reciprocals as illustrated below in Table 3.2. The half diallel crosses made were fifteen hybrids as given by the formula $[n(n-1)/2]$, where n is the number of parents.

Table 3.2: Possible half diallel crosses among the parents

♀ \ ♂	1 Icrixina	2 Rio grande	3 Tima	4 Tropimech	5 Petomech	6 Roma Savana
1		1×2	1×3	1×4	1×5	1×6
2			2×3	2×4	2×5	2×6
3				3×4	3×5	3×6
4					4×5	4×6
5						5×6

3.4 Population Evaluation

The 15 crosses, 6 parents and 4 checks were evaluated at two locations in a 5 × 5 partially balanced lattice design with three replications at each location. The populations were evaluated during rainy season between July-October, 2014 to synchronize flowering stage with high temperature months (September and October) as shown in Appendices i. Plot size was 2 × 2m with 1m alleys between the plots. Seeds were sown on tray nurseries inside screen house on 17th July, 2014. Experimental fields were ploughed and ridged on 13th August, 2014. Seedlings were transplanted to field at 4-5

leaf stage on three rows at inter-row spacing of 60cm and intra-row spacing of 50cm on 17th August, 2014. N.P.K. 15:15:15 fertilizer was applied at the rate of 45kgN, 45kgP_2O_5 and 45kgK_2O/ha at two weeks after transplanting followed by Urea (46%N) at the rate of 64.4kgN/ha at five weeks after transplanting. Three hoe weedings were done at two, four and six weeks after transplanting. Data were taken on five random plants from the middle of the plots leaving the plants on either side of the plot to avoid border effect.

Infection of Septoria leaf spot (*Septeria lycopersici*) was observed in both locations. The symptoms of the disease include round, yellow and watery soaked spots under the leaves and the disease occurred when the plant started fruiting. The disease defoliated plants which leads to the failure of fruit maturity and also exposed the fruits to sun which caused sunscald. A fungicide, mancozeb was applied at 2kg in 400l/ha for 10 days interval at the onset of the disease for 6 weeks. The disease severity among the genotypes was scored according to Joshi (2011) based on visual assessment of symptom severity (appendix iii) at a scale of 0-5 with 0.5 increment, 0 = no disease symptom, 0.5 = less than 10% leaf area with symptoms, 1 = 10-20% leaf area with symptoms, 1.5 = 20-30% leaf area with symptoms, 2 = 30-40% leaf area with symptoms, 2.5 = 40-50% leaf area with symptoms, 3 = 50-60% leaf area with symptoms, 3.5 = 60-70% leaf area with symptoms, 4 = 70-80% leaf area with symptoms, 4.5 = 80-90% leaf area with symptoms and 5 = 90-100% leaf area with symptoms. Tima, Tima × Petomech and Tima × Roma Savana were less susceptible to septoria leaf spot at Bagauda. Similarly, Tima × Petomech and Tima × Roma Savana were less susceptible to septoria leaf spot at Samaru (appendix ii).

3.5 Data Collection and Observations

Data was collected on the following parameters:

1. **Plant height** (cm): Average height of five random plants per plot measured from the base to the tip of the plant using a meter rule.
2. **Days to 50% flowering**: Number of days from transplanting to first flower appearance in 50 per cent of the plants in a plot.
3. **Number of branches per plant**: Average number of branches counted on five random plants per plot.
4. **Number of clusters per plant**: Average number of fruiting clusters from five random plants were recorded.
5. **Number of flowers per cluster**: Average number of flowers per cluster for the first inflorescence on five random plants.
6. **Number of flowers per plant**: Average number of flowers per plant on five random plants per plot.
7. **Number of fruits per cluster**: Average of three random fruit bunches per plot counted before first picking.
8. **Number of fruits per plant**: Total number of fruits harvested per plot from all the pickings divided by the number of plants per plot.
9. **Average fruit weight (g):** Average fruit weight was measured using a digital weighing scale (Mettler Instruments, GMBH, Switzerland: model: FEJ-3000B) and computed using the following formula:

$$\text{Average fruit weight} = \frac{\text{Total fruit weight from all the pickings}}{\text{Total number of fruits from all the pickings}}$$

10. **Fruit length (cm):** Average length of twenty fruits per plot measured from the base of the calyx to the tip of the fruit using a digital vernier caliper at third picking.
11. **Fruit width (cm):** Average width of twenty fruits per plot measured using digital vernier caliper at the center (equatorial length) of the fruit at third picking.
12. **Fruit shape index:** The fruit shape index was calculated by dividing the average fruit length by the average fruit width.

    Fruit shape index = average fruit length /average fruit width
13. **Fruit yield per plant (g):** Average fruit weight of five tagged plants per plot obtained using digital weighing scale (Mettler, GMBH, Switzerland: model: FEJ -3000B).
14. **Percentage fruit set per plot (%):** The total number of fruits divided by the total number of flowers per plot multiplied by 100.

$$\text{Percentage fruit set (\%)} = \frac{\text{Total number of fruits}}{\text{Total number of flowers}} \times 100$$

15. **Leaf chlorophyll content:** The leaf chlorophyll content was determined using a SPAD chlorophyll meter (SPAD 502plus. Konica Minolta, Tokyo, Japan). Three leaves were randomly sampled on each of the five plants and three SPAD readings were taken at tip, center and the edge of the leaf and average recorded.
16. **Canopy temperature depression:** The leaf canopy temperature was recorded using handheld infrared Thermometer (Spectrum technologies, Inc. U.S.A). The canopy temperature depression was estimated using the following equation:

$$\text{Canopy temperature depression} = T_a - T_c$$

Where: T_a = Air temperature

T_c = canopy temperature

17. **Cell membrane thermostability:** cell membrane thermostability test was conducted in Plant Science Department laboratory according to Kuo *et al.* (1993). Ten leaf disks of 10mm diameter were punched from new uppermost leaves of each genotype from each replication. The leaf disks were washed three times with distilled water to remove electrolytes from the injured cell at the cut edge and any surface adhering electrolytes. Leaf disks were then placed in a 20ml test tube and 10ml of deionized water was added. The test tubes were covered with test tube caps and incubated in a water bath (Water bath TT60D Multipurpose, Techmel and Techmel, U.S.A) at 30^{o}C, 40^{o}C and 50^{o}C for one hour, while control tubes were maintained at 25^{o}C at the same time period. After incubation in the water bath, the test tubes were cooled to room temperature and the electrolyte conductivity of the solutions were measured using an electrical conductivity meter (Waterproof EC Meter, Spectrum Technologies. Inc. U.S.A). After initial readings, the test tubes were then boiled for 30 minutes to completely kill leaf tissue and release all of the electrolytes. The test tubes were cooled to 25^{o}C and final electrolyte conductivities were measured. The cell membrane thermostability and relative high temperature injury were measured using the following equations:

Percent cell membrane thermostability (CMS (%)) = $[(1-(T_1/T_2)/(1-(C_1/C_2)]\times 100$

Relative heat injury (%) = 100 - CMS

Where C, T and CMS refer to the electrical conductivity of control, heat treated samples and cell membrane stability, respectively, and the subscripts 1 and 2 refer to electrical conductivity readings before and after boiling, respectively. The genotypes were classified according to Kuo *et al.* (1993) as follows:

- Heat tolerant (HT): HI < 25%
- Moderately heat tolerant (MHT): 25% < HI < 50%
- Slightly heat tolerant (SHT): 50% < HI < 75%
- Heat sensitive (HS): HI > 75%

3.6 Statistical Analysis

Analysis of variance (ANOVA) for individual location as well as for combined locations was computed using statistical software (SAS, 2004). The ANOVA was computed on plot mean values for all characters across the two locations. Least significant difference was used to separate the means. The following model (Bohren *et al.*, 1961) was used in one location in one year:

$$x_{ijk} = \mu + r_i + g_j + e_{ijk}$$

Where:

x_{ijk} = Observation of the i^{th} line and j^{th} line in the k^{th} replication

μ = The population mean

r_i = Effect of the i^{th} line due to replication

g_j = Effect of the j^{th} line due to genotype

e_{ijk} = Experimental error

The statistical model used for the combined analysis of variance across the two locations for one year is presented as:

$$x_{ijk} = \mu + l_i + r_{ij} + g_k + (rl)_{ij} + (gl)_{ik} + e_{ijk}$$

Where: x_{ijk} = Observation of the k^{th} genotype and j^{th} replication in i^{th} location

μ = Overall mean

l_i = The effect of the i^{th} location

r_{ij} = The effect of the j^{th} replication in the i^{th} location

g_k = The effect of the k^{th} genotype

$(rl)_{ij}$ = Replication × Location interaction

$(gl)_{ik}$ = The interaction effect between k^{th} genotype in the i^{th} location

e_{ijk} = Experimental error

i = Location (1, 2)

j = Replications (1, 2, 3)

k = Genotype (1, 2….25)

Table 3.3: Form of Analysis of variance for one location

Source of variation	df	MS	EMS
Replication	$(r-1)$	m_4	
Block(*replication*)	$r(b-1)$	m_3	$\sigma_e^2 + g\sigma_{br}^2$
Genotype	$(g-1)$	m_2	$\sigma_e^2 + br\sigma_g^2$
Error	$(g-1)\ (r-1)$	m_1	σ_e^2

df = degree of freedom, r = Number of replications, b = blocks, g = Number of genotypes, σ_e^2 = Error variance, σ_g^2 = Genotypic variance and EMS = Expected mean squares.

Table 3.4: Form of analysis of variance combined across locations

Source of variation	df	MS	EMS
Location	$(l-1)$		
Block(*replication* × *location*)	$rl(b-1)$		
Replication in location	$l(r-1)$	m_l	
Genotype	$(g-1)$	m_g	$\sigma_e^2 + br\sigma_{gl}^2 + blr\sigma_g^2$
Genotype × *Location*	$(g-1)\ (l-1)$	m_{gl}	$\sigma_e^2 + br\sigma_{gl}^2$
Error	$l(r-1)(g-1)$	m_e	σ_e^2
Total	$\lg r - 1$		

Where: $l =$ Location, $b =$ blocks, $g =$ Genotype, σ_{gl}^2 = Genotype × location interaction variance σ_g^2 = Variance due to genotype, σ_e^2 = Error variance and EMS = Expected mean squares.

Diallel analysis was used for fixed effects, according to Gardner-Eberhart analysis III (1966). The following model was used

$$y_{ijk} = \mu + g_i + g_j + s_{ij} + R_k + e_{ijk}$$

Where:

y_{ijk} = The performance of the k^{th} plot of the cross between the i^{th} and the j^{th} parents.

μ = Overall mean

g_i = Effect common to all progeny of the i^{th} line

g_j = Effect common to all progeny of the of the j^{th} line

S_{ij} = Effect specific to the progeny of mating i^{th} x j^{th} line

R_k = Effect of the k^{th} replication

e_{ijk} = Experimental error

The model below was used for combining ability analysis across the locations:

$$y_{ijkt} = \mu + g_i + g_j + s_{ij} + l_t + (gl)_{it} + (gl)_{jt} + (sl)_{ijt} + r_{kt} + e_{ijkt}$$

Where:

y_{ijkt} =The yield of a cross between i^{th} and j^{th} parents in the k^{th} replication in the t^{th} location.

μ = Overall mean

g_i = Effect common to all progeny of the i^{th} parent

g_j = Effect common to all progeny of the j^{th} parent

s_{ij} = Effect specific to the progeny of mating i^{th} and j^{th} parents

l_t = The average effect of the t^{th} location

$(gl)_{it}$ = Genotype x location interaction effect of the i^{th} parent in that location.

$(gl)_{jt}$ = Genotype x location interaction effect of the j^{th} parent in that location

$(sl)_{ijt}$ = Specific effect of mating i^{th} parent and j^{th} parent in that location

r_{kt} = Effect of the k^{th} replication in t^{th} location

e_{ijkt} = Experimental error

i = 1-6 parents, j = 1-6 parents, k = 1-3 replications, l = 1-2 locations

Form of analysis of variance for combining ability for individual location is presented below in Table 3.5 (Matzinger *et al.* 1959; Kempthorne, 1956).

Table 3.5: Form of analysis of variance for combining ability for one location

Source of variation	df	MS	EMS
Replication	$(r-1)$		
parent	$n-1$		
parent vs *crosses*	1		
Crosses	$[n(n-1)/2]-1$	m_4	
GCA	$(n-1)$	m_3	$\sigma_e^2+\sigma_s^2+r(n+2)\sigma_g^2$
SCA	$n(n-3)/2$	m_2	$\sigma_e^2+r\sigma_s^2$
Error	$(r-1)[(n(n+1)/2]-1$	m_1	σ_e^2

Key: g = GCA, s = SCA, r = replication and n = number of parents.

Form of analysis of variance for combining ability combined across locations is presented below in Table 3.6 (Johnson and King, 1997).

Table 3.6: Form for analysis of variance for combining ability combined across locations

Source of variation	df	MS	EMS
location	$(l-1)$		
replication(*location*)	$l(r-1)$		
Parent	$(n-1)$		
Parent vs *cross*	1		
Crosses	$[n(n-1)/2]-1$		$\sigma_e^2 + r\sigma_{cl}^2 + rl\sigma_c^2$
GCA	$(n-1)$	m_6	$\sigma_e^2 + r\sigma_{cl}^2 + rl\sigma_s^2 + rl(n-2)\sigma_g^2$
SCA	$n(n-3)/2$	m_5	$\sigma_e^2 + r\sigma_{cl}^2 + rl\sigma_s^2$
Crosses × *location*	$(l-1)$ $([n(n-1)/2]-1)$	m_4	$\sigma_e^2 + r\sigma_{cl}^2$
GCA× *location*	$(n-1)(l-1)$	m_3	$\sigma_e^2 + r\sigma_{sl}^2 + r(n-2)\sigma_{gl}^2$
SCA× *location*	$(n(n-3)/2)$ $(l-1)$	m_2	$\sigma_e^2 + r\sigma_{sl}^2$
Error	$l(r-1)$ $(n[(n+1)/2]-1)$	m_1	σ_e^2

Key: n = number of parent, r = replication, c = cross g = GCA, s = SCA, p = parent, l = location and e =error.

3.6.1 Estimation of GCA and SCA Variances

Component due to GCA and SCA for single location were determined using the formula below:

$$\sigma^2_{GCA} = \frac{M_3 - M_2}{r(n+2)} \qquad \text{Table 3.5}$$

$$\sigma^2_{SCA} = \frac{M_2 - M_1}{r} \qquad \text{Table 3.5}$$

Component due to GCA and SCA across locations were determined using the formula below:

$$\sigma^2_{GCA} = \frac{M_6 - M_5}{rl(n-2)} \qquad \text{Table 3.6}$$

$$\sigma^2_{SCA} = \frac{M_5 - M_4}{rl} \qquad \text{Table 3.6}$$

$$\sigma^2_{g\times l} = \frac{M_3 - M_2}{r(n-2)} \qquad \text{Table 3.6}$$

$$\sigma^2_{s\times l} = \frac{M_2 - M_1}{r} \qquad \text{Table 3.6}$$

The ratio of the GCA variance to SCA variance was calculated using (Singh and Chaudhary, 1985) formula:

$$GCA : SCA = \frac{\sigma^2_{GCA}}{\sigma^2_{SCA}}$$

Where:

σ^2_{GCA} = Variance due to general combining ability effects.

σ^2_{SCA} = Variance due to specific combining ability effects.

$\sigma^2_{g\times l}$ = General combining ability × location variance.

$\sigma^2_{s\times l}$ = Specific combining ability × location variance.

l = Locations.

n = Number of parents.

r = Replications.

Average degree of dominance was calculated according to Peyman *et al.* (2012). When the inbreeding coefficient (F) of parents equal to zero (no inbreeding), the additive and non-additive variances were calculated as follows:

$$\sigma^2_A = 4\sigma^2_{GCA} \qquad \sigma^2_D = 4\sigma^2_{SCA}$$

Therefore, Degree of dominance (DH) = $\sqrt{\frac{\sigma^2_D}{\sigma^2_A}}$

The values of degree of dominance were classified according to Lagervall (1961): 0 = no dominance, less than unity = partial dominance, 1 = complete dominance and greater than unity = overdominance.

3.6.2 Estimation of General Combining ability (GCA) and Specific Combining Ability (SCA) Effects

The GCA and SCA effects were estimated using Griffing's (1956) method 2 model 1, where the genotype effects were fixed. The relative importance of additive and dominance effects were estimated by the ratio of the variances of fixed effects (Singh and Chaudhary, 1985).

$$\text{GCA Effects} = \frac{1}{n(n-2)}(nX_{i.} - 2X..)$$

$$\text{SCA Effects} = X_{ij} - \frac{1}{n-2}(X_{i.} + X._{j}) + \frac{2}{(n-1)(n-2)}X..$$

Where:

$X_{i.}$ and $X._{j}$ = Means of the i^{th} and j^{th} parents, respectively.

$X..$ = Grand mean

n = number of parents

The significance of general and specific combining ability effects were tested using the formula of Singh and Chaudhary (1985).

$$S.E.(g_i) = \sqrt{\frac{(n-1)\sigma_e^2}{n(n+2)}}$$

$$S.E.(s_{ij}) = \sqrt{\frac{n(n-1)\sigma_e^2}{(n+1)(n+2)}}$$

Where:

σ_e^2 = Error mean square, n = Number of parents

$S.E.(g_i)$ = Standard error of effect common to all progeny of the i^{th} parent

$S.E.(s_{ij})$ = Standard error of effect specific to the progeny of mating i^{th} and j^{th} parents

3.6.3 Estimation of Heterosis

Heterosis for individual crosses was estimated based on the difference between F_1 and their parents. Better parent heterosis (heterobeltiosis) was calculated for each individual hybrid in each location and for the combined locations according to Hayes *et al.* (1965) as follows:

$$\text{Heterobeltiosis } (\%) = \frac{(F_1 - B_P)}{B_P} \times 100$$

Where:

F_1 = Average performance of hybrid formed between j^{th} *and* i^{th} parents.

B_P = Average performance of the better parent.

The significance of better parent heterosis was tested using the formula of Wynne *et al.* (1970). The Calculated t was tested against the Table value of t at error d.f for tests of significance.

$$S.E.(BP) = \sqrt{\frac{2\sigma_e^2}{r}} \qquad t_{value} = \frac{Heterobeltiosis}{S.E.(BP)}$$

Where

S.E. (BP) = Standard error between F_1 and better parent required for significance at 5% and 1% probability levels.

σ_e^2 = Error mean squares

r = Number of replications.

3.6.4 Estimation of Heritability

Broad sense heritability (h_b^2) and narrow sense heritability (h_n^2) were calculated using the components of variance (Alireza *et al.*, 2012) as follow:

$$h_b^2 = \frac{\sigma_g^2}{\sigma_p^2}$$

$$\sigma_g^2 = 4\sigma_{gca}^2 + 4\sigma_{sca}^2$$

$$\sigma_p^2 = 4\sigma_{gca}^2 + 4\sigma_{sca}^2 + \sigma_e^2$$

$$h_b^2 = \frac{4\sigma_{gca}^2 + 4\sigma_{sca}^2}{4\sigma_{gca}^2 + 4\sigma_{sca}^2 + \sigma_e^2}$$

$$h_n^2 = \frac{4\sigma_{gca}^2}{4\sigma_{gca}^2 + 4\sigma_{sca}^2 + \sigma_e^2}$$

The broad sense heritability (h_b^2) and narrow sense heritability (h_n^2) across locations were estimated using component variance (Johnson and King, 1997) as follow:

$$h_b^2 = \frac{4\sigma_{gca}^2 + 4\sigma_{sca}^2}{4\sigma_{gca}^2 + 4\sigma_{sca}^2 + 4\sigma_{gl}^2 + 4\sigma_{sl}^2 + \sigma_e^2}$$

$$h_n^2 = \frac{4\sigma_{gca}^2}{4\sigma_{gca}^2 + 4\sigma_{sca}^2 + 4\sigma_{gl}^2 + 4\sigma_{sl}^2 + \sigma_e^2}$$

Where:

h_b^2 = Broad sense heritability.

h_n^2 = Narrow sense heritability.

σ_g^2 = Total genetic variance.

σ_p^2 = Phenotypic variance.

σ_{gca}^2 = Variance due to general combining ability effect.

σ_{sca}^2 = Variance due to specific combining ability effects.

σ_{gl}^2 = Variance due to general combining ability × location interaction.

σ_{sl}^2 = Variance due to specific combining ability × location interaction.

σ_e^2 = Error variance.

The heritability was categorized according to Robinson *et al*. (1949) as follows:

Low = 0-30%, moderate = 30-60% and high = >60%.

3.6.5 Estimation of Genotypic and Phenotypic Correlations

Genotypic and phenotypic correlations were computed to determine the association between characters according to Singh and Chaudhary (1985). Correlation coefficients were calculated from the components of variance and covariance. The genotypic components were computed by equating the genotypic variances and covariances to the expected mean squares and cross products as follows:

Genotypic correlation $r_{g_{xy}} = \dfrac{\sigma^2_{g_x g_y}}{\sqrt{\sigma^2_{g_x} \times \sigma^2_{g_y}}}$

Where:

$r_{g_{xy}}$ = genotypic correlation coefficient of characters y and x,

$\sigma^2_{g_x g_y}$ = genotypic covariance of characters x and y,

$\sigma^2_{g_x}$ = genotypic variance of character x,

$\sigma^2_{g_y}$ = genotypic variance of character y,

Phenotypic correlation coefficient:

$$r_p = \frac{m_{g_x g_y}}{\sqrt{m_{g_x} \times m_{g_y}}}$$

Where:

r_p = phenotypic correlation of characters x and y,

m_{g_x} = entry mean squares of character x,

m_{g_y} = entry mean squares of character y,

$m_{g_x g_y}$ = entry mean product of the characters x and y.

CHAPTER FOUR

4.0 RESULTS

4.1 ANALYSIS OF VARIANCE

The analyses of variance for Bagauda, Samaru and combined across locations are presented in Tables 4.1, 4.2 and 4.3 respectively. The results for seventeen characters measured at Bagauda showed that the mean squares due to genotypes were highly significant ($p \leq 0.01$) for nine characters and significant ($p \leq 0.05$) for average fruit weight and leaf chlorophyll content (Table 4.1). There were no significant differences among the genotypes in respect to plant height, days to 50% flowering, number of branches per plant, number of flowers per cluster, fruit diameter and canopy temperature depression. Highly significant ($p \leq 0.01$) differences among the genotypes in Samaru were observed for thirteen characters and significant difference ($p \leq 0.05$) for number of flowers per cluster, leaf chlorophyll content and canopy temperature depression, while fruit diameter revealed non-significant differences among the genotypes (Tab le 4.2).

The result of the combined analysis across locations (Table 4.3) indicated highly significant genotypic variation ($p \leq 0.01$) for fifteen characters, while canopy temperature depression was significant ($p \leq 0.05$). The differences among genotypes in respect of fruit diameter was statistically not significant. The mean squares for genotype × location interaction were highly significant ($p \leq 0.01$) for number of branches per plant, number of flowers per plant, percent fruit set and leaf chlorophyll content (Table 4.3). Significant ($p \leq 0.05$) differences for genotypes × location were recorded for plant height and number of clusters per plant respectively. However, the mean

squares of genotype × location interaction for days to 50% flowering, number of flowers per cluster, number of fruits per cluster, average fruit weight, fruit length, fruit diameter, fruit shape index, fruit yield per plant and canopy temperature depression were statistically not significant (Table 4.3). The mean squares for location were highly significant ($p \leq 0.01$) for plant height, days to 50% flowering, number of branches per plant, number of clusters per plant, number of flowers per plant, number of fruits per plant, fruit yield per plant, percentage fruit set, leaf chlorophyll content and canopy temperature depression.

Table 4.1: Mean squares for seventeen agronomic, heat tolerance and physiological characters at Bagauda during 2014 rainy season

Source of variation	df	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Replication	2	41.82	5.69	4.51	16.34	0.64	583.85	0.31	38.12
Block(replication)	12	83.24	7.62	11.49	18.52	0.56	123.05	0.72	20.07
Genotype	24	92.60	6.26	10.32	30.60**	1.17	342.16**	0.87**	81.21**
Error	36	57.38	3.55	7.12	8.72	0.14	135.16	0.32	19.05

df = Degrees of freedom, PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant.

Table 4.1 continued

Source of variation	df	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Replication	2	310.20	0.41	0.22	0.03	1130.18	63.47	191.16	18.18	22159.18**
Block(replication)	12	320.87	0.21	0.07	0.03	11673.99	64.50	111.14	2.82	37.58
Genotype	24	264.83*	1.05**	1.07	0.11**	46842.15**	437.91**	127.44*	2.84	143.49
Error	36	141.13	0.29	0.12	0.04	12562.78	121.57	57.65	2.33	83.84

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

Table 4.2: Mean squares for seventeen agronomic, heat tolerance and physiological characters at Samaru during 2014 rainy season

Source of variation	df	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Replication	2	216.12	14.65	74.68	12.12	0.93	1008.31	0.25	144.78
Block(replication)	12	63.14	17.50	87.03	10.61	0.51	341.32	0.74	84.81
Genotype	24	126.38**	30.08**	118.37**	39.71**	1.97*	1832.62**	1.00**	155.45**
Error	36	26.87	7.50	16.17	4.99	0.99	276.84	0.31	47.25

df = Degrees of freedom, PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant.

Table 4.2 continued

Source of variation	df	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Replication	2	201.73	0.39	2.25	0.30	2713.37	50.51	112.59	3.11	15559.43
Block(replication)	12	76.03	0.39	0.18	0.06	34440.27	11.92	30.47	2.35	150.73
Genotype	24	196.63**	1.62**	0.07	0.13**	36442.69**	266.66**	53.19*	5.40*	289.52
Error	36	57.35	0.21	0.11	0.03	15617.90	17.49	27.69	2.60	327.45

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

Table 4.3: Mean squares for seventeen agronomic, heat tolerance and physiological characters combined across locations during 2014 rainy season

Source of variation	df	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Location	1	6084.75**	74.91**	7408.92**	1912.66**	0.52	182490.07**	0.02	8198.32**
Block(replication × location)	24	73.19	12.56	49.26	14.56	0.53	232.19	0.73	52.44
Replication(location)	4	128.97	10.17	39.59	14.23	0.78	796.08	0.28	91.45
Genotype	24	138.51**	27.53**	74.18**	57.40**	3.01**	1535.64**	1.86**	200.66**
Genotype × location	24	80.47*	8.81	54.51**	12.91*	0.13	639.14**	0.02	36.01
Error	72	42.13	5.53	11.65	6.85	1.09	205.10	0.31	33.15

df = Degrees of freedom, PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant.

Table 4.3 continued

Source of variation	df	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Location	1	29.06	0.57	0.69	0.01	6507841.92**	1082.13**	3080.85**	338.19**	1026.99*
Block(replication × location)	24	198.45	0.30	0.13	0.04	23057.13	38.21	70.80	2.59	94.16
Replication(location)	4	255.96	0.40	1.23	0.16	1921.78	56.10	151.88	10.65	18859.30
Genotype	24	325.04**	2.36**	0.12	0.20**	66310.62**	491.53**	71.41**	4.23*	214.88
Genotype × location	24	136.43	0.31	0.04	0.03	16974.22	213.03**	109.22**	4.01	218.13
Error	72	99.24	0.25	0.12	0.03	14090.34	69.53	42.67	2.47	205.64

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

4.2 Mean Performance

The mean performance of parents, crosses and checks for seventeen traits at Bagauda is presented in Table 4.4. Days to fifty percent flowering, ranged from 68.00 days (Roma VF, UC82 B and Icrixina) to 75.33 days (Tima × Roma Savana), with a mean of 70.47. Number of flowers per cluster, number of fruits per cluster and number of fruits per plant ranged from 4.40 (Tropimech × Roma Savana) to 6.93 (Icrixina × Rio Grande), 3.87 (Rio Grande × Tropimech) to 5.73 (Icrixina × Petomech) and 4.49 (Rio Grande × Roma Savana) to 26.60 (Roma VF) with a mean of 5.69, 30.50, 4.71 and 11.69, respectively. The mean performance of average fruit weight, fruit length, fruit diameter, fruit shape index, fruit yield per plant and canopy temperature depression ranged from 20.19g (Icrixina) to 51.54g (Thorgal F_1), 3.56cm (Icrixina) to 5.76cm (Rio Grande × Tima), 3.29cm (Tropimech × Roma Savana) to 4.08cm (UC82 B), 0.98 (Rio Grande × Petomech) to 1.62 (Petomech × Roma Savana), 86.80g (Rio Grande × Petomech) to 541.81g (Icrixina × Rio Grande) and 4.88^{O}C (Icrixina) to 9.10^{O}C (Icrixina × Tropimech) with a mean of 29.28, 4.64, 3.62, 1.27, 260.99 and 7.29, respectively.

Table 4.4: Mean performance of parents, crosses and checks for seventeen agronomic, heat tolerance and physiological characters at Bagauda during 2014 rainy season

Genotype	DFPFL	NFLPC	NFRPC	NFRPP	AFW (g)
Icrixina	68.00	6.33	4.53	15.53	20.19
Rio Grande	69.33	4.58	4.13	9.13	36.45
Tima	70.67	4.58	4.73	11.13	25.60
Tropimech	71.00	5.37	4.33	6.56	30.57
Petomech	70.33	4.75	4.27	6.43	26.57
Roma Savana	70.67	5.40	4.07	13.07	25.89
Icrixina × Rio Grande	70.00	6.93	5.47	14.80	44.73
Icrixina × Tima	70.33	6.42	5.67	16.20	21.08
Icrixina × Tropimech	68.33	6.79	5.67	16.67	21.52
Icrixina × Petomech	69.00	6.37	5.73	18.10	45.14
Icrixina × Roma Savana	70.33	6.87	5.20	20.45	21.45
Rio Grande × Tima	72.33	5.68	4.73	13.69	28.10
Rio Grande × Tropimech	70.33	4.50	3.87	7.51	29.23
Rio Grande × Petomech	73.00	5.09	4.47	4.56	34.37
Rio Grande × Roma Savana	70.33	6.52	4.67	4.49	39.34
Tima × Tropimech	69.67	6.07	5.27	10.89	23.17
Tima × Petomech	70.33	5.50	4.93	9.40	20.23
Tima × Roma Savana	75.33	6.17	4.93	8.00	25.36
Tropimech × Petomech	72.33	5.40	4.13	5.00	35.17
Tropimech × Roma Savana	75.00	4.40	4.00	9.04	23.08
Petomech × Roma Savana	69.33	5.68	4.80	21.88	23.65
Roma VF	68.00	5.84	4.53	26.60	20.39

Table 4.4 continued

Genotype	DFPFL	NFLPC	NFRPC	NFRPP	AFW (g)
UC82 B	68.00	6.05	5.07	7.88	30.38
Thorgal F_1	69.00	5.15	4.20	6.84	51.54
Jaguar F_1	70.67	5.18	4.40	8.36	27.78
Range	68.00-75.33	4.40-6.93	3.87-5.73	4.49-26.60	20.19-51.54
Mean	70.47	5.69	4.71	11.69	29.28
SE±	1.09	0.63	0.33	2.52	6.86
CV	2.67	19.11	11.92	37.34	40.58

DFPFL= Days to 50% flowering, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster NFRPP = Number of fruits per plant and AFW = average fruit weight.

Table 4.4 continued

Genotype	FRL (cm)	FRD (cm)	FRSI	FRYP (g)	CTD(^{o}C)
Icrixina	3.56	3.41	1.05	299.63	4.88
Rio Grande	5.27	3.70	1.42	157.81	7.78
Tima	4.90	3.73	1.32	260.47	8.55
Tropimech	4.64	3.58	1.30	91.40	7.74
Petomech	4.62	3.54	1.30	135.92	8.30
Roma Savana	5.06	3.62	1.40	321.67	7.84
Icrixina × Rio Grande	4.24	3.62	1.16	541.81	6.86
Icrixina × Tima	3.76	3.46	1.09	341.95	8.32
Icrixina × Tropimech	3.76	3.69	1.02	325.22	9.10
Icrixina × Petomech	3.63	3.70	0.98	354.60	7.24
Icrixina × Roma Savana	3.75	3.54	1.06	474.91	7.39
Rio Grande × Tima	5.76	3.80	1.54	252.33	8.51

Table 4.4 continued

Genotype	FRL (cm)	FRD (cm)	FRSI	FRYPP (g)	CTD (^{o}C)
Rio Grande × Tropimech	4.97	3.64	1.37	158.07	7.26
Rio Grande × Petomech	5.07	3.85	1.32	86.80	5.69
Rio Grande × Roma Savana	5.71	3.70	1.54	157.07	6.33
Tima × Tropimech	4.72	3.43	1.38	232.67	7.26
Tima × Petomech	4.33	3.67	1.18	190.33	7.37
Tima × Roma Savana	4.59	3.66	1.26	186.00	6.73
Tropimech × Petomech	4.97	3.36	1.48	145.50	6.85
Tropimech × Roma Savana	4.86	3.29	1.00	184.80	6.81
Petomech × Roma Savana	5.36	3.30	1.62	474.91	7.35
Roma VF	5.42	3.38	1.60	541.35	7.00
UC82 B	4.74	4.08	1.16	205.26	7.78
Thorgal F_1	4.04	3.90	1.04	216.95	6.60
Jaguar F_1	4.30	3.75	1.14	188.07	6.69
Range	3.56-5.76	3.29-4.08	0.98-1.62	86.80-541.81	4.88-9.10
Mean	4.64	3.62	1.27	260.99	7.29
SE±	0.31	0.20	0.12	64.71	0.88
CV	11.54	9.51	14.94	42.94	20.94

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, and CTD = Canopy temperature depression.

The mean performance at Samaru (Table 4.5) showed that the ranges for days to 50% flowering, number of flowers per cluster, number of fruits per cluster and number of fruits per plant were 61.00 days (Icrixina × Tropimech) to 75.33 days (Tima × Roma Savana), 4.42 (Tropimech × Roma Savana) to 7.87 (Icrixina × Roma Savana), 3.87 (Rio Grande × Tropimech) to 6.03 (Icrixina × Rio Grande) and 11.07 (Rio Grande × Roma Savana) to 38.33 (Roma VF) with a mean of 69.05, 5.81, 100.29, 4.73 and 26.47, respectively. Average fruit weight, fruit length, fruit diameter, fruit shape index, fruit yield per plant and canopy temperature depression ranged from 20.00g (Petomech × Roma Savana) to 53.00g (Thorgal F_1), 3.46cm (Icrixina × Tropimech) to 6.20cm (Rio Grande × Roma Savana), 3.38cm (Tropimech × Petomech) to 4.09 (Thorgal F_1), 0.91 (Icrixina × Tropimech) to 1.68 (Rio Grande × Tropimech), 445.70g (Petomech) to 894.10g (Icrixina × Tima) and 4.83^{O}C (Thorgal F_1) to 13.03^{O}C (Tima × Roma Savana) with a mean of 28.40, 4.76, 3.75, 1.28, 677.58 and 10.29, respectively.

Table 4.5: Mean performance of parents, crosses and checks for agronomic, heat tolerance and physiological characters at Samaru during 2014 rainy season

Genotype	DFPFL	NFLPC	NFRPC	NFRPP	AFW (g)
Icrixina	67.00	6.33	4.53	28.27	20.29
Rio Grande	69.67	4.58	4.13	21.40	33.69
Tima	70.67	5.22	4.73	28.67	27.68
Tropimech	71.00	5.37	4.33	25.47	27.48
Petomech	69.33	4.75	4.27	19.13	22.67
Roma Savana	70.67	5.40	4.07	33.80	22.46
Icrixina × Rio Grande	62.00	7.60	6.03	36.07	23.79
Icrixina × Tima	66.00	6.97	5.67	34.20	26.84
Icrixina × Tropimech	61.00	7.45	5.67	30.87	24.18
Icrixina × Petomech	69.00	6.37	5.73	33.20	18.57
Icrixina × Roma Savana	70.33	7.87	5.20	31.20	24.91
Rio Grande × Tima	69.00	6.02	4.73	23.93	34.76
Rio Grande × Tropimech	70.33	4.50	3.87	19.33	28.24
Rio Grande × Petomech	73.00	5.09	4.47	19.87	38.14
Rio Grande × Roma Savana	70.33	6.58	4.67	11.07	48.23
Tima × Tropimech	69.67	6.07	5.27	24.93	27.21
Tima × Petomech	67.00	5.50	4.93	25.80	25.54
Tima × Roma Savana	75.33	6.17	4.9333	30.60	23.48
Tropimech × Petomech	72.33	5.40	4.13	23.00	25.80
Tropimech × Roma Savana	71.00	4.42	4.00	22.47	26.49
Petomech × Roma Savana	66.00	5.68	4.80	37.20	20.00
Roma VF	68.00	5.84	4.53	38.33	21.36

Table 4.5 continued.

Genotype	DFPFL	NFLPC	NFRPC	NFRPP	AFW (g)
UC82 B	68.00	5.72	5.07	31.73	23.47
Thorgal F_1	69.00	5.15	4.20	13.9	53.00
Jaguar F_1	70.67	5.18	4.40	17.40	41.62
Range	61.00-75.33	4.42-7.87	3.87-6.03	11.07-38.33	20.00-53.00
Mean	69.05	5.81	4.73	26.47	28.40
SE±	1.58	0.58	0.32	3.97	4.37
CV	3.97	17.11	11.71	25.96	26.67

DFPFL= Days to 50% flowering, NFLPC = Number of flowers per cluster, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight.

Table 4.5 continued.

Genotype	FRL (cm)	FRD (cm)	FRSI	FRYPP (g)	CTD (^{o}C)
Icrixina	3.52	3.64	0.96	573.20	9.69
Rio Grande	5.77	3.89	1.50	565.70	11.59
Tima	4.310	3.73	1.16	774.10	11.54
Tropimech	4.93	3.84	1.31	690.80	9.26
Petomech	4.42	3.63	1.22	445.70	11.27
Roma Savana	5.14	3.61	1.42	727.20	9.47
Icrixina × Rio Grande	3.60	3.61	1.01	842.90	10.48
Icrixina × Tima	3.53	3.41	1.04	894.10	9.37
Icrixina × Tropimech	3.46	3.81	0.91	726.90	8.60
Icrixina × Petomech	3.61	3.70	0.98	607.60	9.21
Icrixina × Roma Savana	4.58	3.67	1.24	754.70	9.04
Rio Grande × Tima	5.93	3.81	1.58	715.70	11.51
Rio Grande × Tropimech	6.20	3.75	1.68	476.70	11.05

Table 4.5 continued

Genotype	FRL (cm)	FRD (cm)	FRSI	FRYPP (g)	CTD (^{o}C)
Rio Grande × Petomech	5.88	4.03	1.47	657.10	11.03
Rio Grande × Roma Savana	6.04	4.15	1.49	539.80	10.91
Tima × Tropimech	4.58	3.94	1.21	668.50	11.99
Tima × Petomech	4.84	3.70	1.31	656.10	10.75
Tima × Roma Savana	4.62	3.71	1.26	699.10	13.03
Tropimech × Petomech	4.76	3.38	1.43	590.90	10.79
Tropimech × Roma Savana	4.67	3.81	1.24	600.90	9.68
Petomech × Roma Savana	5.38	3.50	1.55	745.80	11.00
Roma VF	5.24	3.63	1.44	805.10	10.11
UC82 B	4.20	4.01	1.05	733.60	10.57
Thorgal F_1	4.56	4.09	1.17	726.40	4.83
Jaguar F_1	5.36	3.80	1.42	720.90	10.56
Range	3.46-6.20	3.38-4.09	0.91-1.68	445.70-894.10	4.83-13.03
Mean	4.76	3.75	1.28	677.58	10.29
SE±	0.27	0.19	0.10	72.15	0.93
CV	9.54	8.94	12.57	18.44	15.68

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content and CTD Canopy temperature depression.

Across location results (Table 4.6) indicates that, the mean performance for the days to 50% flowering, number of flowers per cluster, number of fruits per cluster and number of fruits per plant ranged from 64.67 days (Icrixina × Tropimech) to 75.33 days (Tima × Roma Savana), 4.42 (Tropimech × Roma Savana) to 7.37 (Icrixina × Roma Savana), 3.87 (Rio Grande × Tropimech) to 5.75 (Icrixina × Rio Grande), and 7.78 (Rio Grande × Roma Savana) to 32.47 (Roma VF) with average of 69.76, 5.75, 4.72 and 19.08, respectively. However, the ranges of average fruit weight, fruit length, fruit diameter, fruit shape index, fruit yield per plant and canopy temperature depression were 20.24g (Icrixina) to 52.27g (Thorgal F_1), 3.54cm Icrixina) to 5.88cm (Rio Grande × Roma Savana), 3.37cm (Tropimech × Petomech) to 4.04cm (UC82 B), 0.97 (Icrixina × Tropimech) to 1.59 (Petomech × Roma Savana), 290.83g (Petomech) to 692.37g (Icrixina × Rio Grande) and 5.72^0C (Thorgal F_1) to 10.04^0C (Tima) with a mean of 28.84, 4.70, 3.69, 1.28, 469.29 and 8.79, respectively.

Table 4.6: Mean performance of parents, crosses and checks for seventeen agronomic, heat tolerance and physiological characters combined across locations during 2014 rainy season

Genotype	DFPFL	NFLPC	NFRPC	NFRPP	AFW (g)
Icrixina	67.50	6.33	4.53	21.90	20.24
Rio Grande	69.50	4.58	4.13	15.27	35.07
Tima	70.67	5.22	4.73	19.90	26.64
Tropimech	71.00	5.37	4.33	16.01	29.02
Petomech	69.83	4.75	4.27	12.78	24.62
Roma Savana	70.67	5.40	4.07	23.43	24.17
Icrixina × Rio Grande	66.00	7.27	5.75	25.43	34.26
Icrixina × Tima	68.17	6.69	5.67	25.20	23.96
Icrixina × Tropimech	64.67	7.12	5.67	23.77	22.85
Icrixina × Petomech	69.00	6.37	5.73	25.65	31.86
Icrixina × Roma Savana	70.33	7.37	5.20	25.83	23.18
Rio Grande × Tima	70.67	5.85	4.73	18.81	31.88
Rio Grande × Tropimech	70.33	4.50	3.87	13.42	28.74
Rio Grande × Petomech	73.00	5.09	4.47	12.21	36.26
Rio Grande × Roma Savana	70.33	6.55	4.67	7.78	43.79
Tima × Tropimech	69.67	6.07	5.27	17.91	25.19
Tima × Petomech	68.67	5.50	4.93	17.60	22.89
Tima × Roma Savana	75.33	6.17	4.93	19.30	24.42
Tropimech × Petomech	72.33	5.40	4.13	14.00	30.49
Tropimech × Roma Savana	73.00	4.42	4.00	15.76	24.79
Petomech × Roma Savana	67.67	5.68	4.80	29.54	21.82
Roma VF	68.00	5.84	4.53	32.47	20.88
UC82 B	68.00	5.88	5.07	19.81	26.92

Table 4.6 continued.

Genotype	DFPFL	NFLPC	NFRPC	NFRPP	AFW (g)
Thorgal F_1	69.00	5.15	4.20	10.39	52.27
Jaguar F_1	70.67	5.18	4.40	12.88	34.70
Range	64.67-75.33	4.42-7.37	3.87-5.75	7.78-32.47	20.24-52.27
Mean	69.76	5.75	4.72	19.08	28.84
SE±	0.96	0.43	0.23	2.35	4.07
CV	3.37	18.12	11.82	30.17	34.55

PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant.

Table 4.6 continued

Genotype	FRL (cm)	FRD (cm)	FRSI	FRYPP (g)	CTD (^{o}C)
Icrixina	3.54	3.53	1.01	436.42	7.29
Rio Grande	5.52	3.79	1.46	361.74	9.69
Tima	4.61	3.73	1.24	517.27	10.04
Tropimech	4.79	3.71	1.30	391.10	8.50
Petomech	4.52	3.59	1.26	290.83	9.77
Roma Savana	5.10	3.61	1.41	524.43	8.66
Icrixina × Rio Grande	3.92	3.62	1.08	692.37	8.67
Icrixina × Tima	3.64	3.44	1.06	618.04	8.85
Icrixina × Tropimech	3.61	3.75	0.97	526.04	8.85
Icrixina × Petomech	3.62	3.70	0.98	481.10	8.22
Icrixina × Roma Savana	4.16	3.61	1.15	614.47	8.22
Rio Grande × Tima	5.85	3.80	1.56	484.00	10.01
Rio Grande × Tropimech	5.59	3.70	1.52	317.40	9.15

Table 4.6 continued

Genotype	FRL (cm)	FRD (cm)	FRSI	FRYPP (g)	CTD (^{o}C)
Rio Grande × Petomech	5.47	3.94	1.39	371.93	8.36
Rio Grande × Roma Savana	5.88	3.93	1.52	348.43	8.62
Tima × Petomech	4.59	3.69	1.25	423.20	9.06
Tima × Roma Savana	4.60	3.68	1.26	442.57	9.88
Tropimech × Petomech	4.87	3.37	1.45	368.22	8.82
Tropimech × Roma Savana	4.76	3.55	1.12	392.83	8.25
Petomech × Roma Savana	5.37	3.40	1.590	610.35	9.18
Roma VF	5.33	3.50	1.52	673.21	8.56
UC82 B	4.47	4.04	1.11	469.43	9.17
Thorgal F_1	4.30	3.99	1.10	471.68	5.72
Jaguar F_1	4.83	3.78	1.283	454.50	8.62
Range	3.54-5.88	3.37-4.04	0.97-1.59	290.83-692.37	5.72-10.04
Mean	4.70	3.69	1.28	469.29	8.79
SE±	0.21	0.14	0.07	48.46	0.64
CV	10.56	9.22	13.79	25.29	17.87

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content and CTD = Canopy temperature depression.

Genotype × location results (Table 4.7) showed that, the mean performance for plant height ranged from 40.30cm (Tropimech × Petomech) to 58.70cm (Roma VF) at Bagauda and from 53.07cm (UC 82B) to 86.83cm (Thorgal F_1) at Samaru with mean of 50.0cm and 62.81cm, respectively. Number of branches per plant ranged from 4.85 (Tropimech × Roma Savana) to 14.07 (Roma VF) at Bagauda and from 13.13 (Rio Grande × Tropimech) to 36.93 (Roma VF) with average of 9.52 and 23.58, respectively. For number of clusters per plant, the values ranged from 5.00 (Tima × Roma Savana) to 17.40 (Icrixina × Rio Grande) and 10.87(Thorgal F_1) to 24.53(Icrixina × Roma Savana) with mean of 9.89 and 17.04 for Bagauda and Samaru, respectively. Number of flowers per plant ranged from 15.42 (Rio Grande × Petomech) to 62.40 (Roma VF) with mean of 30.53 at Bagauda while at Samaru, the values ranged from 53.47 (Jaguar F_1) to 132.73 (Icrixina × Rio Grande) with mean of 100.29. Percentage fruit set ranged from 28.02% (Rio Grande × Roma Savana) to 73.95% (Icrixina × Rio Grande) and from 29.77% (Rio Grande × Roma Savana) to 74.10% (Icrixina × Tima) with average of 43.12 and 37.74 for Bagauda and Samaru, respectively. The values for leaf chlorophyll content ranged from 43.57 (Icrixina) to 65.97 (Jaguar F_1) for Bagauda and from 35.70 (UC82 B) to 55.83 (Tropimech × Petomech) for Samaru. The mean for leaf chlorophyll content were 55.56 and 46.49 for Bagauda and Samaru, respectively.

Table 4.7: Genotype × location interaction for agronomic, heat tolerance and physiological characters during 2014 rainy season

Genotype	PHT (cm)		NBPP		NCPP	
	Bagauda	Samaru	Bagauda	Samaru	Bagauda	Samaru
Icrixina	53.04	57.87	9.22	16.85	13.87	16.77
Rio Grande	51.13	58.73	10.00	16.23	6.92	12.30
Tima	56.11	53.93	11.40	16.13	6.78	15.97
Tropimech	50.87	53.23	9.07	14.80	5.00	16.37
Petomech	53.51	54.60	13.67	22.00	8.08	14.87
Roma Savana	46.63	67.90	9.067	35.73	13.53	20.47
Icrixina × Rio Grande	51.44	62.37	8.87	27.47	17.40	22.80
Icrixina × Tima	51.31	63.47	8.167	30.13	14.00	21.27
Icrixina × Tropimech	45.29	64.00	8.00	33.13	11.17	24.33
Icrixina × Petomech	58.13	61.00	9.53	29.93	10.52	22.93
Icrixina × Roma Savana	43.93	65.10	10.53	33.27	15.68	24.53
Rio Grande × Tima	46.91	66.90	9.10	18.73	8.67	13.17
Rio Grande × Tropimech	55.81	61.72	7.60	13.13	9.82	13.27
Rio Grande × Petomech	48.73	68.91	9.00	21.53	4.83	15.93
Rio Grande × Roma Savana	41.91	60.90	10.43	17.33	6.82	11.27

Table 4.7 continued

Genotype	PHT (cm)		NBPP		NCPP	
	Bagauda	Samaru	Bagauda	Samaru	Bagauda	Samaru
Tima × Tropimech	47.99	62.27	8.80	23.80	7.38	16.13
Tima × Petomech	48.43	60.73	9.40	20.13	8.22	15.73
Tima × Roma Savana	54.07	66.37	11.07	22.87	5.00	19.47
Tropimech × Petomech	40.30	54.10	6.80	18.27	8.17	12.60
Tropimech × Roma Savana	46.53	64.68	4.85	24.13	8.58	17.47
Petomech × Roma Savana	54.15	71.00	11.47	36.47	13.02	20.93
Roma VF	58.70	68.09	14.07	36.93	15.88	16.07
UC 82 B	47.83	53.07	10.40	29.13	10.60	16.00
Thorgal F_1	54.34	86.83	8.32	16.40	8.58	10.87
Jaguar F_1	44.69	62.47	9.20	14.87	8.83	14.40
Range	40.30-58.70	53.07-86.83	4.85-14.07	13.13-36.93	5.00-17.40	10.87-24.53
Mean	50.07	62.81	9.52	23.58	9.89	17.04
SE±	4.37	2.99	1.54	2.32	1.71	1.29
CV	15.13	8.25	28.03	17.06	29.84	13.11

PHT = Plant height, NBPP = Number of branches per plant, NCPP = Number of clusters per plant and NFLPP = Number of flowers per plant.

Table 4.7 continued

Genotype	NFLPP		PFRS (%)		LCC	
	Bagauda	Samaru	Bagauda	Samaru	Bagauda	Samaru
Icrixina	56.07	119.47	31.39	32.50	43.57	50.50
Rio Grande	23.80	62.53	40.95	38.98	55.60	43.10
Tima	19.33	111.53	49.74	33.56	61.57	46.10
Tropimech	15.67	87.47	37.01	34.63	59.37	45.50
Petomech	23.53	100.93	32.06	30.43	60.63	42.63
Roma Savana	32.93	104.20	41.09	36.61	51.83	46.23
Icrixina × Rio Grande	49.20	132.73	73.95	64.34	56.77	52.73
Icrixina × Tima	43.87	125.87	38.34	74.10	51.43	49.13
Icrixina × Tropimech	35.00	132.27	47.55	32.50	55.40	46.90
Icrixina × Petomech	45.72	126.40	62.88	33.86	55.60	47.17
Icrixina × Roma Savana	26.60	131.53	63.94	42.66	57.13	54.23
Rio Grande × Tima	26.60	73.40	49.45	35.25	48.73	44.23
Rio Grande × Tropimech	17.80	66.73	41.46	34.30	65.47	41.17
Rio Grande × Petomech	15.42	92.80	39.26	31.37	53.37	46.63
Rio Grande × Roma Savana	23.88	63.67	28.02	29.77	58.70	44.67
Tima × Tropimech	23.62	120.20	49.44	31.31	59.40	47.17

Table 4.7 continued

Genotype	NFLPP		PFRS (%)		LCC	
	Bagauda	Samaru	Bagauda	Samaru	Bagauda	Samaru
Tima × Petomech	27.63	83.87	34.58	35.62	61.07	43.90
Tima × Roma Savana	17.77	124.53	44.26	32.97	62.33	44.83
Tropimech × Petomech	20.71	72.20	29.62	35.64	52.80	55.83
Tropimech × Roma Savana	25.60	101.67	38.13	31.97	49.93	42.43
Petomech × Roma Savana	43.40	121.33	50.40	35.59	47.90	50.90
Roma VF	62.40	114.60	65.60	53.62	47.30	46.67
UC82 B	41.07	121.27	65.60	33.65	56.10	35.70
Thorgal F_1	22.40	62.67	33.40	31.98	50.93	48.13
Jaguar F_1	35.13	53.47	29.48	36.35	65.97	45.80
Range	15.42-62.40	53.47-132.73	28.02-73.95	29.77-74.10	43.57-65.97	35.70-55.83
Mean	30.53	100.29	43.12	37.74	55.56	46.49
SE±	6.71	9.61	6.37	2.42	4.38	3.04
CV	38.08	16.59	25.57	11.08	13.67	11.32

NFLPP = number of flowers per plant, PFRS = Percentage fruit set and LCC = Leaf chlorophyll content.

4.3 Combining ability

4.3.1 ANOVA for Combining Ability

The analysis of variance for combining ability of seventeen traits measured at Bagauda, Samaru and combined across locations are presented in Tables 4.8, 4.9 and 4.10, respectively. Analysis of variance for Bagauda (Table 4.8) indicated that mean squares due to parents were highly significant ($p \leq 0.01$) for number of clusters per plant, number of flowers per plant and fruit length. The parents vs. crosses were highly significant ($p \leq 0.01$) for number of fruits per cluster and significant ($p \leq 0.05$) for number of branches per plant, number of flowers per cluster and percentage fruit set, while other traits expressed non-significant differences. The mean squares due to crosses were highly significant ($p \leq 0.01$) for number of clusters per plant, number of flowers per plant, number of fruits per plant, fruit length, fruit shape index, fruit yield per plant and percentage fruit set. Days to 50% flowering and number of fruits per cluster showed significant differences at $p \leq 0.05$. The other traits expressed non-significant mean squares due to crosses. The mean squares due to general combining ability (GCA) were highly significant ($p \leq 0.01$) for number of clusters per plant, number of flowers per plant, number of fruits per cluster, number of fruits per plant, fruit length, fruit shape index, fruit yield per plant, and percentage fruit set. Days to 50% flowering, number of flowers per cluster, average fruit weight and cell membrane thermostability showed significant differences at $p \leq 0.05$, while the remaining traits recorded non-significant difference. Highly significant ($p \leq 0.01$) of specific combining ability (SCA) differences were observed for number of fruits per plant and percentage fruit set, while significant differences ($p \leq 0.05$) were noticed for Days to 50% flowering, number of clusters per plant, fruit shape index and fruit yield per plant.

Table 4.8: Mean squares of combining ability for agronomic, heat tolerance and physiological characters at Bagauda during 2014 rainy season

Source of variation	df	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Replication	2	77.31	10.87	10.08	40.01	1.89	451.02	1.02	82.36	180.82
Parents	5	30.60	3.87	10.07	42.21**	1.14	645.02**	0.19	39.64	89.99
Parents vs Cross	1	107.24	14.63	28.74*	10.95	4.90*	0.409	4.01**	38.743	31.24
Crosses	14	79.38	13.11*	8.76	41.30**	1.94	413.93**	1.11*	100.73**	223.94
GCA	5	24.66	13.23*	14.08	68.32**	3.49*	681.90**	2.50**	157.29**	339.18*
SCA	9	109.78	13.03*	5.80	26.29*	1.08	265.05	0.33	69.31**	159.92
Error	40	21.65	1.72	2.05	3.57	0.37	42.65	0.15	7.08	46.04

df = degrees of freedom, PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight. ** and * are significantly different at 1% and 5% levels of probability respectively.

Table 4.8 continued

Source of variation	df	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Replication	2	1.32	0.06	0.11	49740.14	421.73	90.48	2.90	18885.62
Parents	5	1.08**	0.04	0.05	27192.30	139.77	140.36	5.32	102.80
Parents vs Cross	1	0.03	0.00008	0.01	50394.79	699.96*	1.22	0.77	132.87
Crosses	14	1.49**	0.08	0.14**	57746.18**	502.57**	79.04	2.19	159.69
GCA	5	3.61**	0.10	0.23**	95134.71**	626.82**	19.77	3.02	225.62*
SCA	9	0.32	0.06	0.09*	36974.77**	433.33**	11196	1.74	123.06
Error	40	0.09	0.03	0.01	4657.63	38.57	20.77	0.78	27.93

df = degrees of freedom, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability respectively.

The analysis of variance for combining ability of Samaru (Table 4.9) revealed that the mean squares due to parents were highly significant ($p \leq 0.01$) for number of branches per plant, number of flowers per plant, fruit length, and fruit shape index; significant differences ($p \leq 0.05$) for plant height and number of clusters per plant, whereas the others traits were not significant. The mean squares due to parents vs. crosses showed highly significant ($p \leq 0.01$) for plant height, number of clusters per plant, number of flowers per cluster, number of fruits per cluster and percentage fruit set and significant differences for number of branches per plant. The mean squares due to crosses showed highly significant differences ($p \leq 0.01$) for days to 50% flowering, number of branches per plant, number of clusters per plant, number of flowers per cluster, number of flowers per plant, number of fruits per cluster, fruit length, fruit shape index and percentage fruit set. Significant ($p \leq 0.05$) differences were exhibited by average fruit weight and canopy temperature depression. Highly significant ($p \leq 0.01$) mean squares due to GCA were observed for days to 50% flowering, number of branches per plant, number of clusters per plant, number of flowers per cluster, number of flowers per plant, number of fruits per cluster, number of fruits per plant, fruit length, fruit shape index, percentage fruit set and canopy temperature depression while significant differences ($p \leq 0.05$) were recorded for fruit yield per plant. SCA recorded highly significant ($p \leq 0.01$) mean squares for days to 50% flowering, number of flowers per plant, fruit length and percentage fruit set and significant ($p \leq 0.05$) mean squares for number of clusters per plant and fruit shape index.

Table 4.9: Mean squares of combining ability for agronomic, heat tolerance and physiological characters at Samaru during 2014 rainy season

Source of variation	df	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Replication	2	233.82	22.02	32.27	20.97	0.65	526.77	0.19	240.34	259.82
Parents	5	89.33*	6.59	190.28**	21.34*	1.14	1235.56**	0.19	84.96	71.940
Parents Vs Cross	1	440.94**	10.42	248.60*	51.43**	8.98**	616.47	4.56**	8.09	53.28
Crosses	14	48.10	45.33**	138.85**	61.03**	3.37**	2108.76**	1.31**	157.97**	168.72*
GCA	5	37.08	52.06**	280.36**	138.63**	7.02**	3990.77**	2.89**	268.93**	267.61**
SCA	9	54.23	41.59**	60.23	17.92*	1.33	1063.20**	0.429	96.32	113.78
Error	40	11.63	3.79	12.28	2.27	0.31	105.08	0.15	19.92	22.61

df = degrees of freedom, PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight. ** and * are significantly different at 1% and 5% levels of probability respectively.

Table 4.9 continued

Source of variation	df	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Replication	2	0.25	1.73	0.29	4449.34	63.68	114.00	0.115	13596.05
Parents	5	1.80**	0.04	0.11**	45130.23	27.56	23.81	3.62	175.36
Parents Vs Cross	1	0.12	0.002	0.01	30881.20	237.58**	40.94	0.13	67.35
Crosses	14	2.73**	0.14	0.17**	35945.19	495.78**	56.20	4.30*	393.32
GCA	5	6.43**	0.13	0.36**	60121.03*	722.12**	53.60	8.69**	396.69
SCA	9	0.67**	0.14	0.06*	22514.17	370.04**	57.64	1.86	391.45
Error	40	0.07	0.04	0.01	7895.41	6.07	9.97	0.62	95.90

df = degrees of freedom, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability respectively.

The combining ability mean squares combined across locations are presented in Table 4.10. The mean squares due to locations were highly significant ($p \leq 0.01$) for plant height, days to 50% flowering, number of branches per plant, number of clusters per plant, number of flowers per plant, number of fruits per plant, fruit yield per plant, percentage fruit set, leaf chlorophyll content and canopy temperature depression and significant ($p \leq 0.05$) for fruit diameter. Highly significant ($p \leq 0.01$) mean squares regarding parents were observed for days to 50% flowering, average fruit weight, fruit length and fruit shape index, while significant ($p \leq 0.05$) mean squares were recorded for number of fruits per plant. The mean squares due to parents vs. cross were not significant for all traits except number of fruits per cluster, which recorded significant difference at ($p \leq 0.05$). The mean squares due to crosses showed highly significant ($p \leq 0.01$) differences for days to 50% flowering, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, fruit length, fruit diameter, fruit shape index, number of fruits per plant and fruit yield per plant. The number of flowers per plant expressed significant difference at $p \leq 0.05$. GCA mean squares revealed highly significant differences ($p \leq 0.01$) for number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, fruit length, fruit shape index and percentage fruit set, while significant differences ($p \leq 0.05$) were observed for days to 50% flowering and fruit yield per plant. Highly significant ($p \leq 0.01$) mean squares due to SCA were observed for number of flowers per cluster and number of fruits per cluster, and significant differences ($p \leq 0.05$) for number of fruits per plant, fruit diameter and fruit yield per plant. Parent × locations mean squares were highly significant ($p \leq 0.01$) for number of branches per plant and

significant for leaf chlorophyll content, while others traits exhibited non-significant difference. The mean squares due to parents vs. crosses × location were not significant for all traits except plant height and number of branches per plant which recorded highly significant differences ($p \leq 0.01$). The mean squares due to cross × location were highly significant ($p \leq 0.01$) for number of branches per plant, number of flowers per plant and percentage fruit set, whereas number of clusters, leaf chlorophyll content and canopy temperature depression showed significant differences at $p \leq 0.05$. GCA × location mean squares were highly significant ($p \leq 0.01$) for number of branches per plant, number of flowers per plant and canopy temperature depression, and non-significant for the others traits. The mean squares due to SCA × location revealed highly significant differences ($p \leq 0.01$) for percentage fruit set and significant ($p \leq 0.05$) for number of flowers per plant and leaf chlorophyll. The other traits expressed non-significant differences.

Table 4.10: Mean squares of combining ability for agronomic, heat tolerance and physiological characters combined across locations during 2014 rainy season

Source of variation	df	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Locations	1	4592.70**	89.17**	6260.40**	1947.08**	0.77	172269.85**	0.02	7219.96**	70.29
Replication(location)	4	4592.70	14.51	21.04	13.48	0.66	531.31	0.22	137.10	283.217
Parents	5	17.63	9.96**	96.49	50.56	2.28	1409.85	0.38	104.04*	153.44**
Parents vs Cross	1	56.64	0.18	54.15	54.93	13.57	324.33	8.55*	41.12	83.06
Crosses	14	84.50	46.61**	84.03	84.65**	5.14**	1867.16*	2.38**	232.69**	236.57
GCA	5	37.24	57.25*	166.48	191.24**	10.16**	3750.52	5.36**	408.97**	426.62
SCA	9	110.76	40.70	38.22	25.43	2.35**	820.84	0.73**	134.76*	131.00
Parent × location	5	102.29	0.50	103.87**	12.99	0.00	470.73	0.00	20.56	8.49
Parents vs Cross × location	1	491.5**	24.87	223.19**	7.46	0.31	292.55	0.01	5.71	1.46
Crosses × location	14	42.98	11.82	63.58**	17.69*	0.17	655.53**	0.03	26.01	156.09
GCA × location	5	24.51	8.05	127.95**	15.71	0.35	922.14**	0.03	17.25	180.17
SCA × location	9	53.24	13.92	27.81	18.78	0.07	507.41*	0.03	30.87	142.71
Error	80	16.64	1.67	7.16	2.92	0.34	73.87	0.15	13.50	34.32

df = degrees of freedom, PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight. ** and * are significantly different at 1% and 5% levels of probability respectively.

Table 4.10 continued

Source of variation	df	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Locations	1	0.34	0.57*	0.002	5258608.46**	1312.22**	2381.63**	321.28**	784.95
Replication(location)	4	0.28	0.95	0.16	2613.84	99.77	252.92	4.52	16240.84
Parents	5	2.67**	0.06	0.15**	49862.02	111.37	37.93	6.54	193.75
Parents Vs Cross	1	0.02	0.0005	0.00002	80087.35	876.57	28.14	0.14	194.70
Crosses	14	3.83**	0.17**	0.28**	78066.21**	660.45	46.88	1.20	304.06
GCA	5	9.81**	0.18	0.57**	136734.03*	1258.59**	10.99	3.71	452.27
SCA	9	0.52	0.17*	0.11	45472.97*	328.15	66.82	1.05	221.73
Parent × location	5	0.21	0.02	0.01	22460.51	55.95	126.24*	2.40	84.40
Parents vs Cross × location	1	0.13	0.001	0.02	1188.64	60.98	14.02	0.76	5.51
Crosses × location	14	0.39	0.05	0.03	15625.16	337.89**	88.36*	4.50*	248.94
GCA × location	5	0.24	0.06	0.01	18521.71	90.34	62.39	8.00**	170.04
SCA × location	9	0.47	0.04	0.04	14015.97	475.42**	102.79*	2.55	292.77
Error	80	0.08	0.03	0.01	6276.52	22.32	15.37	0.70	61.92

df = degrees of freedom, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability.** and * are significantly different at 1% and 5% levels of probability respectively.

4.3.2 Estimates of General and Specific Combining Ability Variances and Average Degree of Dominance

The components for GCA variance, SCA variance, GCA/SCA ratio and average degree of dominance of sixteen traits measured at Bagauda, Samaru and combined across locations are presented in Tables 4.11, 4.12 and 4.13, respectively. SCA variances were higher than GCA variances (Table 4.11) for all traits except number of fruits per cluster and fruit length. The GCA/SCA ratios were therefore less than unity for all traits, except number of fruits per cluster and fruit length and negative values were obtained for plant height and leaf chlorophyll content. The average degree of dominance showed positive and greater than unity values for all traits, except number of fruits per cluster and fruit length, whereas plant height and leaf chlorophyll content recorded negative average degree of dominance. Higher SCA variances than GCA variances were observed for all traits except number of fruits per cluster and fruit length at Samaru (Table 4.12). Less than unity GCA/SCA ratios were recorded for all traits, except number of fruits per cluster and fruit length. The average degree of dominance was greater than unity for all traits, except number of fruits per cluster and fruit length.

The results combined across locations (Table 4.13) showed that SCA variances were higher than GCA variances for all traits, except number of branches per plant, number of clusters per plant, number of flowers per plant, number of fruits per cluster, average fruit weight, fruit length, fruit shape index, percentage fruit set, canopy temperature depression and cell membrane thermostability. GCA/SCA ratios observed for all traits were less than unity, except for number of clusters per plant, number of fruits per cluster fruit length and canopy temperature depression. Plant height, number of branches per plant, average fruit weight, percentage fruit set, canopy temperature

depression and cell membrane thermostability expressed negative GCA/SCA ratio. The average degree of dominance for all traits were positive and greater than unity except for number of branches per plant, number of clusters per plant, number of flowers per plant, number of fruits per cluster, average fruit weight, fruit length fruit shape index, percentage fruit set and cell membrane thermostability which recorded values less than unity.

Table 4.11: Estimates of combining ability variance components for agronomic, heat tolerance and physiological characters at Bagauda during 2014 rainy season

Variance	Characters								
	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
σ^2_{GCA}	-3.55	0.008	0.35	1.75	0.10	17.37	0.09	3.67	7.47
σ^2_{SCA}	29.38	3.77	1.25	7.57	0.24	74.13	0.06	20.74	37.96
σ^2_D	117.51	15.08	5.00	30.29	0.95	296.53	0.24	82.97	151.84
σ^2_A	-14.19	0.03	1.38	7.01	0.40	69.48	0.36	14.66	29.88
GCA/SCA Ratio	-0.12	0.002	0.28	0.23	0.42	0.23	1.51	0.18	0.20
DH	-2.89	21.27	1.90	2.08	1.54	2.07	0.81	2.38	2.25

PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight. σ^2_{GCA} = General combining ability variance, σ^2_{SCA} = Specific combining ability, σ^2_D = Dominance variance, σ^2_A = Additive variance and DH = Average degree of dominance.

Table 4.11 continued

Variance	Characters							
	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
σ^2_{GCA}	0.14	0.002	0.006	2423.33	8.05	-3.84	0.05	4.27
σ^2_{SCA}	0.08	0.01	0.03	10772.38	131.65	30.40	0.32	31.71
σ^2_A	0.55	0.01	0.02	9693.32	32.22	-15.37	0.21	17.09
σ^2_D	0.31	0.04	0.11	43089.52	526.61	121.59	1.28	126.84
GCA/SCA Ratio	1.79	0.17	0.22	0.22	0.06	-0.13	0.17	0.13
DH	0.75	2.45	2.14	2.11	4.04	-2.81	2.45	2.72

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression, CMT = Cell membrane thermostability, σ^2_{GCA} = General combining ability variance, σ^2_{SCA} = Specific combining ability, σ^2_D = Dominance variance, σ^2_A = Additive variance and DH = Average degree of dominance.

Table 4.12: Estimates of combining ability variance components for agronomic, heat tolerance and physiological characters at Samaru during 2014 rainy season

Variance	Characters								
	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
σ^2_{GCA}	-0.71	0.44	9.17	5.03	0.24	121.98	0.10	7.19	6.41
σ^2_{SCA}	14.20	12.60	15.98	5.22	0.34	319.37	0.09	25.47	30.39
σ^2_D	56.80	50.40	63.93	20.87	1.36	1277.49	0.37	101.87	121.56
σ^2_A	-2.86	1.75	36.69	20.12	0.95	487.93	0.41	28.77	25.64
GCA/SCA ratio	-0.05	0.03	0.57	0.96	0.70	0.38	1.10	0.28	0.21
DH	4.46	5.37	1.32	1.02	1.20	1.62	0.95	1.88	2.18

PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight. σ^2_{GCA} = General combining ability variance, σ^2_{SCA} = Specific combining ability, σ^2_D = Dominance variance, σ^2_A = Additive variance and DH = Average degree of dominance.

Table 4.12 continued

Variance	Characters							
	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
σ^2_{GCA}	0.24	-0.0004	0.01	1566.95	14.67	-0.17	0.28	0.22
σ^2_{SCA}	0.20	0.03	0.02	4872.92	121.32	15.89	0.41	98.52
σ^2_D	0.80	0.13	0.07	19491.68	485.29	63.56	1.65	394.07
σ^2_A	0.96	-0.002	0.05	6267.81	58.68	-0.67	1.14	0.87
GCA/SCA ratio	1.20	-0.01	0.75	0.32	0.12	-0.01	0.69	0.002
DH	0.91	8.06	1.15	1.76	2.88	9.74	1.21	21.24

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression, CMT = Cell membrane thermostability, σ^2_{GCA} = General combining ability variance, σ^2_{SCA} = Specific combining ability, σ^2_D = Dominance variance, σ^2_A = Additive variance and DH = Average degree of dominance.

Table 4.13: Estimates of combining ability variance components for agronomic, heat tolerance and physiological characters across locations during 2014 rainy season

Variance	Characters								
	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
σ^2_{GCA}	-3.06	0.69	5.34	6.91	0.33	122.07	0.19	11.43	12.32
σ^2_{SCA}	11.30	4.81	-4.23	1.29	0.36	27.55	0.12	18.13	-4.18
$\sigma^2_{GCA\times location}$	-2.39	-0.49	8.35	-0.26	0.02	34.56	0.00	-1.14	3.12
$\sigma^2_{SCA\times location}$	12.20	4.08	6.88	5.29	-0.09	144.51	-0.04	5.79	36.13
σ^2_D	45.19	19.25	-16.91	5.16	1.45	110.21	0.47	72.50	-16.73
σ^2_A	-12.25	2.76	21.38	27.64	1.30	488.28	0.77	45.70	49.27
GCA/SCA Ratio	-0.27	0.14	-1.26	5.36	0.90	4.43	1.65	0.63	-2.95
DH	3.69	2.64	0.89	0.43	1.06	0.48	0.78	1.26	0.58

PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight. σ^2_{GCA} = General combining ability variance, σ^2_{SCA} = Specific combining ability, σ^2_D = Dominance variance, σ^2_A = Additive variance and DH = average degree of dominance.

Table 4.13 continued

Variance	Characters							
	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
σ^2_{GCA}	0.39	0.0004	0.02	3802.54	38.77	-2.33	0.11	9.61
σ^2_{SCA}	0.02	0.02	0.01	4974.64	-1.62	-3.59	-0.58	-4.54
$\sigma^2_{GCA\times location}$	-0.02	0.002	-0.003	375.48	-32.09	-3.37	0.45	-10.23
$\sigma^2_{SCA\times location}$	0.13	0.003	0.01	2579.82	151.03	29.14	0.62	76.95
σ^2_D	0.09	0.08	0.05	19898.54	-6.49	-14.36	-2.30	-18.14
σ^2_A	1.55	0.002	0.08	15210.18	155.07	-9.305	0.44	38.42
GCA/SCA Ratio	17.87	0.02	1.44	0.76	-23.88	0.65	-0.19	-2.12
DH	0.24	6.93	0.83	1.14	0.20	1.24	2.28	-0.69

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression, CMT = Cell membrane thermostability, σ^2_{GCA} = General combining ability variance, σ^2_{SCA} = Specific combining ability, σ^2_D = Dominance variance, σ^2_A = Additive variance and DH = average degree of dominance.

4.3.3 Estimates of Combining Ability Effects

Tables 4.14, 4.15 and 4.16 indicate estimates of general combining ability (gca) effect and specific combining ability (sca) effects for seventeen traits measured at Bagauda, Samaru and combined across locations, respectively.

4.3.3.1 Estimates of Combining Ability Effects for Bagauda

The estimates of general combining ability effect (gca) and specific combining ability effect (sca) for sixteen traits measured at Bagauda are presented in Table 4.17.

4.3.3.1.1 Plant height

The gca effects were not significant for all parents regarding plant height. However, Icrixina had the highest positive gca effects (1.28) followed by Petomech (1.19). The estimates of sca effects for plant height were positive and significant in hybrids Rio Grande × Tropimech (9.12) and Tropimech × Petomech (7.62).

4.3.3.1.2 Days to 50% Flowering

Among the parents, Roma Savana (1.25) and Icrixina (-1.83) showed significant positive and negative gca effects for days to 50% flowering respectively. Out of fifteen hybrids, six revealed significant sca effects, of which three hybrids expressed significant negative sca effects for days to 50% flowering.

4.3.3.1.3 Number of branches per plant

Tropimech (-2.12) recorded highest significant gca effects among the parents while Tropimech × Roma Savana (-2.89) showed significant negative sca effects for number of branches per plant.

4.3.3.1.4 Number of clusters per plant

Highly significant positive gca effect was observed for Icrixina (4.750). Out of fifteen hybrids, two hybrids exhibited positive effects.

4.3.3.1.5 Number of flowers per cluster

Icrixina showed highly significant positive gca effects (0.98), while significant negative gca effects were recorded for Tropimech (-0.57). Only Tropimech × Roma Savana revealed significant negative sca effects (-0.95) for this trait.

4.3.3.1.6 Number of flowers per plant

Among the parents, Icrixina expressed highly significant positive gca effects for a number of flowers per plant. Significant positive sca effects were observed for Icrixina × Rio Grande (11.93) and Petomech × Roma Savana (13.97), while Icrixina × Roma (-14.71) recorded highly significant negative sca effects for number of flowers per plant.

4.3.3.1.7 Number of fruits per cluster

Highly significant positive gca effects were recorded for Icrixina (0.81) and significant negative gca effect for Tropimech (-0.39) for number of fruits per cluster. None of the hybrids indicated significant sca effects.

4.3.3.1.8 Number of fruits per plant

The estimates of gca effects revealed that Icrixina (6.50) and Rio Grande (-3.80) showed highly significant positive and negative gca effects for number of fruits per

plant respectively, whereas Tropimech (-2.78) expressed significant negative gca effect for this trait. Highly significant positive sca effect was noticed in Rio Grande × Tima (5.95). Rio Grande × Roma Savana (-4.67) and Tima × Roma Savana (-4.44) exhibited significant negative sca effect for number of fruits per plant.

4.3.3.1.9 Average fruit weight

Among the parents, only Tima (-6.67) recorded significant negative gca effect. The sca effect was not significant among the hybrids for average fruit weight.

4.3.3.1.10 Fruit length

Highly significant positive gca effects were observed in Rio Grande (0.65) and Icrixina (-1.00) respectively. The highest significant positive sca effect was expressed by the cross Rio Grande × Tima (0.48).

4.3.3.1.11 Fruit Diameter

Parents and crosses showed non-significant differences for gca and sca effects for fruit diameter.

4.3.3.1.12 Fruit shape index

Rio Grande recorded highly significant gca effect (0.15), while Icrixina (-0.26) showed highly significant negative gca effect among the parents. The estimates of sca effects for fruit shape index were significant in three crosses. A highly significant positive sca effect was observed for Petomech × Roma Savana (0.26), but negative significant sca effects were recorded for Tima × Petomech (-0.18) and Tropimech × Roma Savana (-0.29) respectively.

4.3.3.1.13 Fruit yield per plant

The parents Icrixina (167.27) and Tropimech (-80.63) revealed highly significant positive gca and significant negative gca effects, respectively. Out of fifteen crosses, Icrixina × Rio Grande (143.96) and Petomech × Roma Savana (203.24) exhibited highly significant positive sca effects, while Rio Grande × Petomech (-114.62) recorded significant negative sca effect for fruit yield per plant.

4.3.3.1.14 Percentage fruit set

The parent Icrixina (14.06) indicated highly significant gca effect, whereas Tropimech (-6.06) recorded significant negative gca effects among the parents. Highly significant positive sca effects were observed for Icrixina × Rio Grande (13.38) and significant for Tima × Tropimech (13.00). Icrixina × Tima (-18.21) and Rio Grande × Roma Savana (-17.07) showed significant negative sca effects among the crosses.

4.3.3.1.15 Leaf chlorophyll content

The estimates of gca effects were non-significant for all the parents. Only Rio Grande × Tima (-9.16) showed significant negative sca effects among the crosses.

4.3.3.1.16 Canopy temperature depression

The parents and crosses revealed non-significant gca and sca effects for the trait.

4.3.3.1.17 Cell membrane thermostability

The parents and crosses also revealed non-significant gca and sca effects for the trait.

Table 4.14: General combining ability and specific combining ability effects of agronomic, heat tolerance and physiological characters for Bagauda during 2014 rainy season

Parent/cross	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Icrixina	1.28	-1.83**	0.14	4.75**	0.98**	14.18**	0.81**	6.50**
Rio Grande	-0.04	0.17	0.12	-0.56	-0.19	-5.64	-0.33	-3.80**
Tima	0.94	0.67	0.50	-1.62	0.09	-4.00	0.26	-0.51
Tropimech	-2.27	0.08	-2.12**	1.16	-0.57*	-5.24	-0.39*	-2.78*
Petomech	1.19	-0.33	0.42	-1.25	-0.36	2.30	-0.11	-0.32
Roma Savana	-1.10	1.25*	0.95	-0.16	0.05	-1.61	-0.23	0.91
SE(gi)±	1.502	0.423	0.462	0.610	0.196	2.108	0.125	0.859
Icrixina × Rio Grande	1.21	0.60	-0.30	3.25*	0.25	11.93*	0.09	0.05
Icrixina × Tima	0.10	0.43	-1.38	0.92	-0.54	4.95	-0.30	-1.83
Icrixina × Tropimech	-2.72	-0.98	1.07	-2.37	0.49	-2.68	0.35	0.90
Icrixina × Petomech	6.66	0.10	0.07	-2.94*	-0.15	0.50	0.14	-0.12
Icrixina × Roma Savana	-5.25	-0.15	0.53	1.14	-0.05	-14.71**	-0.28	1.00
Rio Grande × Tima	-2.97	0.43	-0.42	0.89	-0.12	-4.30	-0.10	5.95**
Rio Grande × Tropimech	9.12*	-0.98	0.70	1.58	-0.64	-0.06	-0.31	2.04
Rio Grande × Petomech	-1.42	2.10*	-0.44	-3.31*	-0.26	-9.98	0.003	-3.37
Rio Grande × Roma Savana	-5.94	-2.15*	0.46	-2.41	0.76	2.40	0.32	-4.67*
Tima × Tropimech	0.32	-2.15*	1.52	0.21	0.66	4.12	0.50	2.14

Table 4.14 continued

Parent/cross	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Tima × Petomech	-2.69	-1.07	-0.42	1.15	-0.13	0.59	-0.11	-1.81
Tima × Roma Savana	5.24	2.35*	0.71	-3.17*	0.14	-5.37	0.003	-4.44*
Tropimech × Petomech	7.62*	-1.52	0.40	-0.63	-0.44	5.09	0.26	3.95
Tropimech × Roma Savana	0.90	2.60*	-2.89*	-0.05	-0.95*	3.71	-0.28	-1.13
Petomech × Roma Savana	5.06	-2.65*	1.19	4.48**	0.01	13.97*	0.24	9.25
$SE(s_{ij})\pm$	3.406	0.960	0.048	1.383	0.445	4.780	0.283	1.948

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant. ** and * are significantly different at 1% and 5% levels of probability respectively.

Table 4.14 continued

Parent/cross	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Icrixina	2.11	-1.00**	0.01	-0.26**	167.27**	14.06**	-0.59	0.64	-0.98
Rio Grande	7.79	0.65**	0.16	0.15**	-43.17	0.43	1.09	-0.43	0.29
Tima	-6.67*	0.003	0.02	0.03	-41.37	-3.59	1.07	0.46	2.16
Tropimech	-3.33	0.03	-0.10	-0.02	-80.63*	-6.06*	1.08	0.23	2.31
Petomech	3.26	0.05	-0.02	0.06	-29.16	-3.42	-1.99	-0.47	-8.05
Roma Savana	-3.16	0.27	-0.08	0.04	27.07	-1.42	-0.67	-0.44	4.26
SE(gi)±	2.190	0.097	0.056	0.032	22.027	2.004	1.471	0.285	1.712

Table 4.14 continued

Parent/cross	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Icrixina × Rio Grande	5.74	-0.04	-0.15	0.002	143.96**	13.38**	0.53	-0.62	2.19
Icrixina × Tima	-3.46	0.13	-0.16	0.05	-57.70	-18.21**	-4.79	-0.05	6.43
Icrixina × Tropimech	-6.35	0.11	0.18	0.03	-35.18	-6.54	-0.83	0.96	-4.40
Icrixina × Petomech	10.67	-0.05	0.11	-0.09	-57.27	6.16	2.44	-0.21	-6.89
Icrixina × Roma Savana	-6.60	-0.15	0.01	0.01	6.18	5.21	2.65	-0.08	2.67
Rio Grande × Tima	-1.23	0.48*	0.03	0.09	63.13	6.52	-9.16*	1.21	-7.50
Rio Grande × Tropimech	-4.33	-0.34	-0.02	-0.03	8.12	1.00	7.56	0.18	-4.25
Rio Grande × Petomech	-5.78	-0.26	0.12	-0.16	-114.62*	-3.83	-1.47	-0.69	2.17
Rio Grande × Roma Savana	5.60	0.16	0.02	0.09	-100.58	-17.07**	2.55	-0.08	7.39
Tima × Tropimech	4.07	0.06	-0.08	0.11	80.92	13.00*	1.51	-0.70	5.86
Tima × Petomech	-5.46	-0.35	0.09	-0.18*	-12.89	-4.50	6.25	0.11	2.74
Tima × Roma Savana	6.08	-0.32	0.13	-0.07	-73.45	3.18	6.20	-0.57	-7.53
Tropimech × Petomech	-6.14	-0.26	0.12	-0.17	18.47	6.99	2.03	0.19	-3.65
Tropimech × Roma Savana	0.47	-0.09	0.03	-0.29**	-35.39	-0.48	-6.21	-0.26	-0.86
Petomech × Roma Savana	-5.56	0.40	-0.20	0.26**	203.24**	9.16	-5.18	0.98	-1.67
$SE(s_{ij})\pm$	4.966	0.220	0.127	0.073	49.952	4.546	3.336	0.646	3.87

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability respectively.

4.3.3.2 Estimates of Combining Ability Effects for Samaru

The estimates of general combining ability (gca) effects and specific combining ability (sca) effects for seventeen traits measured at Samaru are presented in Table 4.15.

4.3.3.2.1 Plant height

The estimates of gca effects were not significantly different among the parents. Among the crosses, only Tropimech × Petomech (6.18) exhibited significant positive sca effect.

4.3.3.2.2 Days to 50% flowering

Highly significant positive gca effects were observed for Roma Savana (2.22), while negatively and significantly gca effect was recorded for Icrixina (-3.94). Four and three crosses showed significant positive and negative sca effects, respectively. The highest significant positive sca effect was observed for Tima × Roma Savana (3.57) followed by Icrixina × Petomech (3.32), Icrixina × Roma Savana (3.32) and Rio Grande × Petomech (3.23), whereas, Petomech × Roma Savana (-5.85) revealed highest significant negative sca effect followed by Icrixina × Tropimech (-3.93) and Tima × Petomech (-3.35).

4.3.3.2.3 Number of branches per plant

Among the parents, Icrixina (7.62) and Rio Grande (-6.31) expressed highly significant positive and negative gca effects, respectively. The estimates of sca effects were not significantly different among the crosses.

4.3.3.2.4 Number of clusters per plant

The estimates of gca effects were highly significant positive for Icrixina (6.13) and significant negative for Rio Grande (-3.54) and Tropimech (-1.70). Among crosses, Tropimech × Petomech (3.20) and Petomech × Roma Savana (2.67) showed significant positive sca effects while Rio Grande × Roma Savana (-4.08) exhibited significant negative sca effects.

4.3.3.2.5 Number of flowers per cluster

Icrixina showed highly significant positive gca effect (1.42), whereas Tropimech (-0.68) and Petomech (-0.63) exhibited significant negative gca effects. Out of fifteen crosses, only Tropimech × Roma Savana (-1.06) recorded highest significant negative sca effects.

4.3.3.2.6 Number of flowers per plant

The parent Icrixina (31.430) and Rio Grande (-23.43) recorded highly significant positive and negative gca effects, respectively. Highly significant positive sca effects were observed for Tima × Tropimech (21.89) and significant positive sca effects were recorded in Icrixina × Rio Grande (20.12), Tropimech × Petomech (18.30) and Petomech × Roma Savana (18.42), while Rio Grande × Roma Savana (-22.43) expressed highly significant negative sca effects for number of flowers per plant.

4.3.3.2.7 Number of fruits per cluster

Among the parents, Icrixina recorded highly significant gca effects (0.90), while Tropimech exhibited significant negative gca effects (-0.44). The estimates of sca effects for the trait were not significant among the crosses.

4.3.3.2.8 Number of fruits per plant

Highly significant positive and negative gca effects were observed for Icrixina (7.74) and Rio Grande (-6.08) respectively. Significant positive sca effects were recorded for Icrixina × Rio Grande (7.49) and Petomech × Roma Savana (9.67), whereas Rio Grande × Roma Savana (-9.26) expressed significant negative sca effects for the trait.

4.3.3.2.9 Average fruit weight

Highly significant positive gca effects were observed for Rio Grande (8.61) among the parent, while significant negative gca effects were recorded in Icrixina (-5.11). Out of fifteen crosses, only Rio Grande × Roma Savana recorded highly significant positive sca effect (10.78) for the trait.

4.3.3.2.10 Fruit length

The estimates of gca effects revealed that Rio Grande (0.90) and Roma Savana (0.35) showed highly significant positive gca effects, whereas Icrixina exhibited highly significant negative gca effects. Among the crosses, Icrixina × Roma Savana (0.73) and Icrixina × Rio Grande (-0.84) indicated highly significant positive and negative sca effects, respectively. The significant sca effects were also observed in Rio Grande × Tropimech (0.54) among the crosses.

4.3.3.2.11 Fruit diameter

The estimates of gca and sca effects were not significant among the parents and crosses for the trait.

4.3.3.2.12 Fruit shape index

The estimates of gca effects were not significant among the parents for fruit shape index. Among the crosses, only Icrixina × Roma Savana (0.08) and Rio Grande × Tropimech (0.20) revealed significant positive sca effects.

4.3.3.2.13 Fruit yield per plant

Parents Icrixina (108.48) and Tropimech (-80.08) showed highly significant positive and significant negative gca effects, respectively. Significant negative sca effects for fruit yield were observed only in Icrixina × Petomech (-145.64).

4.3.3.2.14 Percentage fruit set

Highly significant positive gca effects were observed for parents Icrixina (13.43) and Tima (3.87) for percentage fruit set. Tropimech (-7.01), Petomech (-5.42) and Roma Savana (-5.20) exhibited significant negative gca effects for the trait. Among the crosses, four and eight crosses showed significant positive and negative sca effects, respectively. Significant positive sca effects were observed for Icrixina × Tima (18.04) followed by Icrixina × Rio Grande (11.84), Petomech × Roma Savana (7.46) and Tropimech × Roma Savana (5.42). Highest significant negative sca effects were found in Icrixina × Petomech (-12.81) followed by Icrixina × Tropimech (-12.67), Tropimech × Petomech (-9.32) and Rio Grande × Tima (-7.69).

4.3.3.2.15 Leaf chlorophyll content

Among the parents, only Icrixina showed significant positive gca effects for leaf chlorophyll content. The estimates of sca effects for leaf chlorophyll content revealed highly significant negative sca effects for the crosses Tropimech × Petomech (-7.54) and Icrixina × Petomech (-5.29).

4.3.3.2.16 Canopy temperature depression

Tima recorded highly significant positive gca effects (0.90) while Icrixina showed highly significant negative gca effect (-1.53). Out of fifteen crosses, only Tima × Roma Savana expressed significant positive sca effects (1.30) for the canopy temperature depression.

4.3.3.2.17 Cell membrane thermostabilty

The parents and crosses showed non-significant gca and sca effects for the trait.

Table 4.15: General combining ability and specific combining ability effects of agronomic, heat tolerance and physiological characters for Samaru during 2014 rainy season

Parent/cross	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Icrixina	-0.48	-3.94**	7.62**	6.31**	1.42**	31.43**	0.90**	7.74**
Rio Grande	0.74	0.14	-6.31**	-3.54**	-0.19	-23.43**	-0.23	-6.08**
Tima	0.47	0.72	-1.94	-1.21	0.04	1.20	0.21	1.22
Tropimech	-2.77	0.06	-2.74	-1.70*	-0.68*	-7.50	-0.44*	-3.49
Petomech	-0.52	0.81	0.72	-0.62	-0.63*	-6.62	-0.16	1.12
Roma Savana	2.55	2.22*	2.66	0.76	0.04	4.92	-0.28	-0.51
SE(gi)±	1.101	0.628	1.131	0.486	0.180	3.308	0.125	1.440
Icrixina × Rio Grande	-1.47	-3.02	1.47	1.91	0.26	20.12*	0.43	7.49*
Icrixina × Tima	-0.10	0.40	-0.23	-1.96	-0.61	-11.38	-0.38	-1.68
Icrixina × Tropimech	3.68	-3.93*	3.57	1.60	0.60	3.72	0.27	-0.29
Icrixina × Petomech	-1.57	3.32*	-3.10	-0.88	-0.54	-3.03	0.05	-2.58
Icrixina × Roma Savana	-0.54	3.23*	-1.70	-0.67	0.29	-9.43	-0.37	-2.94
Rio Grande × Tima	2.12	-0.68	2.30	-0.20	0.06	-8.98	-0.18	1.87
Rio Grande × Tropimech	0.18	1.32	-2.50	0.39	-0.74	-6.95	-0.40	1.99
Rio Grande × Petomech	5.13	3.23*	2.43	1.98	-0.20	18.24*	-0.08	-2.09
Rio Grande × Roma Savana	-5.96	-0.85	-3.70	-4.08**	0.62	-22.43**	0.24	-9.26*
Tima × Tropimech	0.99	0.07	3.80	0.93	0.60	21.89**	0.56	0.29

Table 4.15 continued

Parent/cross	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Tima × Petomech	-2.79	-3.35*	-3.33	-0.56	-0.02	-15.33	-0.06	-3.46
Tima × Roma Savana	-0.23	3.57*	-2.53	1.79	-0.02	13.80	0.06	2.97
Tropimech × Petomech	6.18*	-2.65	4.40	3.20*	-0.60	18.30*	0.21	1.54
Tropimech × Roma Savana	1.33	-0.10	-0.47	0.28	-1.06*	-0.36	-0.22	-0.44
Petomech × Roma Savana	5.40	-5.85**	8.40	2.67*	0.16	18.42*	0.29	9.67*
$SE(s_{ij})\pm$	2.696	1.425	2.565	1.103	0.408	7.503	0.231	3.480

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant. ** and * are significantly different at 1% and 5% levels of probability respectively.

Table 4.15 continued

Parent/cross	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Icrixina	-5.11*	-1.28**	-0.12	-0.32	108.48**	13.43**	3.21*	-1.53**	2.58
Rio Grande	8.61**	0.94**	0.17	0.19	-40.02	0.32	-1.97	0.54	8.86
Tima	-0.22	-0.10	-0.02	-0.02	60.32	3.87**	-2.01	0.96**	0.52
Tropimech	-1.70	-0.06	0.01	0.001	-82.08*	-7.01**	-0.95	-0.18	-3.32
Petomech	-2.67	0.15	-0.09	0.07	-33.70	-5.42**	1.78	-0.01	-8.29
Roma Savana	1.09	0.35**	0.05	0.08	-13.00	-5.20**	-0.06	0.21	-0.35
SE(gi)±	1.535	0.085	0.065	0.032	28.678	0.795	1.019	0.254	3.16

Table 4.15 continued

Parent/cross	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Icrixina × Rio Grande	-7.45	-0.84**	-0.18	-0.16	96.01	11.84**	4.03	0.91	-6.24
Icrixina × Tima	4.42	0.13	-0.18	0.08	46.88	18.04**	0.47	-0.62	0.54
Icrixina × Tropimech	3.25	0.016	0.19	-0.06	22.01	-12.67**	-2.82	-0.26	-1.09
Icrixina × Petomech	-1.39	-0.03	0.18	-0.06	-145.64*	-12.81**	-5.29*	0.18	18.83
Icrixina × Roma Savana	1.18	0.73**	0.01	0.08*	-19.27	-4.32*	3.62	-0.21	-12.03
Rio Grande × Tima	-1.37	0.31	-0.08	0.12	16.91	-7.69**	0.75	-0.56	0.21
Rio Grande × Tropimech	-6.42	0.54*	-0.16	0.20*	-79.62	2.24	-3.37	0.12	-6.35
Rio Grande × Petomech	4.45	0.01	0.22	-0.08	52.33	-2.29	-0.64	-0.07	-1.14
Rio Grande × Roma Savana	10.78**	-0.03	0.20	-0.07	-85.64	-4.10*	-0.77	-0.40	13.51
Tima × Tropimech	1.39	-0.05	0.23	-0.07	11.85	-4.31*	2.67	0.64	-1.21
Tima × Petomech	0.69	0.02	-0.08	-0.03	-49.00	-1.59	-3.33	-0.76	-8.97
Tima × Roma Savana	-5.14	-0.40	-0.05	-0.10	-26.64	-4.45*	-0.56	1.30*	9.42
Tropimech × Petomech	-2.43	0.11	0.27	-0.06	-28.26	-9.32**	-7.54**	-0.41	-5.42
Tropimech × Roma Savana	-0.65	-0.41	0.02	-0.13	17.50	5.42*	-4.02	-0.92	3.24
Petomech × Roma Savana	-6.17	0.11	-0.19	0.11	114.05	7.46**	1.72	0.23	-14.14
SE(sij)±	3.480	0.194	0.146	0.072	65.036	1.803	2.311	0.576	7.17

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability respectively.

4.3.3.3 Estimates of Combining Ability Effects combined across locations

Table 4.16, shows estimates of general combining ability effect (gca) and specific combining ability effect (sca) for seventeen traits combined across locations.

4.3.3.3.1 Plant height

The estimates of gca effects were not significant among all the parents. Among fifteen crosses, only Tropimech × Petomech (6.90) recorded significant positive sca effect for plant height.

4.3.3.3.2 Days to 50% flowering

Parents Roma Savana (1.74) and Icrixina (-2.89) showed highly significant positive and negative gca effects, respectively. Two and four crosses exhibited significant positive and negative sca effects, respectively. The highest significant positive sca effect was observed for Tima × Roma Savana (2.96), while highest significant negative sca effect was recorded for Petomech × Roma Savana (-4.25).

4.3.3.3.3 Number of branches per plant

Among the parents, only Icrixina showed significant positive gca effects (3.88) for number of branches per plant. The estimates of sca effect were not significant among the crosses for number of branches per plant.

4.3.3.3.4 Number of clusters per plant

Icrixina indicated highly significant positive gca effects (5.53) and Rio Grande recorded significant negative gca effect (-2.05). The estimates of sca effects for number of clusters per plant were not significant among the crosses.

4.3.3.3.5 Number of flowers per cluster

Highly significant positive gca effects were recorded for Icrixina (1.11) while highly significant negative gca effects were also observed for Tropimech (-0.63) and Petomech (-0.49) respectively. Significant positive sca effects were recorded for Rio Grande × Roma Savana (0.69) and Tima × Tropimech (0.63), while Tropimech × Roma Savana exhibited highly significant negative sca effects (-1.00) followed by Rio Grande × Tropimech (-0.69) and Icrixina × Tima (-0.58).

4.3.3.3.6 Number of flowers per plant

Icrixina expressed highly significant positive gca effects (22.81) among the parents for number of flowers per plant. Out of fifteen crosses, none exhibited significant sca effects for the trait.

4.3.3.3.7 Number of fruits per cluster

The parents which showed significant positive gca effects were Icrixina (0.85) and Tima (0.23). Significant negative gca effects were observed for Tropimech (-0.42), Rio Grande (-0.28) and Roma Savana (-0.25). Among the crosses, only Tima × Tropimech (0.53) expressed highly significant positive sca effects for the trait.

4.3.3.3.8 Number of fruits per plant

Highly significant positive gca effects were recorded for the parent Icrixina (7.12), whereas Rio Grande exhibited significant negative gca effect. Only two crosses revealed significant sca effects. Highly significant positive sca effects were observed for

Petomech × Roma Savana (9.46) and significant negative sca effects were noticed for Rio Grande × Roma Savana (-6.97).

4.3.3.3.9 Average fruit weight

Rio Grande exhibited highly significant positive gca effects (8.20) for average fruit weight among the parents. Out of fifteen crosses, only Rio Grande × Roma Savana show significant positive sca effects (8.19).

4.3.3.3.10 Fruit length

Highly significant positive gca effects were recorded for Rio Grande (0.79) and Roma Savana (0.31) while significant negative gca effects were observed for Icrixina (-1.14). Among the crosses, Rio Grande × Tima showed highly significant positive sca effect (0.39) while Icrixina × Rio Grande (-0.44) and Tima × Roma Savana (-0.36) exhibited significant negative sca effects for fruit length.

4.3.3.3.11 Fruit diameter

Among the parents, only Rio Grande revealed significant positive gca effects (0.17) for fruit diameter. The estimates of sca effects for fruit diameter were not significant among the crosses.

4.3.3.3.12 Fruit shape index

Rio Grande (0.17) and Icrixina (-0.29) recorded highly significant positive and negative gca effects, respectively. Out of fifteen crosses, Petomech × Roma Savana (0.18) and Tropimech × Roma Savana (-0.21) expressed highly significant positive and negative sca effects, respectively.

4.3.3.3.13 Fruit yield per plant

Icrixina recorded highly significant positive gca effects (137.88) among the parents. The estimates of sca effects for fruit yield per plant were not significant among the crosses.

4.3.3.3.14 Percentage fruit set

Highly significant positive negative gca effects were observed for Icrixina (13.74) and Tropimech (-6.54) respectively. Whereas, Petomech expressed significant negative gca effect (-4.42). Icrixina × Rio Grande (12.61) and Petomech × Roma Savana (8.13) showed highly significant sca effects, respectively. Highly significant negative sca effects were recorded for Icrixina × Tropimech (-9.60) and Rio Grande × Roma Savana (-10.59).

4.3.3.3.15 Leaf chlorophyll content

The estimates of gca and sca effects were not significant among all the parents and the crosses.

4.3.3.3.16 Canopy temperature depression

The estimates of gca and sca effects revealed non-significant differences among the parents and among the crosses.

4.3.3.3.17 Cell membrane thermostability

The parents and crosses expressed non-significant gca and sca effects for the trait.

Table 4.16: General combining ability and specific combining ability effects for agronomic, heat tolerance and physiological characters across locations during 2014 rainy season

Parent/cross	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Icrixina	0.40	-2.89**	3.88*	5.53**	1.11**	22.81**	0.85**	7.12**
Rio Grande	0.35	0.15	-3.10	-2.05*	-0.19	-14.54	-0.28*	-4.94*
Tima	0.71	0.69	-0.72	-1.42	0.07	-1.40	0.23*	0.36
Tropimech	-2.52	0.07	-2.43	-1.43	-0.63**	-6.37	-0.42**	-3.14
Petomech	0.33	0.24	0.57	-0.94	-0.49**	-2.16	-0.14	0.40
Roma Savana	0.73	1.74**	1.80	0.30	0.04	1.66	-0.25*	0.20
SE(gi)±	1.317	0.417	0.864	0.552	0.188	2.774	0.125	1.186
Icrixina × Rio Grande	-0.13	-1.21	0.59	2.58	0.25	16.03	0.26	3.77
Icrixina × Tima	0.002	0.42	-0.81	-0.52	-0.58*	-3.22	-0.34	-1.75
Icrixina × Tropimech	0.48	-2.46*	2.32	-0.39	0.55	0.52	0.31	0.31
Icrixina × Petomech	2.55	1.71	-1.52	-1.91	-0.34	-1.26	0.09	-1.35
Icrixina × Roma Savana	-2.90	1.54	-0.58	0.24	0.12	-12.07	-0.32	-0.97
Rio Grande × Tima	-0.43	-0.13	0.94	0.35	-0.03	-6.64	-0.14	3.91
Rio Grande × Tropimech	4.65	0.17	-0.90	0.99	-0.69*	-3.50	-0.36	2.01
Rio Grande × Petomech	1.86	2.67*	1.00	-0.67	-0.23	4.13	-0.04	-2.73
Rio Grande × Roma Savana	-5.95	-1.50	-1.62	-3.24	0.69*	-10.02	0.28	-6.97*
Tima × Tropimech	0.66	-1.04	2.66	0.57	0.63*	13.00	0.53**	1.21

Table 4.16 continued

Parent/cross	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP
Tima × Petomech	-2.74	-2.20*	-1.88	0.29	-0.08	-7.37	-0.09	-2.64
Tima × Roma Savana	2.50	2.96**	-0.91	-0.69	0.06	4.22	0.03	-0.74
Tropimech × Petomech	6.90*	-2.08*	2.40	1.29	-0.52	11.69	0.24	2.74
Tropimech × Roma Savana	1.11	1.25	-1.68	0.12	-1.00**	1.67	-0.25	-0.79
Petomech × Roma Savana	5.23	-4.25**	4.80	3.57*	0.13	16.19	0.27	9.46**
$SE(s_{ij})\pm$	2.986	0.946	1.958	1.251	0.427	6.291	0.283	2.689

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant. ** and * are significantly different at 1% and 5% levels of probability respectively.

Table 4.16 continued

Parent/cross	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Icrixina	-1.50	-1.14**	-0.05	-0.29**	137.88**	13.74**	1.31	-0.44	0.80
Rio Grande	8.20**	0.79**	0.17*	0.17**	-41.60	0.38	-0.44	0.06	4.57
Tima	-3.45	-0.05	-0.003	0.01	9.47	0.14	-0.47	0.71	1.34
Tropimech	-2.52	-0.01	-0.05	-0.01	-81.36	-6.54**	0.06	0.03	-0.50
Petomech	0.30	0.10	-0.05	0.07	-31.43	-4.42*	-0.10	-0.24	-8.17
Roma Savana	-1.03	0.31**	-0.02	0.06	7.03	-3.31	-0.37	-0.11	1.96
SE(gi)±	1.891	0.091	0.056	0.032	25.570	1.525	1.265	0.270	2.54

Table 4.16 continued

Parent/cross	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Icrixina × Rio Grande	-0.86	-0.44**	-0.17	-0.08	119.99	12.61**	2.28	0.14	-2.02
Icrixina × Tima	0.48	0.13	-0.17	0.07	-5.41	-0.08	-2.16	-0.34	3.48
Icrixina × Tropimech	-1.55	0.06	0.18	-0.01	-6.58	-9.60**	-1.83	0.35	-2.75
Icrixina × Petomech	4.64	-0.04	0.14	-0.08	-101.45	-3.37	-1.43	-0.01	5.97
Icrixina × Roma Savana	-2.71	0.29	0.01	0.10	-6.55	0.45	3.14	-0.15	-4.68
Rio Grande × Tima	-1.30	0.39*	-0.03	0.11	40.02	-0.59	-4.21	0.33	-3.65
Rio Grande × Tropimech	-5.37	0.10	-0.09	0.09	-35.75	1.62	2.09	0.15	-5.30
Rio Grande × Petomech	-0.67	-0.12	0.17	-0.12	-31.146	-3.06	-1.06	-0.38	0.52
Rio Grande × Roma Savana	8.19*	0.07	0.11	0.01	-93.11	-10.59**	0.89	-0.24	10.45
Tima × Tropimech	2.73	0.01	0.07	0.020	46.38	4.35	2.09	-0.03	2.32
Tima × Petomech	-2.39	-0.17	0.08	-0.11	-30.95	-3.04	1.46	-0.33	-3.11
Tima × Roma Savana	0.47	-0.36*	0.04	-0.09	-50.04	-0.64	2.82	0.37	0.95
Tropimech × Petomech	-4.28	-0.08	0.19	-0.12	-4.90	-1.16	-2.76	-0.11	-4.53
Tropimech × Roma Savana	-0.09	-0.25	0.03	-0.21**	-8.95	2.47	-5.11	-0.59	1.19
Petomech × Roma Savana	-5.87	0.26	-0.19	0.18**	158.65	8.31*	-1.73	0.61	-7.91
$SE(s_{ij})\pm$	4.288	0.207	0.126	0.073	57.986	3.458	2.869	0.612	5.76

AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability respectively.

4.4 Estimates of Heterosis

The percent better parent heterosis for Bagauda, Samaru and combined across locations are presented in Tables 4.17, 4.18 and 4.19, respectively.

4.4.1 Heterobeltiosis for Bagauda

The heterobeltiosis of hybrids at Bagauda is presented in Table 4.17.

4.4.1.1 Plant Height

Seven out 15 hybrids showed significant negative heterobeltiosis for plant height. The heterobeltiosis effects ranged from -24.69% (Tropimech × Petomech) to 9.15% (Rio Grande × Tropimech).

4.4.1.2 Days to fifty percent flowering

Negative heterosis over better parent was observed for days to 50% flowering in one hybrid, while three hybrids exhibited significant positive heterobeltiosis and ranged from -3.76% (Icrixina × Tropimech) to 6.59% (Tima × Roma Savana).

4.4.1.3 Number of branches per plant

Twelve hybrids expressed highly significant negative heterosis for number of branches per plant over the better parent. Among them, hybrid Icrixina × Roma Savana exhibited highly significant positive heterosis (14.21%). The range of heterosis was -50.22% to 14.21% for Tropimech × Petomech and Icrixina × Roma Savana respectively.

4.4.1.4 Number of clusters per plant

Five and six hybrids out of fifteen indicated highly significant positive and negative heterosis for the number of clusters per plant over the better parent. Three hybrids revealed non-significant positive heterosis. The highest positive heterosis over the better parent was observed in the hybrid Rio Grande × Tropimech (41.91%) and the minimum for the Icrixina × Tima (0.94%).

4.4.1.5 Number of flowers per cluster

Ten crosses expressed highly significant positive heterosis over the better parent for number of flowers per cluster and two hybrids showed significant negative heterosis over the better parent. The values ranged from -18.52% (Tropimech × Roma Savana) to 24.02% (Rio Grande × Tima).

4.4.1.6 Number of flowers per plant

The range of heterosis over better parent was from -52.56% (Icrixina × Roma Savana) to 31.79% (Petomech × Roma Savana). Out fifteen hybrids, only two hybrids showed significant positive heterosis, while eight hybrids had significant negative heterosis over the better parent for this trait.

4.4.1.7 Number of fruits per cluster

Highly significant positive heterosis were manifested by eleven crosses, one hybrid exhibited no heterobeltiosis effect, whereas, three hybrids had highly significant negative heterosis over the better parent. The highest positive heterosis was observed for the hybrid Icrixina × Petomech (26.49%) followed by the cross Icrixina × Tropimech (25.17%), Icrixina × Rio Grande (20.75%) and Icrixina × Tima (19.87%).

4.4.1.8 Number of fruits per plant

Percent heterosis over better parent ranged from -65.65% (Rio Grande × Roma Savana) to 67.41% (Petomech × Roma Savana). Out of fifteen hybrids, five and nine crosses showed significant positive and negative heterosis over the better parent.

4.4.1.9 Average fruit weight

The heterosis over better parent ranged from -29.60 (Icrixina × Tropimech) to 69.89% (Icrixina × Petomech). There were two and six hybrids that expressed significant positive and negative heterosis over better parent, respectively.

4.4.1.10 Fruit length

Among fifteen hybrids, four and eleven hybrids revealed highly significant positive and negative heterosis over the better parent, respectively. The heterobeltiosis varied from -25.89% (Icrixina × Roma Savana) to 9.30% (Rio Grande × Tima).

4.4.1.11 Fruit diameter

Highly significant positive and negative heterosis over better parents were recorded in four and nine crosses, respectively. Rio Grande × Roma Savana indicated no heterotic effect among the hybrids. The heterobeltiosis effects ranged from -8.84% (Petomech × Roma Savana) to 4.52% (Icrixina × Petomech).

4.4.1.12 Fruit shape index

Five hybrids showed highly significant positive heterosis for fruit shape index, while ten crosses expressed highly significant negative heterosis over the better parent. The

range of heterosis varied from -28.57% to 15.17% for the Tropimech × Roma Savana and Petomech × Roma Savana, respectively.

4.4.1.13 Fruit yield per plant

The magnitude of heterosis over the better parent was not significant for all the hybrids. However, eight and seven hybrids showed significant positive and negative heterosis over the better parent, respectively. The hybrid Icrixina × Rio Grande (80.83%) exhibited maximum positive heterosis followed by Petomech × Roma Savana (47.64%), Icrixina × Roma Savana (47.64%) and Icrixina × Petomech (18.35%) and lowest positive heterosis was recorded for Rio Grande × Tropimech (0.16%).

4.4.1.14 Percentage Fruit set

Five hybrids expressed highly significant positive heterosis over better parent, while four hybrids exhibited significant negative heterosis over the better parent. The heterobeltiosis effects ranged from -31.81% (Rio Grande × Roma Savana) to 96.13% (Icrixina × Petomech).

4.4.1.15 Leaf chlorophyll content

The better parent heterosis for leaf chlorophyll content varied from -20.85% (Rio Grande × Tima) to 10.27% (Rio Grande × Tropimech). Only five exhibited non-significant positive heterosis and two hybrids showed significant negative heterosis over the better parent.

4.4.1.16 Canopy temperature depression

The magnitude of heterobeltiosis for canopy temperature depression ranged from -31.45% (Rio Grande × Petomech) to 17.57% (Icrixina × Tropimech). Out fifteen hybrids, only Icrixina × Tropimech showed highly significant positive heterosis over better parent while thirteen crosses recorded highly significant negative heterosis over the better parent.

4.4.1.17 Cell membrane thermostability

Only Icrixina × Tima expressed significant positive heterosis over better parent, while seven hybrids exhibited significant negative heterosis over the better parent at 30^{o}C. The heterobeltiosis effects ranged from -33.20% (Icrixina × Petomech) to 18.66% (Icrixina × Tima). At 40^{o}C, only two hybrids recorded significant heterobeltiosis, whereas, twelve hybrids showed significant negative heterosis over the better parent and range from -70.45 (Icrixina × Tropimech) to 25.15% (Rio Grande × Tropimech). Out of fifteen hybrids, only five and four hybrids at 50^{o}C recorded significant positive and negative heterobeltiosis, respectively. The range of heterobeltiosis varied from -70.85% (Icrixina × Petomech) to 83.65% (Rio Grande × Tropimech).

Table 4.17**:** Percent better parent heterosis of hybrids for agronomic, heat tolerance and physiological characters at Bagauda during 2014 rainy season

Hybrid	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Icrixina × Rio Grande	-3.02	0.97	-11.30**	25.45**	9.48**	-12.25	20.75**	-4.70	22.72*
Icrixina × Tima	-8.55	-0.48	-28.36**	0.94	1.42	-21.76*	19.87**	4.31	-17.66
Icrixina × Tropimech	-14.61*	-3.76*	-13.23**	-19.47**	7.27**	-37.58**	25.17**	7.34*	-29.60**
Icrixina × Petomech	8.63	-1.89	-30.29**	-24.15**	0.63	-18.46	26.49**	16.55**	69.89**
Icrixina × Roma Savana	-17.18*	-0.48	14.21**	13.05**	8.53**	-52.56**	14.79**	31.68**	-17.15
Rio Grande × Tima	-16.4*	2.35	-20.18**	25.29**	24.02**	11.76	0.00	23.00**	-22.92*
Rio Grande × Tropimech	9.15	-0.94	-24.00**	41.91**	-16.20**	-25.21*	-10.62**	-17.74**	-19.81*
Rio Grande × Petomech	-8.93	3.80*	-34.16**	-40.22**	7.16**	-35.21**	4.68**	-50.05**	-5.71
Rio Grande × Roma Savana	-18.03**	-0.48	4.30	-49.59**	20.74**	-27.48**	13.08**	-65.65**	7.93
Tima × Tropimech	-14.47**	-1.87	-22.81**	8.85**	13.04**	22.19*	11.42**	-2.16	-24.21*
Tima × Petomech	-13.69*	-0.48	-31.24**	1.73	15.79**	17.42	4.23**	-15.54**	-23.86*
Tima × Roma Savana	-3.64	6.59**	-2.89	-63.05**	14.26**	-46.04**	4.23**	-38.79**	-2.05
Tropimech × Petomech	-24.69**	1.87	-50.22**	1.11	0.56	-11.98	-4.62**	-23.78**	15.05
Tropimech × Roma Savana	-8.53	5.63**	-46.53**	-36.59**	-18.52**	-22.26*	-7.62**	-30.83**	-24.50*
Petomech × Roma Savana	1.20	-1.90	-16.09**	-3.77	5.19**	31.79**	12.41**	67.41**	-10.99
SE±	6.185	1.538	2.179	2.411	0.887	9.492	0.462	3.564	9.610

PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight.

Table 4.17 continued

Hybrid	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT		
								(30°C)	(40°C)	(50°C)
Icrixina × Rio Grande	-19.54**	-2.16**	-18.31**	80.83	80.59**	2.10	-11.82**	-9.59	-28.02**	-44.569**
Icrixina × Tima	-23.27**	-7.24**	-17.42**	14.12	-22.92*	-16.47*	-2.69*	18.66*	-43.15**	-27.52*
Icrixina × Tropimech	-18.97**	3.07**	-21.54**	8.54	28.48**	-6.69	17.57**	-17.55*	-70.45**	34.17**
Icrixina × Petomech	-21.43**	4.52**	-24.62**	18.35	96.13**	-8.30	-12.77**	-33.20**	-67.79**	-70.85**
Icrixina × Roma Savana	-25.89**	-2.21**	-24.29**	47.64	55.61**	10.23	-5.74**	-1.77	-38.68**	-12.45
Rio Grande × Tima	9.30**	1.88**	8.45**	-3.13	-0.58	-20.85**	-0.47	-11.03	-55.58**	21.87*
Rio Grande × Tropimech	-5.69**	-1.62**	-3.52**	0.16	1.25	10.27	-6.68**	-30.86**	25.15**	83.65**
Rio Grande × Petomech	-3.80**	4.05**	-7.04**	-45.00	-4.13	-11.97	-31.45**	-17.59*	-36.96**	32.50**
Rio Grande × Roma Savana	8.35**	0.00	8.45**	-51.17	-31.81**	5.58	-19.26**	2.03	15.88*	67.15**
Tima × Tropimech	-3.67**	-8.04**	4.55**	-10.67	-0.60	-3.52	-15.09**	11.75	-5.41	15.47
Tima × Petomech	-11.63**	-1.61**	-10.61**	-26.93	-30.48**	-0.81	-13.80**	-19.18*	-27.85**	4.41
Tima × Roma Savana	-9.29**	-1.88**	-10.00**	-42.18	-11.02	1.23	-21.29**	-15.41*	-40.00**	-3.00
Tropimech × Petomech	7.11**	-6.15**	13.85**	7.05	-19.97*	-11.07	-17.47**	-1.49	-30.13**	9.87
Tropimech × Roma Savana	-3.95**	-9.12**	-28.57**	-42.55	-7.20	-3.67	-13.14**	-1.68	2.99	12.00
Petomech × Roma Savana	5.93**	-8.84**	15.71**	47.64	22.66*	-7.58	-11.45**	-20.38*	-23.56*	-31.56**
SE±	0.440	0.283	0.163	91.516	9.003	6.199	1.246	7.48	7.224	10.483

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

4.4.2 Heterobeltiosis for Samaru

The heterobeltiosis for seventeen traits at Samaru was presented in Table 4.18.

4.4.2.1 Plant height

Six hybrids expressed significant positive heterosis over the better parent. The hybrid Rio Grande × Roma Savana exhibited negative significant heterosis among the hybrids. The estimates of heterobeltiosis ranged from -10.31% (Rio Grande × Roma Savana) to 17.1% (Rio Grande × Petomech).

4.4.2.2 Days to fifty percent flowering

The heterosis over better parent for days to fifty percent flowering ranged from -14.08% (Icrixina × Tropimech) to 6.95% (Tima × Roma Savana). Significant positive and negative heterobeltiosis was observed two and five hybrids respective. Hybrid Tropimech × Roma Savana expressed no heterobeltiotic effect among the hybrids.

4.4.2.3 Number of branches per plant

The magnitude of heterosis over better parent ranged from -35.99% (Tima × Roma Savana) to 96.62% (Icrixina × Tropimech). Out of fifteen hybrids, six crosses showed significant positive heterosis while five crosses show negative heterobeltiosis for number of branches per plant.

4.4.2.4 Number of clusters per plant

Significant positive and negative heterobeltiosis were manifested in six hybrids, which varied from -44.94% (Rio Grande × Roma Savana) to 45.08% (Icrixina × Tropimech). Six hybrids also revealed significant negative heterosis over the better parent.

4.4.2.5 Number of flowers per cluster

Better parent heterosis for number of flowers per cluster varied from -18.15% (Tropimech × Roma Savana) to 24.33% (Icrixina × Roma Savana). Among the fifteen hybrids only eleven revealed significant positive heterosis, while two hybrids exhibited significant negative heterosis over the better parent.

4.4.2.6 Number of flowers per plant

The heterosis over better parent ranged -38.90% (Rio Grande × Roma Savana) to 16.44% (Petomech × Roma Savana). However, none of the hybrids expressed significant positive heterotic effect, while two hybrids showed significant negative heterosis over the better parent.

4.4.2.7 Number of fruits per cluster

Highly significant positive heterosis over better parent regarding number of fruits per cluster was recorded in eleven hybrids, whereas three crosses exhibited highly significant negative better parent heterosis. The heterobeltiosis varied from -10.62% (Rio Grande × Roma Tropimech) to 33.11% (Icrixina × Rio Grande).

4.4.2.8 Number of fruits per plant

Among the hybrids, better parent heterosis for number of fruits per plant ranged from -67.25% (Rio Grande × Roma Savana) to 27.59% (Icrixina × Rio Grande). Out of fifteen hybrids, three and five hybrids showed significant positive and negative heterobeltiosis, respectively.

4.4.2.9 Average fruit weight

The heterobeltiosis exhibited by the hybrids for average fruit weight varied from -29.39% (Icrixina × Rio Grande) to 43.16% (Rio Grande × Roma Savana). Out of fifteen crosses, only Rio Grande × Roma Savana revealed highly significant positive heterobeltiosis, while four hybrids showed significant negative heterosis over better parent.

4.4.2.10 Fruit length

The magnitude of heterobeltiosis ranged from -37.61% (Icrixina × Rio Grande) to 9.50% (Tima × Petomech). There were six and nine hybrids that exhibited highly significant positive and negative heterobeltiosis, respectively.

4.4.2.11 Fruit diameter

The heterobeltiosis for fruit diameter ranged from -11.98% (Tropimech × Petomech) to 6.68% (Rio Grande × Roma Savana). Five hybrids expressed significant positive heterosis over the better parent.

4.4.2.12 Fruit shape index

The better parent heterosis for fruit shape index varied from -32.67% (Icrixina × Rio Grande) to 12.00% (Rio Grande × Tropimech). Among the fifteen hybrids, six indicated significant positive heterosis over the better parent.

4.4.2.13 Fruit yield per plant

Among all the hybrids, none of them expressed significant heterosis over better parent and ranged from -30.99% (Rio Grande × Tropimech) to 47.06% (Icrixina × Rio Grande). However, maximum positive heterosis was observed in Icrixina × Rio Grande (47.06%), followed by Rio Grande × Petomech (16.15%) and Icrixina × Tima (15.51%).

4.4.2.14 Percentage fruit set

Significant positive heterosis over better parents were manifested in three hybrids. The range of heterobeltiosis varied from -23.63% (Rio Grande × Roma Savana) to 120.80% (Icrixina × Tima).

4.4.2.15 Leaf chlorophyll content

The magnitude of over better parent heterosis ranged from -9.52% (Rio Grande × Tropimech) to 22.70% (Tropimech × Petomech). Out of fifteen hybrids, only two and exhibited significant positive heterobeltiosis.

4.4.2.16 Canopy temperature depression

Only two hybrids out of fifteen cross combinations showed significant positive heterobeltiosis. Whereas, ten hybrids recorded significant negative heterosis over better parent. The heterobeltiosis varied from -18.80% (Icrixina × Tima) to 12.91% (Tima × Roma Savana).

4.4.2.17 Cell membrane thermostability

No hybrid expressed significant positive heterosis over better parents for cell membrane thermostability at 30^{o}C, however significant negative heterobeltiosis were manifested in six hybrids. The range of heterobeltiosis varied from -83.31% (Tima × Petomech) to 11.73% (Tima × Roma Savana).The magnitude of over better parent heterosis at 40^{o}C ranged from -86.78% (Petomech × Roma Savana) to 67.08% (Icrixina × Petomech). Out of fifteen hybrids, only five hybrids exhibited significant positive heterobeltiosis. At 50^{o}C, only two hybrids out of fifteen cross combinations showed significant positive heterobeltiosis. Whereas, five hybrids recorded significant negative heterosis over better parent. The heterobeltiosis varied from -74.82% (Icrixina × Roma Savana) to 253.30% (Rio Grande × Roma Savana).

Table 4.18: Percent better parent heterosis of hybrids for agronomic, heat tolerance and physiological characters at Samaru during 2014 rainy season

Hybrid	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Icrixina × Rio Grande	6.20	-11.01**	63.03**	35.96**	20.06**	11.10	33.11**	27.59**	-29.39**
Icrixina × Tima	9.68*	-6.61**	78.81**	26.83**	10.11**	5.36	19.87**	19.29**	-3.03
Icrixina × Tropimech	10.59*	-14.08**	96.62**	45.08**	17.69**	10.71	25.17**	9.20	-12.01
Icrixina × Petomech	5.41	-0.48	36.05**	36.73**	0.63	5.80	26.49**	17.44**	-18.09**
Icrixina × Roma Savana	-4.12	-0.48	-6.88*	19.83**	24.33**	10.09	14.79**	-7.69	10.91
Rio Grande × Tima	13.91**	-2.36	15.40**	-17.53**	15.33**	-34.19*	0.00	-16.53**	3.18
Rio Grande × Tropimech	5.09	-0.94	-19.10**	-18.94**	-16.20**	-23.71	-10.62**	-24.11**	-16.18*
Rio Grande × Petomech	17.33**	4.78*	-2.14	7.13**	7.16**	-8.06	4.68**	-7.15	13.21*
Rio Grande × Roma Savana	-10.31*	-0.48	-51.50	-44.94**	21.85**	-38.90**	13.08**	-67.25**	43.16**
Tima × Tropimech	15.46**	-1.87	47.55**	-1.47	13.04**	7.77	11.42**	-13.05*	-1.70
Tima × Petomech	11.23*	-5.19*	-8.50*	-1.50	5.36**	-24.80	4.23**	-10.01	-7.73
Tima × Roma Savana	-2.25	6.59**	-35.99**	-4.89*	14.26**	11.66	4.23**	-9.47	-15.17*
Tropimech × Petomech	-0.92	1.87	-16.95**	-23.03**	0.56	-28.47*	-4.62**	-9.70	-6.11
Tropimech × Roma Savana	-4.74	0.00	-32.47**	-14.66**	-18.15**	-2.43	-7.62**	-33.52**	-3.60
Petomech × Roma Savana	4.57	-6.61**	2.071	2.25	5.19**	16.44	12.41**	10.06	-11.78
SE±	4.232	2.236	3.283	1.824	0.812	13.585	0.455	5.612	6.183

PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight.

Table 4.18 continued

Hybrid	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT		
								(30°C)	(40°C)	(50°C)
Icrixina × Rio Grande	-37.61**	-7.20**	-32.67**	47.05	65.06**	4.42	-9.58**	3.34	-9.14	-10.29
Icrixina × Tima	-18.10**	-8.58**	-10.34**	15.50	120.80**	-2.71	-18.80**	-0.67	-7.40	-23.80
Icrixina × Tropimech	-29.82**	-0.78**	-30.53**	5.23	-6.15	-7.13	-11.25**	-13.74	-28.54*	-1.35
Icrixina × Petomech	-18.33**	1.65**	2.08**	6.00	4.18	-6.59	-18.28**	-4.35	67.08**	-57.13*
Icrixina × Roma Savana	-10.89**	0.82**	-12.68**	3.78	16.53**	7.39	-6.71**	-85.24**	-9.68	-74.82**
Rio Grande × Tima	2.77**	-2.06**	5.33**	-7.54	-9.57**	-4.06	-0.69	8.01	41.54**	-6.79
Rio Grande × Tropimech	7.45**	-3.60**	12.00**	-30.99	-12.01**	-9.52*	-4.66**	-40.98*	37.17**	-12.67
Rio Grande × Petomech	1.98**	3.60**	-2.00**	16.16	-19.52**	2.48	-4.83**	-33.23*	-29.78*	145.60**
Rio Grande × Roma Savana	4.68**	6.68**	-0.67**	-25.77	-23.63**	-3.37	-5.87**	5.45	-0.99	253.30**
Tima × Tropimech	-7.10**	2.60**	-7.63**	-13.64	-9.59*	2.32	3.90**	-27.92	25.23*	-72.67**
Tima × Petomech	9.50**	-0.80**	7.38**	-15.24	6.14	-4.77	-6.85**	-83.31**	50.50**	-51.33*
Tima × Roma Savana	-10.12**	-0.54	-11.28**	-9.69	-9.94	-3.03	12.91**	11.73	-23.09*	-36.01
Tropimech × Petomech	-3.45**	-11.98**	9.16**	-14.46	2.92	22.70**	-4.26**	-33.62*	1.67	-43.67
Tropimech × Roma Savana	-9.14**	-0.78*	-12.68**	-17.37	-12.67**	-8.22	2.22	0.92	-53.98**	-45.91*
Petomech × Roma Savana	4.67**	-3.58**	9.15**	2.56	-2.79	10.10*	-2.40	-69.22**	-86.78**	11.27
SE±	0.374	0.271	0.141	32.269	3.415	4.297	1.317	14.775	10.615	22.721

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

4.4.3 Heterobeltiosis combined across locations

The heterobeltiosis for seventeen traits across locations is presented in Table 4.19.

4.3.3.1 Plant height

The heterosis over better parent for plant height ranged from -12.69% (Tropimech × Petomech) to 9.25% (Roma Savana × Petomech). Among all the hybrids, only Tropimech × Petomech showed significant negative heterobeltiosis.

4.4.3.2 Days to 50% flowering

The magnitude of heterosis over better parent for days to 50% flowering varied from -8.92% (Icrixina × Tropimech) to 6.59% (Tima × Roma Savana). Out fifteen hybrids, two hybrids exhibited significant positive heterosis, while three hybrids expressed significant negative heterosis over the better parent.

4.4.3.3 Number of branches per plant

Significant positive heterosis regarding number of branches per plant was observed in eight hybrids. The highest positive heterosis was observed for Icrixina × Tropimech (72.34%) followed by Icrixina × Tima (39.07%), Icrixina × Rio Grande (38.49%) and Tima × Tropimech (36.63%). Four hybrids exhibited significant negative heterobeltiosis.

4.4.3.4 Number of clusters per plant

The heterobeltiosis for number of clusters per plant ranged from -46.76% (Rio Grande × Roma Savana) to 31.20% (Icrixina × Rio Grande). Seven hybrids indicated positive heterosis over the better parent.

4.4.3.5 Number of flowers per cluster

Out of fifteen hybrids, eleven showed significant positive heterobeltiosis. The heterobeltiosis varied from -18.15% (Tropimech × Roma Savana) to 21.30% (Rio Grande × Roma Savana).

4.4.3.6 Number of flowers per plant

Three hybrids expressed significant negative heterosis over better parent for number of flowers per plant. The values ranged from -36.15% (Rio Grande × Roma Savana) to 20.13% (Petomech × Roma Savana).

4.4.3.7 Number of fruits per cluster

Highly significant positive heterobeltiosis was manifested in eleven hybrids, while significant negative heterobeltiosis was observed in three hybrids. Rio Grande × Tima had no heterotic effect over the better parent. It ranged from -10.62% (Rio Grande × Tropimech) to 26.93% (Icrixina × Rio Grande).

4.4.3.8 Number of fruits per plant

Five hybrids showed significant positive heterosis, while eight hybrids expressed significant negative heterosis over the better parent. The better parent heterosis ranged from -66.79% (Rio Grande × Roma Savana) to 26.08% (Petomech × Roma Savana).

4.4.3.9 Average fruit weight

The better parent heterosis for average fruit weight varied from -21.26% (Icrixina × Tropimech) to 29.41% (Icrixina × Petomech). Out of fifteen hybrids, only Icrixina

× Petomech and Rio Grande × Roma Savana revealed significant positive heterosis over better parent.

4.4.3.10 Fruit length

The heterobeltiosis for fruit length ranged from -28.99% (Icrixina × Rio Grande) to 6.52% (Rio Grande × Roma Savana). Five hybrids showed significant positive heterosis over the better parent.

4.4.3.11 Fruit diameter

Better parent heterosis for fruit diameter varied from -9.16% (Icrixina × Rio Grande) to 3.96% (Rio Grande × Petomech). Out of fifteen hybrids, four hybrids revealed significant positive heterosis over better parent respectively. Icrixina × Roma Savana had no heterotic effect over the better parent.

4.4.3.12 Fruit shape index

Significant positive heterobeltiosis were observed in five hybrids. The heterobeltiosis effects ranged from -26.03% (Icrixina × Rio Grande) to 12.77% (Petomech × Roma Savana).

4.4.3.13 Fruit yield per plant

The magnitude of heterosis over better parent varied from -25.09% (Tropimech × Roma Savana) to 58.65% (Icrixina × Rio Grande). None of the hybrids exhibited significant difference among them. However, the Icrixina × Rio Grande (58.65%) showed maximum positive heterosis followed by Icrixina × Petomech (20.53%), Icrixina

× Tima (19.49%) and Icrixina × Roma Savana (17.17), while the lowest positive heterobeltiosis was recorded for Rio Grande × Petomech (2.82%).

4.4.3.14 Percentage fruit set

Significant positive heterosis regarding percentage fruit set was observed in four hybrids. The heterobeltiosis varied from -27.68% (Rio Grande × Roma Savana) to 73.05% (Icrixina × Rio Grande).

4.4.3.15 Leaf chlorophyll content

Heterosis over better parent for leaf chlorophyll content ranged from -13.65% (Rio Grande × Tima) to 13.56% (Icrixina × Roma Savana). Out of fifteen hybrids, only two revealed significant positive heterosis, whereas two hybrids expressed significant negative heterobeltiosis.

4.4.3.16 Canopy temperature depression

The heterobeltiosis for canopy temperature depression varied from -15.86% (Icrixina × Petomech) to 4.12% (Icrixina × Tropimech). All the hybrids except Icrixina × Tropimech (4.12%) recorded highly significant negative heterosis over the better parent.

4.4.3.17 Cell membrane thermostability

None among the hybrids recorded significant heterobeltiosis regarding cell membrane thermostability at 30^{o}C. The heterobeltiosis varied from -49.38% (Tima × Petomech) to 9.53% (Icrixina × Tima). Significant positive heterobeltiosis were observed in five hybrids at 40^{o}C. The heterobeltiosis effects ranged from -76.53% (Petomech × Roma

Savana) to 49.81% (Petomech × Roma Savana). Out of fifteen hybrids, only three hybrids revealed significant positive heterosis, whereas five hybrids expressed significant negative heterobeltiosis at 50^{o}C. The heterobeltiosis for cell membrane thermostability at 50^{o}C varied from -64.68% (Icrixina × Petomech) to 115.25% (Rio Grande × Roma Savana).

Table 4.19: Percent better parent heterosis of hybrids for agronomic, heat tolerance and physiological characters across locations during 2014 rainy season

Hybrid	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Icrixina × Rio Grande	2.61	-5.04**	38.49**	31.20**	14.85**	3.65	26.93**	16.12**	-2.31
Icrixina × Tima	3.50	-3.54	39.07**	15.08**	5.69**	-3.30	19.87**	15.07**	-10.06
Icrixina × Tropimech	-1.46	-8.92**	72.34**	15.86**	12.48**	-4.72	25.17**	8.54	-21.26*
Icrixina × Petomech	7.41	-1.19	10.66**	9.20**	0.63	-1.95	26.49**	17.12**	29.41**
Icrixina × Roma Savana	-4.82	-0.48	-2.23	18.35**	16.43**	-9.91	14.79**	10.24*	-4.10
Rio Grande × Tima	3.44	0.00	1.09	-3.96	12.07**	-32.60*	0.00	-5.48	-9.10
Rio Grande × Tropimech	6.97	-0.94	-13.08**	8.05**	-16.20**	-18.03	-10.62**	-16.18**	-18.05*
Rio Grande × Petomech	7.08	4.54*	-14.36**	-9.58**	7.16**	-13.05	4.68**	-20.04**	3.39
Rio Grande × Roma Savana	-10.23	-0.48	-38.04**	-46.76**	21.30**	-36.15**	13.08**	-66.79**	24.86**
Tima × Tropimech	0.20	-1.87	36.63**	3.43	13.04**	9.90	11.42**	-10.00*	-13.20
Tima × Petomech	-0.80	-2.83	7.26*	4.36*	5.36**	-14.79	4.23**	-11.56*	-14.08
Tima × Roma Savana	5.15	6.59**	-24.24**	-28.06**	14.26**	3.76	4.23**	-17.63**	-8.33
Tropimech × Petomech	-12.69*	1.87	5.03	-9.58**	0.56	-25.34*	-4.62**	-12.55*	5.07
Tropimech × Roma Savana	-2.92	2.82	21.46**	-23.35**	-18.15**	-7.20	-7.62**	-32.74**	-14.58
Petomech × Roma Savana	9.25	-4.25*	7.01*	-0.12	5.19**	20.13	12.41**	26.08**	-11.37
SE±	5.210	1.920	2.787	2.137	0.852	11.693	0.455	4.701	8.134

PHT = Plant height, DFPFL= Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight. ** and * are significantly different at 1% and 5% levels of probability, respectively.

Table 4.10 continued

Hybrid	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT		
								30°C	40°C	50°C
Icrixina × Rio Grande	-28.99**	-4.49**	-26.03**	58.65	73.05**	10.94*	-10.53**	-3.77	-21.66*	-32.69*
Icrixina × Tima	-21.04**	-7.77**	-14.52**	19.48	34.98**	-6.59	-11.85**	9.53	-14.52	-26.22*
Icrixina × Tropimech	-24.63**	1.08**	-25.38**	20.54	11.75	-2.44	4.12**	-15.76	-6.34	22.74
Icrixina × Petomech	-19.91**	3.06**	-22.22**	10.24	51.44**	-0.48	-15.86**	-19.57	18.29*	-64.68**
Icrixina × Roma Savana	-18.43**	0.00	-18.44**	17.17	37.19**	13.56*	-5.08**	-38.26**	-3.92	-34.06*
Rio Grande × Tima	5.98**	0.26	6.85**	-6.43	1.68	-13.65*	-0.30	-2.02	39.40**	11.47
Rio Grande × Tropimech	1.27**	-2.37**	4.11**	-18.84	-5.21	1.70	-5.57**	-35.64**	49.81**	38.45**
Rio Grande × Petomech	-0.91*	3.96**	-4.79**	2.82	-11.61	-3.16	-14.43**	-24.99*	-6.43	89.58*
Rio Grande × Roma Savana	6.52**	3.69**	4.11**	-33.56	-27.68**	4.72	-11.04**	6.78	11.65	115.25**
Tima × Tropimech	-2.92**	-1.07**	-0.77**	-12.89	-3.07	-1.02	-4.08**	-6.41	22.58*	-25.90*
Tima × Petomech	-0.43	-1.07**	-0.79**	-18.19	-15.73*	-2.51	-9.76**	-49.38**	36.02**	-23.67
Tima × Roma Savana	-9.80**	-1.34**	-10.64**	-15.61	-7.27	-0.46	-1.59	-3.41	-19.35*	-9.37
Tropimech × Petomech	1.67**	-9.16**	11.54**	-5.85	-8.91	3.60	-9.72**	-16.62	3.89	-13.48
Tropimech × Roma Savana	-6.67**	-4.31**	-20.57**	-25.09	-9.78	-11.92*	-4.73**	-0.54	-41.73**	-4.87
Petomech × Roma Savana	5.29**	-5.83**	12.77**	16.38	10.68	-4.32	-6.04**	-41.80**	-76.53**	-0.94
SE±	0.408	0.283	0.141	96.920	6.808	5.334	1.283	11.709	8.471	12.333

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

4.6 Cell Membrane Thermostability

The percent cell membrane thermostability and heat injury of twenty five genotypes at Bagauda, Samaru and combined across locations are presented in Tables 4.20, 4.21 and 4.22, respectively. At Bagauda (Table 4.20), the percent cell membrane thermostability at 30^{o}C, 40^{o}C and 50^{o}C ranged from 58.03% - 99.44%, 19.10 - 64.63% and 7.54 - 34.71%, respectively. The heat injury at 30^{o}C, 40^{o}C and 50^{o}C ranged from 0.56 - 44.02%, 35.37 - 80.90% and 65.29-92.46%, respectively. The maximum cell membrane thermostability was observed for Icrixina × Tima, Icrixina and Icrixina × Tropimech, at 30^{o}C, 40^{o}C and 50^{o}C, respectively. While, the minimum cell membrane thermostability were recorded for Icrixina × Petomech, Icrixina × Tropimech and Icrixina × Petomech at 30^{o}C, 40^{o}C and 50^{o}C, respectively. Highest heat injury was observed for Icrixina × Petomech, Icrixina × Tropimech and Icrixina × Petomech at 30^{o}C, 40^{o}C and 50^{o}C, respectively. Minimum heat injury at 30^{o}C, 40^{o}C and 50^{o}C were recorded for Icrixina × Tima, Icrixina and Icrixina × Tropimech, respectively. Seventeen genotypes were heat tolerant at 30^{o}C, but at 40^{o}C most of the genotypes were moderately and slightly heat tolerant, whereas four genotypes were slightly heat tolerant at 50^{o}C.

The percent cell membrane thermostability and heat injury for Samaru (Table 4.21) shows that the ranges of cell membrane thermostability at 30^{o}C, 40^{o}C and 50^{o}C were 7.75 to 88.59%, 10.83 to 81.90% and 3.45 to 36.84%, respectively. Heat injury at 30^{o}C, 40^{o}C and 50^{o}C ranged from 11.41 to 92.25%, 18.10 to 89.17%, and 63.16 to 96.55%, respectively. The highest cell membrane thermostability at 30^{o}C, 40^{o}C and 50^{o}C were expressed for Roma VF (88.59%), Roma Savana (81.90%) and Rio Grande × Petomech (36.84%), respectively. Maximum heat injury at 30^{o}C, 40^{o}C and 50^{o}C were recorded for

UC82 B (92.25%), Petomech × Roma Savana (89.17%) and Icrixina × Roma Savana (96.55%), respectively. UC82 B (7.75%), Petomech × Roma Savana (10.83%) and Icrixina × Roma Savana (3.45%) recorded lowest cell membrane thermostability at 30°C, 40°C and 50°C. Roma VF (11.41%), Roma Savana (18.10%) and Rio Grande × Petomech (63.16%) exhibited lowest heat injury at 30°C, 40°C and 50°C, respectively. Seven genotypes were heat tolerant at 30°C. At 40°C, most of the genotypes were moderately and slightly heat tolerant, while at 50°C, Rio Grande × Petomech was slightly heat tolerant.

The percent cell membrane thermostability and heat injury combined across locations (Table 4.22) reveals that the ranges of cell membrane thermostability at 30°C, 40°C and 50°C were 38.47 to 87.03%, 11.80 to 56.14% and 6.99 to 28.19%, respectively. Heat injury at 30°C, 40°C and 50°C ranged from 12.97 to 61.53%, 43.86 to 88.20%, and 71.81 to 93.01%, respectively. The highest cell membrane thermostability at 30°C, 40°C and 50°C were expressed for Icrixina × Tima (87.03%), Rio Grande × Roma Savana (56.14%) and Rio Grande × Petomech (28.19%), respectively. Icrixina × Tima (12.97%), Rio Grande × Roma Savana (43.86%) and Rio Grande × Petomech (71.81%) recorded lowest heat injury at 30°C, 40°C and 50°C, respectively. Seven genotypes were heat tolerant at 30°C. At 40°C, most of the genotypes were moderately and slightly heat tolerant, while at 50°C, Rio Grande × Petomech was slightly heat tolerant.

Table 4.20: Percent cell membrane thermostability and heat injury of tomato leaves for Bagauda during 2014 rainy season

Genotype	30°C			40°C			50°C		
	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat
Icrixina	83.80	16.2	HT	64.63	35.37	MHT	25.87	74.13	SHT
Rio Grande	84.32	15.68	HT	31.69	68.31	SHT	12.03	87.97	HS
Tima	65.16	35.84	MHT	58.60	41.4	MHT	13.03	86.96	HS
Tropimech	79.90	20.10	HT	31.29	68.71	SHT	15.90	84.10	HS
Petomech	80.40	19.60	HT	41.72	58.28	SHT	14.74	85.26	HS
Roma Savana	89.25	10.75	HT	39.41	60.59	SHT	18.66	81.34	HS
Roma VF	75.32	24.68	HT	37.53	62.47	SHT	15.27	84.73	HS
UC82 B	80.46	19.54	HT	40.44	59.56	SHT	22.45	77.55	HS
Thorgal F_1	77.50	22.50	HT	40.96	59.04	SHT	16.10	83.89	HS
Jaguar F_1	58.03	41.97	MHT	21.79	78.21	HS	12.70	87.30	HS
Icrixina × Rio Grande	75.76	24.24	HT	46.52	53.48	SHT	14.34	85.66	HS
Icrixina × Tima	99.44	0.56	HT	36.74	63.26	SHT	18.75	81.25	HS
Icrixina × Tropimech	69.09	30.91	MHT	19.10	80.90	HS	34.71	65.29	SHT
Icrixina × Petomech	55.98	44.02	MHT	20.82	79.18	HS	7.54	92.46	HS

Table 4.20 continued

Genotype	30°C			40°C			50°C		
	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat
Icrixina × Roma Savana	87.67	12.33	HT	39.63	60.37	SHT	22.65	77.35	HS
Rio Grande × Tima	75.02	24.98	HT	26.03	73.97	SHT	15.88	84.12	HS
Rio Grande × Tropimech	58.30	41.70	MHT	39.66	60.34	SHT	29.20	70.80	SHT
Rio Grande × Petomech	69.49	30.51	MHT	26.30	73.7	SHT	19.53	80.47	HS
Rio Grande × Roma Savana	91.06	8.94	HT	45.67	54.33	SHT	31.19	68.81	SHT
Tima × Tropimech	89.29	10.71	HT	55.43	44.57	MHT	18.36	81.64	HS
Tima × Petomech	64.98	35.02	MHT	42.28	57.72	SHT	15.39	84.61	HS
Tima × Roma Savana	75.50	24.50	HT	35.16	64.84	SHT	18.10	81.90	HS
Tropimech × Petomech	79.20	20.80	HT	29.15	70.85	SHT	17.47	82.53	HS
Tropimech × Roma Savana	87.75	12.25	HT	40.59	59.41	SHT	20.90	79.10	HS
Petomech × Roma Savana	71.06	28.94	MHT	31.89	68.11	SHT	12.77	87.23	HS
Range	55.98-99.44	0.56-44.02		19.10-64.63	35.37-80.90		7.54-34.71	65.29-92.46	
Mean	76.95	23.09		37.72	62.28		18.54	81.46	
CV	14.46	48.37		29.80	18.05		34.16	7.78	

CMT = Cell membrane thermostability, HI = Heat injury, HT = Heat tolerant, MHT = Moderately heat tolerant, SHT = Slightly heat tolerant and HS = Heat sensitive.

Table 4.21: Percent cell membrane thermostability and heat injury of tomato leaves for Samaru during 2014 rainy season

Genotype	30°C			40°C			50°C		
	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat
Icrixina	75.11	23.89	HT	47.27	52.73	SHT	13.70	86.30	HS
Rio Grande	75.75	24.25	HT	40.97	59.03	SHT	4.73	95.27	HS
Tima	52.53	47.47	MHT	29.16	70.84	SHT	7.36	92.64	HS
Tropimech	67.48	32.52	MHT	42.64	57.36	SHT	14.05	85.95	HS
Petomech	71.60	28.40	MHT	32.18	67.82	SHT	15.00	85.00	HS
Roma Savana	70.700	30.00	MHT	81.90	18.10	HT	6.51	93.49	HS
Roma VF	88.59	11.41	HT	50.43	49.57	MHT	7.39	92.61	HS
UC82 B	7.75	92.25	HS	25.90	74.10	SHT	7.06	92.94	HS
Thorgal F_1	63.20	36.8	MHT	37.83	62.17	SHT	15.51	84.49	HS
Jaguar F_1	49.80	50.2	SHT	57.75	42.25	MHT	9.34	90.66	HS
Icrixina × Rio Grande	78.28	21.72	HT	42.95	57.05	SHT	12.29	87.71	HS
Icrixina × Tima	74.61	25.39	MHT	43.77	56.23	SHT	10.44	89.56	HS
Icrixina × Tropimech	64.79	35.21	MHT	33.78	66.22	SHT	13.86	86.14	HS
Icrixina × Petomech	71.84	28.16	MHT	78.98	21.02	HT	6.43	93.57	HS

Table 4.21 continued.

Genotype	30°C			40°C			50°C		
	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat
Icrixina × Roma Savana	11.09	88.91	HS	73.97	26.03	MHT	3.45	96.55	HS
Rio Grande × Tima	81.82	18.18	HT	57.99	42.01	MHT	6.86	93.14	HS
Rio Grande × Tropimech	44.71	55.29	SHT	58.49	41.51	MHT	12.27	87.73	HS
Rio Grande × Petomech	50.58	49.42	MHT	28.77	71.23	SHT	36.84	63.16	SHT
Rio Grande × Roma Savana	79.88	20.12	HT	81.09	18.91	HT	23.00	77.00	HS
Tima × Tropimech	48.64	51.36	SHT	53.40	46.60	MHT	3.84	96.16	HS
Tima × Petomech	11.95	88.05	HS	48.43	51.57	SHT	7.30	92.70	HS
Tima × Roma Savana	78.99	21.01	HT	62.99	37.01	MHT	4.71	95.29	HS
Tropimech × Petomech	47.53	52.47	SHT	43.35	56.65	SHT	8.45	91.55	HS
Tropimech × Roma Savana	71.35	28.65	MHT	37.69	62.31	SHT	7.60	92.40	HS
Petomech × Roma Savana	22.04	77.96	HS	10.83	89.17	HS	16.69	83.31	HS
Range	7.75-88.59	11.41-92.25		10.83-81.90	18.10-89.17		3.45-36.84	63.16-96.55	
Mean	58.42	41.56		48.10	51.90		10.99	89.01	
CV	40.23	56.59		37.58	34.83		65.17	8.04	

CMT = Cell membrane thermostability, HI = Heat injury, HT = Heat tolerant, MHT = Moderately heat tolerant, SHT = Slightly heat tolerant and HS = Heat sensitive.

Table 4.22: Percent cell membrane thermostability and heat injury of tomato leaves combined across locations during 2014 rainy season

Genotype	30°C			40°C			50°C		
	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat
Icrixina	79.46	20.54	HT	36.57	63.45	SHT	19.79	80.21	HS
Rio Grande	80.04	19.96	HT	26.50	73.50	SHT	8.38	91.62	HS
Tima	58.85	41.15	MHT	21.10	78.90	SHT	10.20	89.80	HS
Tropimech	73.69	26.31	MHT	29.27	70.73	SHT	14.98	85.02	HS
Petomech	76	24	MHT	23.46	76.54	SHT	14.87	85.13	HS
Roma Savana	79.98	20.02	MHT	50.28	49.72	HT	12.59	87.41	HS
Roma VF	81.96	18.04	HT	32.85	67.15	MHT	11.33	88.67	HS
UC82 B	44.11	55.8	HS	24.18	75.82	SHT	14.76	85.24	HS
Thorgal F_1	70.35	29.65	MHT	26.97	73.03	SHT	15.81	84.19	HS
Jaguar F_1	53.92	46.08	SHT	35.23	64.77	MHT	11.02	88.98	HS
Icrixina × Rio Grande	77.02	22.98	HT	28.65	71.35	SHT	13.32	86.68	HS
Icrixina × Tima	87.03	12.97	MHT	31.26	68.74	SHT	14.60	85.4	HS
Icrixina × Tropimech	66.94	33.06	MHT	34.25	65.75	SHT	24.29	75.71	HS
Icrixina × Petomech	63.91	36.09	MHT	43.26	56.74	HT	6.99	93.01	HS

Table 4.22 continued.

Genotype	30°C			40°C			50°C		
	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat	CMT	HI	Reaction to heat
Icrixina × Roma Savana	49.38	50.62	HS	48.31	51.69	MHT	13.05	86.95	HS
Rio Grande × Tima	78.42	21.58	HT	36.94	63.06	MHT	11.37	88.63	HS
Rio Grande × Tropimech	51.51	48.49	SHT	43.85	56.15	MHT	20.74	79.26	HS
Rio Grande × Petomech	60.04	39.96	MHT	24.15	75.85	SHT	28.19	71.81	SHT
Rio Grande × Roma Savana	85.47	14.53	HT	56.14	43.86	HT	27.10	72.9	SHT
Tima × Tropimech	68.97	31.03	SHT	35.88	64.12	MHT	11.10	88.9	HS
Tima × Petomech	38.47	61.53	HS	31.91	68.09	SHT	11.35	88.65	HS
Tima × Roma Savana	77.25	22.75	HT	40.55	59.45	MHT	11.41	88.59	HS
Tropimech × Petomech	63.37	36.63	SHT	30.41	69.59	SHT	12.96	87.04	HS
Tropimech × Roma Savana	79.55	20.45	MHT	29.30	70.7	SHT	14.25	85.75	HS
Petomech × Roma Savana	46.55	53.45	HS	11.8	88.2	HS	14.73	85.27	HS
Range	38.47-87.03	12.97-61.53		11.80-56.14	43.86-88.20		6.99-28.19	71.81-93.01	
Mean	67.69	32.31		33.32	66.68		14.77	85.23	
CV	20.67	43.28		29.78	14.88		36.42	6.31	

CMT = Cell membrane thermostability, HI = Heat injury, HT = Heat tolerant, MHT = Moderately heat tolerant, SHT = Slightly heat tolerant and HS = Heat sensitive.

4.5 Heritability

The estimates of broad sense and narrow sense heritabilities for Bagauda, Samaru and combined across locations are presented in Tables 4.23, 4.24 and 4.25, respectively. The estimates of broad sense heritability values for Bagauda (Tables 4.23) were higher than those of narrow sense heritability for all traits and ranged from 61.54% (fruit diameter) to 93.54% (percentage fruit set). The narrow sense heritability estimates were low for all the traits, except number of fruits per cluster and fruit length, which showed moderate narrow sense heritability, while fruit length expressed high narrow-sense heritability. The narrow sense heritability ranged from 0.19% (days to 50% flowering) to 57.73% (fruit length).

The broad sense heritability at Samaru (Table 4.24) displayed high estimates of all the traits and ranged from 76.54% (Fruit yield per plant) to 98.90% (percentage fruit set). Narrow sense heritability was low for plant height, days to 50% flowering, number of flowers per plant, number of fruits per plant, average fruit weight, fruit diameter, fruit yield per plant, percentage fruit set, leaf chlorophyll content and cell membrane thermostability and moderate for number of branches per plant, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, fruit length, fruit shape index and canopy temperature depression. Narrow sense heritability ranged from -0.93% (leaf chlorophyll content) to 52.46% (fruit length).

Broad sense and narrow sense heritabilities combined across locations are presented in Table 4.25. The broad sense heritability ranged from -60.65% (canopy temperature depression) to 100% (number of fruits per cluster). Fruit length and number of fruits per cluster revealed high narrow sense heritability and number of clusters per plant, number

of flowers per cluster, number of flowers per plant, number of fruits per plant and fruit shape index showed moderate narrow sense heritabilities, while plant height, days to 50% flowering, number of branches per plant, average fruit weight, fruit diameter, fruit yield per plant, leaf chlorophyll content and cell membrane thermostability exhibited low narrow sense heritabilities. The narrow sense heritability varied from -13.78% (plant height) to 72.22% (fruit length).

Table 4.23: Broad sense and narrow sense heritability for agronomic, heat tolerance and physiological characters for Bagauda during 2014 rainy season

Heritability	Characters								
	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Broad sense heritability (%)	82.68	89.78	75.74	91.26	78.61	89.56	80.00	93.24	79.79
Narrow sense heritability (%)	-11.36	0.19	16.57	17.14	23.12	17.00	48.00	14.02	13.12

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight.

Table 4.23 continued

Heritability	Characters							
	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Broad sense heritability (%)	90.72	61.54	93.51	91.89	93.54	83.65	65.49	83.75
Narrow sense heritability (%)	57.73	10.26	15.58	16.88	5.39	-12.09	8.85	9.94

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability.

Table 4.24: Broad sense and narrow sense heritability for agronomic, heat tolerance and physiological characters for Samaru during 2014 rainy season

Heritability	Characters								
	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Broad sense heritability (%)	82.27	93.23	89.12	94.75	88.21	94.38	83.52	86.77	86.69
Narrow sense heritability (%)	-4.33	3.15	32.49	46.50	36.50	26.09	43.96	19.10	15.10

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight.

Table 4.24 continued

Heritability	Characters							
	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Broad sense heritability (%)	96.17	74.75	92.31	76.54	98.90	86.31	81.66	80.46
Narrow sense heritability (%)	52.46	-1.01	30.77	18.62	10.67	-0.93	33.14	0.18

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability.

Table 4.25: Broadsense and narrow sense heritability for agronomic, heat tolerance and physiological characters combined across locations during 2014 rainy season

	Characters								
Heritability	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW
Broad sense heritability (%)	37.10	57.85	6.12	58.74	97.87	43.10	100	78.65	14.54
Narrow sense heritability (%)	-13.78	7.26	29.45	49.50	46.81	35.16	61.79	30.41	22.01

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant and AFW = Average fruit weight.

Table 4.25 continued

	Characters							
Heritability	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
Broad sense heritability (%)	75.93	62.01	75.95	65.99	22.98	-24.99	-60.65	5.81
Narrow sense heritability (%)	72.22	1.22	50.63	28.59	23.98	-9.83434	14.19	11.01

FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability.

4.7 Estimates of Correlation Coefficients

The results of genotypic and phenotypic correlations among traits for Bagauda, Samaru and combined across locations are presented in Tables 4.26, 4.27 and 4.28, respectively.

4.7.1 Genotypic and Phenotypic Correlations for Bagauda

4.7.1.1 Plant height

Plant height showed highly significant positive genotypic correlation with number of branches per plant (0.63), number of clusters per plant (0.36), number of flowers per plant (0.83), number of fruits per plant (0.63), fruit shape index (1.00), fruit yield per plant (0.71) and percentage fruit set (0.94). Highly significant negative association was observed between plant height with days to 50% flowering (-0.85), number of flowers per cluster (-0.50), number of fruits per cluster (-0.31), average fruit weight (-(-0.39) and fruit diameter (-1.00). Plant height also recoded highly significant positive phenotypic association with number of flowers per cluster (0.41) and number of fruits per plant (0.37).

4.7.1.2 Days to 50% flowering

Days to 50% flowering exhibited significant positive genotypic correlation with leaf chlorophyll content (0.69) and significant negative association with number of branches per plant (-0.67), number of clusters per plant (-0.61), number of flowers per cluster (-0.50), number of flowers per plant (-0.75), number of fruits per cluster (-0.41), number of fruits per plant (-0.50),), fruit yield per plant (-0.39) and canopy temperature depression (-1.00). At phenotypic level, days to 50% flowering indicated significant positive association with number of fruits per cluster (0.30) and fruit yield per plant

(0.34), but significant negative correlation was observed with number of clusters per plant (-0.29), number of flowers per plant (-0.36) and fruit shape index (-0.22).

4.7.1.3 Number of branches per plant

Number of branches per plant showed significant positive correlation both at genotypic and phenotypic levels with number of fruits per plant (0.51 and 0.68), fruit length (0.36 and 0.37) and canopy temperature depression (1.00 and 0.22), respectively. It also exhibited significant positive genotypic correlation with number of clusters per plant (0.25), number of flowers per cluster (0.54), number of flowers per plant (0.46), number of fruit per cluster (0.25), fruit shape index (0.90), fruit yield per plant (0.52) and percentage fruit set (0.44), while it is significantly negatively correlated with average fruit weight (-0.74), fruit diameter (-1.00) and leaf chlorophyll content (-1.00).

4.7.1.4 Number of clusters per plant

Number of clusters per plant recorded significant positive associations with number of flowers per plant (0.94 and 0.41) and fruit yield per plant (1.00 and 0.27) at both genotypic and phenotypic levels, respectively. Significant positive genotypic correlation was observed with number of flowers per cluster (0.99), number of flowers per plant (0.94), number of fruits per cluster (0.52), number of fruits per plant (0.99), fruit yield per plant (1.00) and percentage fruit set (0.73). Significant negative correlations with average fruit weight (-1.00), fruit length (-0.45) fruit diameter (-1.00) and leaf chlorophyll content (-1.00) were observed at genotypic level.

47.1.5 Number of flowers per cluster

Number of flowers per cluster was significantly positively correlated with number of fruits per cluster (1.00 and 0.38), fruit yield per plant (1.00 and 0.39) and percentage fruit set (0.76) and 0.24) at both genotypic and phenotypic levels, respectively. Significant positive genotypic association with number of flowers per plant (0.80), number of fruits per plant (0.82), average fruit weight (0.23), fruit diameter (1.00) and canopy temperature depression (1.00) were recorded, while significant negative correlation at genotypic level was observed with fruit length (-0.67), fruit shape index (-0.51) and leaf chlorophyll content (-0.69).

4.7.1.6 Number of flowers per plant

Significant positive genotypic correlations were recorded for number of flowers per plant with a number of fruits per cluster (0.80), number of fruits per plant (0.83), fruit yield per plant (0.85) and percentage fruit set (0.61). Significant negative correlations with average fruit weight (-0.66), fruit length (-0.48), fruit diameter (-1.00), leaf chlorophyll content (-0.69) and canopy temperature depression (-0.68) were observed at genotypic level. However, significant positive phenotypic correlations were found for number of flowers per plant with average fruit weight (0.38) and percentage fruit set (0.24).

4.7.1.7 Number of fruits per cluster

The association of number of fruits per cluster was significant in positive direction with number of fruits per plant (0.64), fruit diameter (0.28), fruit yield per plant (0.68), percentage fruit set (0.63) and canopy temperature depression (1.00) at genotypic level

and with fruit length (0.67), fruit shape index (0.28) and fruit yield per plant (0.75) at phenotypic level. Negative significant association was observed with average fruit weight (-0.89), fruit length (-0.80), fruit shape index (-0.58) and leaf chlorophyll content (-0.31) at genotypic level.

4.7.1.8 Number of fruits per plant

Number of fruits per plant recorded significant positive correlation with fruit yield per plant (0.95), percentage fruit set (0.82) and canopy temperature depression (1.00) and significant negative association was recorded with average fruit weight (-1.00), fruit length (-0.31), fruit shape index (-1.00) and leaf chlorophyll content (-1.00) at genotypic level. Only fruit length showed highly significant positive phenotypic correlation with number of fruit per plant (0.35).

4.7.1.9 Average fruit weight

Significant positive genotypic correlation was observed for average fruit weight with fruit yield per plant (0.87), while, significant negative associations with fruit length (-0.40), fruit diameter (-0.66), leaf chlorophyll content (-0.41) and canopy temperature depression (-1.00) were recorded at genotypic level. At phenotypic level, average fruit weight showed significant positive correlations with fruit length (0.37), fruit yield per plant (0.56) and canopy temperature depression (0.53).

4.7.1.10 Fruit length

Fruit length exhibited significant positive genotypic correlation only with fruit shape index (1.00) and significant negative associations with fruit diameter (-1.00), fruit yield

per plant (-0.35), leaf chlorophyll content (-0.36) and canopy temperature depression (-1.00). At phenotypic level, fruit length indicated significant positive correlations with fruit yield per plant (0.35) and canopy temperature depression (0.30).

4.7.1.11 Fruit diameter

Fruit diameter showed highly significant positive correlation with leaf chlorophyll content (1.00) and significant negative correlation with fruit shape index (-1.00), fruit yield per plant (-1.00), percentage fruit set (-1.00) and canopy temperature depression (-1.00) at the genotypic level. Significant positive phenotypic correlation was observed with fruit shape index (0.29), fruit yield per plant (0.41), leaf chlorophyll content (0.27) and canopy temperature depression (0.69).

4.7.1.12 Fruit shape index

The fruit shape index recorded significant positive association with canopy temperature depression (1.00) and significant negative correlation with leaf chlorophyll content (-0.30) at genotypic level. Only fruit yield per plant (0.26) and canopy temperature depression (0.29) expressed significant positive phenotypic correlations with fruit shape index.

4.7.1.13 Fruit yield per plant

Fruit yield per plant exhibited significant positive correlations with percentage fruit set (0.93 and 0.23) at both genotypic and phenotypic levels, respectively. Significant positive genotypic correlations were observed with leaf chlorophyll content (1.00) and canopy temperature depression (0.54).

4.7.1.14 Percentage fruit set

The association of percentage fruit set was significant in positive direction with canopy temperature depression (0.67). Percentage fruit set was significantly negatively correlated with leaf chlorophyll content (-0.22) at genotypic level.

4.7.1.15 Leaf chlorophyll content

Leaf chlorophyll content recorded highly significant positive association with canopy temperature depression (1.00 and 0.30) at genotypic and phenotypic levels, respectively.

4.7.1.16 Cell membrane thermostability

The association of cell membrane thermostability was significant in positive direction with days to 50% flowering (1.00), number of branches per plant (1.00), number of clusters per plant (1.00), number of flowers per cluster (1.00), number of flowers per plant (0.98), number of fruits per cluster (0.68), number of fruits per plant (1.00), average fruit weight (1.00), fruit yield per plant (0.23), percentage fruit set (1.00), leaf chlorophyll content (1.00) and canopy temperature depression (0.72) at genotypic level. Negative significant association was observed with fruit length (-0.62), fruit diameter (-0.55) and plant height (-1.00) at genotypic level.

Table 4.26: Genotypic (upper diagonal) and phenotypic (lower diagonal) correlations for Bagauda during 2014 rainy season

Characters	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW	FRL	FRD	FRSI	FRYP	PFRS	LCC	CTD	CMT
PHT		-0.85**	0.63**	0.36**	-0.53**	0.83**	-0.31**	0.68**	-0.39**	-0.38	-1.00**	1.00**	0.71**	0.94**	-0.09	-0.16	-1.00**
DFPFL	-0.02		-0.67**	-0.61**	-0.50**	-0.75**	-0.41**	-0.50**	0.008	0.50**	0.06	0.19	-0.39**	-0.17	0.69**	-1.00**	1.00**
NBPP	0.11	-0.13		0.25*	0.54**	0.46**	0.25*	0.51**	-0.74**	0.36**	-1.00**	0.90**	0.52**	0.44**	-0.29**	1.00**	1.00**
NCPP	0.09	-0.29**	0.01		0.99**	0.94**	0.52**	0.99**	-1.00**	-0.45**	-1.00**	-0.14	1.00**	0.73**	-1.00**	0.14	1.00**
NFLPC	0.41**	-0.16	-0.06	-0.04		0.80**	1.00**	0.82**	0.23*	-0.67**	1.00**	-0.51**	1.00**	0.76**	-0.69**	1.00**	1.00**
NFLPP	0.13	-0.36**	0.08	0.41**	-0.03		0.80**	0.83**	-0.66**	-0.48**	-1.00**	-0.19	0.85**	0.61**	-1.00**	-0.68**	0.98**
NFRPC	0.19	0.30**	0.003	0.07	0.38**	0.08		0.64**	-0.89**	-0.80**	0.28*	-0.58**	0.68**	0.63**	-0.31**	1.00**	0.68**
NFRPP	0.37**	0.06	0.68**	0.14	0.14	0.18	-0.08		-1.00**	-0.31**	-1.00**	-0.02	0.95**	0.82**	-1.00**	1.00**	1.00**
AFW	0.02	-0.12	0.09	-0.16	0.11	0.38**	0.08	0.17		-0.40**	-0.66**	-0.14	0.87**	0.06	-0.41**	-1.00**	1.00**
FRL	0.07	0.12	0.37**	0.30**	0.28**	0.12	0.67**	0.35**	0.37**		-1.00**	1.00**	-0.35**	-0.16	-0.36**	-1.00**	-0.62**
FRD	-0.07	-0.20	0.20	0.17	0.12	-0.11	0.10	0.12	-0.04	-0.07		-1.00**	-1.00**	-1.00**	1.00**	-1.00**	-0.55**
FRSI	-0.07	-0.22*	0.12	-0.07	-0.09	-0.08	0.28**	-0.07	0.17	0.10	0.29**		-0.04	-0.05	-0.30**	1.00**	-0.04
FRYPP	0.03	0.34**	0.03	0.27*	0.39**	0.10	0.75**	0.10	0.56*	0.35**	0.41**	0.26*		0.93**	1.00**	0.54**	0.23*
PFRS	0.11	-0.15	-0.01	0.12	0.24*	0.24*	0.03	0.09	0.20	0.08	0.03	0.05	0.23*		-0.22*	0.67**	1.00**
LCC	0.09	-0.06	-0.03	0.01	-0.01	0.16	-0.02	0.15	0.15	0.03	0.27*	-0.002	0.12	-0.0003		1.00**	1.00**
CTD	0.02	0.07	0.22*	0.09	0.07	-0.13	0.20	-0.10	0.53**	0.30**	0.69**	0.29**	-0.02	0.01	0.30**		0.72**
CMT	-0.63**	-0.20	-0.61**	-0.06	0.08	-0.63**	-0.18	-0.46**	-0.83**	-0.70**	-0.61**	-0.08	-0.35**	-0.72**	-0.76**	-0.67**	

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant, AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

4.7.2 Genotypic and Phenotypic Correlations for Samaru

4.7.2.1 Plant height

Plant height expressed significant positive correlation with number of branches per plant (0.25), average fruit weight (0.58), fruit length (0.24), fruit yield per plant (0.53) and leaf chlorophyll content (0.41), while fruit diameter (-1.00) and canopy temperature depression (-0.77) recorded highly significant negative association with plant height at genotypic level. Significant positive correlation with fruit shape index (0.23) and significant negative correlation with number of flowers per cluster (-0.23), number of fruits per cluster (-0.26), number of fruits per plant (-0.60) and fruit diameter (-0.22) were recorded at phenotypic level.

4.7.2.2 Days to 50% flowering

Days to 50% flowering had significant positive correlation with average fruit weight (0.30), fruit length (0.68), fruit shape index (0.63) and canopy temperature depression (0.47). Significant negative association with number of branches per plant (-0.60), number of clusters per plant (-0.55), number of flowers per cluster (-0.77), number of flowers per plant (-0.49), number of fruits per plant (-0.53), fruit yield per plant (-0.50) and percentage fruit set (-0.54) were observed at genotypic level.

4.7.2.3 Number of branches per plant

Number of branches per plant showed significant positive genotypic correlations with number of clusters per plant (0.86), number of flowers per cluster (0.68), number of flowers per plant (0.82), number of fruits per cluster (0.80), number of fruits per plant (1.00), fruit yield per plant (0.87), percentage fruit set (0.46) and leaf chlorophyll

content (0.23). Significant negative correlations were recorded with average fruit weight (-0.72), fruit length (-0.40), fruit diameter (-0.96) and fruit shape index (-0.31) at genotypic level. At phenotypic level, number of branches per plant recorded significant positive association with average fruit weight (0.33), fruit length (0.70) and canopy temperature depression (0.24), whereas and significant negative correlation was observed with fruit shape index (-0.73).

4.7.2.4 Number of clusters per plant

Number of clusters per plant exhibited positive significant associations both at genotypic and phenotypic levels with number of flowers per plant (0.90 and 0.49) and number of fruits per plant (0.96 and 0.26). The trait significantly negatively correlated with average fruit weight (-0.82), fruit length (-0.71), and fruit shape index (-0.62) at genotypic level. Number of flowers per cluster also expressed highly significant negative phenotypic and genotypic correlations with fruit diameter (-0.50 and -0.33), respectively.

4.7.2.5 Number of flowers per cluster

Significant positive association of number of flowers per cluster was observed with number of fruits per cluster (1.00 and 0.24), fruit diameter (1.00 and 0.45) and fruit yield per plant (0.86 and 0.50) at both genotypic and phenotypic levels, respectively. Whereas, significant negative correlation was recorded with average fruit weight (-0.34 and -0.24) and fruit shape index (-0.64 and -0.73) at genotypic and phenotypic levels, respectively. Number of flowers per clusters expressed significant positive genotypic correlation with number of flowers per plant (0.85), number of fruits per

plant (0.71), percentage fruit set (0.56) and leaf chlorophyll content (1.00) and significant negative correlation with fruit length (-0.59) and canopy temperature depression (-0.28) at genotypic level. At phenotypic level, number of flowers per cluster showed significant positive association with fruit length (0.70).

4.7.2.6 Number of flowers per plant

At both genotypic and phenotypic levels, number of flowers per plant exhibited significant positive correlations with fruit yield per plant (0.53 and 0.66), respectively, while significant negative correlations were found with average fruit weight (-0.94 and -0.26) at the same levels. Number of flowers per plant also showed significant positive genotypic correlations with number of fruits per cluster (0.93), number of fruits per plant (1.00), percentage fruit set (0.41) and leaf chlorophyll content (0.24) but significantly negatively correlated with fruit length (-0.84), fruit diameter (-1.00) and fruit shape index (-0.78) at genotypic level.

4.7.2.7 Number of fruits per cluster

Number of fruits per cluster was significantly positively correlated with number of fruits per plant (0.76 and 0.22) and fruit yield per plant (1.00 and 0.25) at both genotypic and phenotypic levels, respectively, while significant positive correlation were observed with fruit diameter (0.48), percentage fruit set (0.58) and leaf chlorophyll content (0.71) at genotypic level. Significant negative genotypic associations were recorded with average fruit weight (-0.34), fruit length (-0.80) and fruit shape index (-0.83). At phenotypic level, number of fruits per cluster revealed significant negative correlations with fruit diameter (-0.30) and fruit shape index (-0.73).

4.7.2.8 Number of fruits per plant

Number of fruits per plant indicated significant positive correlations with fruit yield per plant (0.67 and 0.60) both at genotypic and phenotypic levels, respectively, whereas it was significantly negatively associated with fruit diameter (-1.00 and -0.27) at the same levels. Number of fruits per plant recorded significant positive associations with percentage fruit set (0.54) and leaf chlorophyll content (0.55), while significant negative correlations were observed with average fruit weight (-0.89), fruit length (-0.60) and fruit shape index (-0.40) at genotypic level.

4.7.2.9 Average fruit weight

The association of average fruit weight was in positive direction with fruit shape index (0.29 and 0.38) at genotypic and phenotypic levels. Significant positive correlations with fruit length (0.58), fruit diameter (0.87), fruit yield per plant (0.29) were observed at genotypic level. However, significant negative correlations were observed with leaf chlorophyll content (-0.29) and canopy temperature depression (-0.40) at genotypic level and with percentage fruit set (-0.58) at phenotypic level.

4.7.2.10 Fruit length

At genotypic and phenotypic levels, fruit length exhibited significant positive correlation with fruit diameter (1.00 and 0.34). it also showed significant positive correlations with fruit shape index (1.00) and canopy temperature depression (0.40) but significant negative associations with fruit yield per plant (-0.58), percentage fruit set (-0.34) and leaf chlorophyll content (-0.56) at genotypic level. Fruit length was significantly negatively correlated with fruit shape index (-0.73) at phenotypic level.

4.7.2.11 Fruit diameter

Fruit diameter was correlated significantly positively with leaf chlorophyll content (1.00) but significantly negatively correlated with fruit shape index (-0.70), fruit yield per plant (-0.58), percentage fruit set (-1.00) and canopy temperature depression (-1.00) at genotypic level. Highly significant positive association was recorded with fruit shape index (0.70) at phenotypic level.

4.7.2.12 Fruit shape index

Fruit shape index showed significant positive association with canopy temperature depression (0.43), while it was significantly negatively correlated with fruit yield per plant (-0.52), percentage fruit set (-0.24) and leaf chlorophyll content (-0.34) at genotypic level. At phenotypic level, fruit shape index was significantly negatively correlated with number of branches per plant (-0.73), number of flowers per cluster (-0.73) and number of fruits per cluster and fruit length (-0.73). The phenotypic correlation between fruit shape index and fruit diameter was highly significant positive (0.70).

4.7.2.13 Fruit yield per plant

Fruit yield per plant exhibited significant positive correlation with number of flowers per cluster (0.86 and 0.50), number of flowers per plant (0.66 and 0.53), number of fruits per cluster (1.00 and 0.25), number of fruits per plant (0.67 and 0.60) and percentage fruit set (0.90 and 0.51) at both genotypic and phenotypic levels. It also showed significant positive genotypic correlations with plant height (0.53) and leaf chlorophyll content (0.58) but significant negative associations with fruit length (-0.58),

fruit diameter (-0.58), fruit shape index (-0.52) and canopy temperature depression (-0.53) at genotypic level.

4.7.2.14 Percentage fruit set

Percentage fruit set showed significant positive correlation with fruit yield per plant (0.90 and 0.51) at both genotypic and phenotypic levels, respectively. Significant positive correlations with number of branches per plant (0.46), number of clusters per plant (0.41), number of flowers per cluster (0.56), number of flowers per plant (0.41), number of fruits per cluster (0.58), number of fruits per plant (0.54) and leaf chlorophyll content (0.61) were recorded at genotypic level. Percentage fruit set recorded significant negative correlations with fruit length (-0.34), fruit diameter (-1.00) and fruit shape index (-0.24) at genotypic level. The phenotypic correlation between percentage fruit set and average fruit weight was highly significant negative (-0.58).

4.7.2.15 Leaf chlorophyll content

Leaf chlorophyll content indicated significant positive genotypic correlations with plant height (0.41), number of branches per plant (0.23), number of clusters per plant (0.54), number of flowers per cluster (1.00), number of flowers per plant (0.24), number of fruits per cluster (0.71), number of fruits per plant (0.55), fruit diameter (1.00), fruit yield per plant (0.58) and percentage fruit set (0.61). Significant negative genotypic correlations with average fruit weight (-.029), fruit length (-0.56), fruit shape index (-0.34) and canopy temperature depression (-0.47) were observed at genotypic level.

4.7.2.16 Cell membrane thermostability

Significant positive correlations with days to 50% flowering (1.00), number of branches per plant (1.00), number of clusters per plant (1.00), number of flowers per cluster (0.56), number of flowers per plant (0.41), number of fruits per cluster (0.89), number of fruits per plant (1.00),average fruit weight (1.00), fruit yield per plant (0.63), percentage fruit set (1.00), leaf chlorophyll content (1.00) and canopy temperature depression (0.58) were recorded at genotypic level. Cell membrane thermostability recorded significant negative correlations with fruit length (-0.39) and fruit shape index (-0.26) at genotypic level.

Table 4.27: Genotypic (upper diagonal) and phenotypic (lower diagonal) correlations for Samaru during 2014 rainy season

Characters	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
PHT		-0.08	0.25*	-0.01	0.10	-0.10	-0.08	-0.09	0.58**	0.24*	-1.00**	0.19	0.53**	0.07	0.41**	-0.77**	-1.00**
DFPFL	-0.08		-0.60**	-0.55**	-0.77**	-0.49**	-0.76**	-0.53**	0.30**	0.68**	0.06	0.63**	-0.50**	-0.54**	-0.16	0.47**	1.00**
NBPP	-0.04	0.03		0.86**	0.68**	0.82**	0.80**	1.00**	-0.72**	-0.40**	-0.96**	-0.31**	0.87**	0.46**	0.23*	-0.16	1.00**
NCPP	-0.02	0.20	0.07		0.94**	0.90**	0.91**	0.96**	-0.82**	-0.71**	-0.50**	-0.62**	0.64**	0.41**	0.54**	-0.12	1.00**
NFLPC	-0.23*	0.20	-0.10	0.18		0.85**	1.00**	0.71**	-0.34**	-0.59**	1.00**	-0.64**	0.86**	0.56**	1.00**	-0.28*	0.89**
NFLPP	-0.04	0.15	0.12	0.49**	-0.13		0.93**	1.00**	-0.94**	-0.84**	-1.00**	-0.78**	0.66**	0.41**	0.24*	0.04	-1.00**
NFRPC	-0.26*	0.15	0.15	0.13	0.24*	0.15		0.76**	-0.34**	-0.80**	0.48**	-0.83**	1.00**	0.58**	0.71**	0.02	0.53**
NFRPP	-0.60**	-0.04	-0.04	0.26*	0.05	0.15	0.22*		-0.89**	-0.60**	-1.00**	-0.40**	0.67**	0.54**	0.55**	0.004	1.00**
AFW	0.05	-0.15	0.33**	0.25*	-0.24*	-0.26**	0.04	0.02		0.58**	0.87**	0.29**	0.29**	-0.16	-0.29**	-0.40**	1.00**
FRL	-0.14	-0.21	0.70**	-0.14	0.70**	-0.14	0.70	-0.14	0.04		1.00**	1.00**	-0.58**	-0.34**	-0.56**	0.40**	-0.39**
FRD	-0.22*	-0.01	-0.09	-0.33**	0.45**	0.29**	-0.30**	-0.27*	0.03	0.34**		-0.70**	-0.58**	-1.00**	1.00**	-1.00**	-0.60**
FRSI	0.23*	0.18	-0.73**	-0.18	-0.73**	0.11	-0.73**	0.12	0.38**	-0.73**	0.70**		-0.52**	-0.24*	-0.34**	0.43**	-0.26*
FRYPP	0.07	-0.02	0.18	0.18	0.50**	0.53**	0.25*	0.60**	0.18	0.08	0.04	0.01		0.90**	0.58**	-0.53**	0.63**
PFRS	0.04	0.20	0.03	-0.17	0.05	0.03	0.05	0.04	-0.58**	0.13	0.10	0.12	0.51**		0.61 **	-0.14	1.00**
LCC	0.15	-0.14	-0.15	0.10	-0.16	0.16	-0.15	-0.15	-0.05	-0.15	-0.15	-0.16	0.16	-0.16		-0.47**	1.00**
CTD	0.02	-0.10	0.24*	-0.09	-0.14	0.34**	-0.19	-0.04	0.13	-0.13	0.07	0.01	0.14	-0.08	-0.19		0.58**
CMT	-0.37**	-0.21	-0.42**	-0.09	-0.18	-0.29**	0.08	-0.33**	-0.55**	-0.53**	-0.23*	0.01	-0.07	0.12	-0.37**	-0.14	

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant, AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

4.7.3 Genotypic and phenotypic correlations combined across locations

4.7.3.1 Plant height

Plant height revealed significant positive genotypic correlations with number of fruits per plant (0.31), fruit diameter (1.00), fruit yield per plant (0.57) and percentage fruit set (0.39),while significant negative genotypic correlations were observed with leaf chlorophyll content (-1.00) and canopy temperature depression (-0.72). Significant positive and negative phenotypic correlations with fruit length (0.39) and fruit shape index (-0.51) were recorded, respectively.

4.7.3.2 Days to 50% flowering

Days to 50% flowering showed significant positive genotypic correlations with average fruit weight (0.25), fruit length (0.60), fruit diameter (1.00), fruit shape index (0.48), leaf chlorophyll content (1.00) and canopy temperature depression (0.33). Significant negative genotypic associations were noticed with number of branches per plant (-0.56), number of clusters per plant (-0.61), number of flower per cluster (-0.71), number of flower per plant (-0.51) and percentage fruit set (-0.45) at genotypic level. At phenotypic level, significant positive associations with number of clusters per plant (0.30) and number of fruits per cluster (0.27) while significant negative correlation was observed with average fruit weight (-0.30).

4.7.3.3 Number of branches per plant

Significant positive correlations were observed for number of branches per plant with number of fruits per cluster (0.83 and 0.27) at both genotypic and phenotypic levels, respectively. Significant positive genotypic correlations with number of clusters per

plant (0.92), number of flowers per cluster (0.76), number of flower per plant (0.87), number of fruit per plant (1.00), fruit yield per plant (0.97) and percentage fruit set (0.70) were recorded, while significant negative associations were also recorded with average fruit weight (-0.67), fruit length (-0.25), fruit diameter (-1.00) and leaf chlorophyll content (-1.00). Significant positive correlations were found with average fruit weight (0.33) and canopy temperature depression (0.25) while significant negative correlation with number of flower per cluster (-0.35) was observed at phenotypic level.

4.7.3.4 Number of clusters per plant

At genotypic and phenotypic levels, number of clusters per plant exhibited significant positive correlations with number of fruits per cluster (0.81 and 0.27) and fruit yield per plant (0.96 and 0.34), respectively. Significant negative associations with fruit diameter (-1.00 and -0.26) and fruit shape index (-0.43 and -0.52) at both genotypic and phenotypic levels were also recorded. Similarly, significant positive correlations with number of flowers per cluster (0.99), number of flowers per plant (0.88), number of fruits per plant (0.97) and percentage fruit set (0.82) as well as significantly negative correlation with average fruit weight (-0.75) and fruit length (-0.66) were obtained at genotypic level. At phenotypic level, number of clusters per plant showed significant positive correlations with average fruit weight (0.56) and fruit length (0.39).

4.7.3.5 Number of flowers per cluster

The association of number of flowers per cluster was significant in positive direction with number of fruits per cluster (1.00 and 0.27) and fruit yield per plant (0.92 and 0.36) at genotypic and phenotypic levels. Number of flowers per cluster significantly

negatively correlated with fruit shape index (-0.59 and -0.52) at both levels. Number of flowers per cluster also recorded significant positive associations with number of flowers per plant (0.91), number of fruits per plant (0.74) and percentage fruit set (0.73) at genotypic level, and with fruit length (0.39) at phenotypic level. Significant negative correlations were observed for the number of flowers per cluster with average fruit weight (-0.84), fruit length (-0.64), fruit diameter (-1.00) and leaf chlorophyll content (-0.69) at genotypic level.

4.7.3.6 Number of flowers per plant

Number of flowers per plant recorded significant positive correlations with number of fruit per plant (0.96 and 0.27) at both genotypic and phenotypic levels, while significant negative associations were observed with fruit diameter (-1.00 and -0.27) and fruit shape index (-0.54 and -0.52) at both genotypic and phenotypic levels respectively. Similarly, significant positive correlation with number of fruits per cluster (0.94), fruit yield per plant (0.80) and percentage fruit set (0.70) were observed at genotypic level and with fruit length (0.39) at phenotypic level. Number of flowers per plant indicated significant negative genotypic correlation with average fruit weight (-0.84), fruit length (-0.72) and leaf chlorophyll content (-1.00).

4.7.3.7 Number of fruits per cluster

Number of fruits per cluster was significantly positively correlated with number of fruits per plant (0.70), fruit yield per plant (0.88), percentage fruit set (0.71) and canopy temperature depression (0.27) and significantly negatively correlated with average fruit weight (-0.43), fruit length (-0.80), fruit diameter (-1.00) fruit shape index (-0.71) and

leaf chlorophyll content (-0.51) at genotypic level. At phenotypic level, significant positive correlation with fruit length (0.39) and negative association with fruit shape index (-0.52) were observed.

4.7.3.8 Number of fruits per plant

Significant positive correlations were observed for number of fruits per plant with fruit yield per plant (0.90) and percentage fruit set (0.79), while significant negative associations were recorded with average fruit weight (-0.81), fruit length (-0.45), fruit diameter (-1.00) and leaf chlorophyll content (-1.00) at genotypic level. Significant positive phenotypic correlation with fruit length (0.39) and fruit diameter (0.29) and significant negative correlation with fruit shape index (-0.52) were recorded.

4.7.3.9 Average fruit weight

At genotypic and phenotypic levels, average fruit weight correlated with fruit length (0.26 and 0.29) and fruit diameter (1.00 and 0.34). Average fruit weight significantly negatively correlated with fruit yield per plant (-0.52), percentage fruit set (-0.26), leaf chlorophyll content (-0.41) and canopy temperature depression (-0.72) at genotypic level and with fruit yield per plant (0.27) at phenotypic level.

4.7.3.10 Fruit length

Fruit length exhibited significant positive correlation with fruit shape index (1.00 and 0.39) at genotypic and phenotypic levels, respectively, and with canopy temperature depression (0.45) at genotypic level only. While significant negative genotypic correlations were observed for fruit length with fruit diameter (-1.00), fruit yield per

plant (-0.47), percentage fruit set (-0.31) and leaf chlorophyll content (-0.36). Significant positive associations with fruit diameter (0.39) and fruit yield per plant (0.26) were recorded at phenotypic level.

4.7.3.11 Fruit Diameter

Fruit Diameter showed significant positive association with leaf chlorophyll content (1.00 and 0.25) at genotypic and phenotypic levels, respectively. Significant positive correlation was observed for fruit diameter with fruit shape index (1.00), while significant negative correlation with fruit yield per plant (-1.00), percentage fruit set (-0.70) and canopy temperature depression (-1.00) were recorded at genotypic level. Significant positive phenotypic correlation with fruit yield per plant (0.26) was also recorded.

4.7.3.12 Fruit shape index

Fruit shape index significantly positively correlated with days to 50% flowering (0.48), fruit length (1.00), fruit diameter (1.00) and canopy temperature depression (0.65). Fruit shape index recorded significant negative correlations with number of clusters per plant (-0.43 and -0.52), number of flowers per cluster (-0.59 and -0.52), number of flowers per plant (-0.54 and -0.52), number of fruits per cluster (-0.71 and -0.52) at both genotypic and phenotypic levels, respectively. While significant negative association with fruit yield per plant (-0.26) and leaf chlorophyll content (-1.00) were observed at genotypic level.

4.7.3.13 Fruit yield per plant

Fruit yield per plant expressed significant positive correlation with number of clusters per plant (0.96 and 0.34), number of flowers per cluster (0.92 and 0.36) and percentage fruit set (0.97 and 0.30) at both genotypic and phenotypic levels, respectively. Significant positive correlations with plant height (0.57), number of branches per plant (0.97), number of flowers per plant (0.80), number of fruits per cluster (0.88), number of fruits per plant (0.90) and leaf chlorophyll content (0.90) were obtained at genotypic level. Similarly, Significant negative correlations with average fruit weight (-0.52), fruit length (-0.47), fruit diameter (-1.00), fruit shape index (-0.26) and canopy temperature depression (-0.26) were recorded at genotypic level. At phenotypic level, fruit yield per plant significantly positively correlated with average fruit weight (0.27), fruit length (0.22) and fruit diameter (0.26).

4.7.3.14 Percentage fruit set

Significant positive correlations were observed for the percentage fruit set with fruit yield per plant (0.97 and 0.30) at both genotypic and phenotypic levels, respectively. Significant positive associations with plant height (0.39), number of branches per plant (0.70), number of clusters per plant (0.82), number of flowers per cluster (0.73), number of flowers per plant (0.70), number of fruits per cluster (0.71), number of fruits per plant (0.79) and leaf chlorophyll content (1.00) were recorded at genotypic level.

4.7.3.15 Leaf chlorophyll content

Leaf chlorophyll content indicated significant and positive association with canopy temperature depression (1.00 and 0.38) at genotypic and phenotypic levels respectively.

Significant positive correlations with days to 50% flowering (1.00), fruit diameter (1.00), fruit yield per plant (0.90) and percentage fruit set (1.00) were obtained at genotypic level. Leaf chlorophyll content was significantly negatively correlated with plant height (-1.00), number of branches per plant (-1.00), number of clusters per plant (-0.60), number of flowers per cluster (-0.69), number of flowers per plant (-1.00), number of fruits per cluster (-0.51), number of fruits per plant (-1.00), average fruit weight (-0.41), fruit length (-0.36) and fruit shape index (-1.00) at genotypic level.

4.7.3.16 Cell membrane thermostability

Cell membrane thermostability showed significant positive correlation with number of branches (0.80 and 0.66) at genotypic and phenotypic levels, respectively. Significant positive correlations with plant height (1.00), days to 50% flowering (0.79), number of branches per plant (0.80), number of clusters per plant (0.97), number of flowers per cluster (0.45), number of flowers per plant (0.89), number of fruits per cluster (-1.00), number of fruits per plant (1.00),average fruit weight (0.79), fruit yield per plant (0.91), percentage fruit set (1.00), leaf chlorophyll content (0.93) and canopy temperature depression (0.45) were recorded at genotypic level. Cell membrane thermostability recorded significant negative correlations with fruit diameter (-0.55 and 0.33) at genotypic and phenotypic levels, respectively.

Table 4.28: Genotypic (upper diagonal) and phenotypic (lower diagonal) correlations of measured traits across locations during 2014 rainy season

Characters	PHT	DFPFL	NBPP	NCPP	NFLPC	NFLPP	NFRPC	NFRPP	AFW	FRL	FRD	FRSI	FRYPP	PFRS	LCC	CTD	CMT
PHT		-0.18	0.21	0.16	-0.07	0.15	-0.20	0.31**	0.36**	-0.002	1.00**	0.01	0.57**	0.39**	-1.00**	-0.72**	1.00**
DFPFL	-0.07		-0.56**	-0.61**	-0.71**	-0.59**	-0.68**	-0.53**	0.25*	0.60**	1.00**	0.48**	-0.51**	-0.45**	1.00**	0.33**	0.79**
NBPP	-0.08	-0.003		0.92**	0.76**	0.87**	0.83**	1.00**	-0.67**	-0.25*	-1.00**	-0.08	0.97**	0.70**	-1.00**	0.16	0.80**
NCPP	-0.06	0.30**	0.01		0.99**	0.88**	0.81**	0.97**	-0.75**	-0.66**	-1.00**	-0.43**	0.96**	0.82**	-0.60**	-0.12	0.97**
NFLPC	-0.13	0.16	-0.35**	0.06		0.91**	1.00**	0.74**	-0.84**	-0.64**	-1.00**	-0.59**	0.92**	0.73**	-0.69**	-0.22*	0.45**
NFLPP	0.17	0.10	0.08	0.07	0.06		0.94**	0.96**	-0.84**	-0.72**	-1.00**	-0.54**	0.80**	0.70**	-1.00**	-0.07	0.89**
NFRPC	0.17	0.27*	0.27*	0.27*	0.27*	0.06		0.70**	-0.43**	-0.80**	-1.00**	-0.71**	0.88**	0.71**	-0.51**	0.27*	-1.00**
NFRPP	-0.188	0.17	0.17	0.17	0.17	0.27*	-0.19		-0.81**	-0.45**	-1.00**	-0.15	0.90**	0.79**	-1.00**	-0.15	1.00**
AFW	0.06	-0.30**	0.33**	0.56**	-0.07	0.16	0.21	0.16		0.26*	1.00**	0.09	-0.52**	-0.26*	-0.41**	-0.72**	0.79**
FRL	0.39**	-0.20	0.02	0.39**	0.39**	0.39**	0.39**	0.39**	0.29**		-1.00**	1.00**	-0.47**	-0.31**	-0.36**	0.45**	1.00**
FRD	-0.03	-0.10	-0.004	-0.26*	-0.06	-0.27*	-0.20	0.29**	0.34**	0.39**		1.00**	-1.00**	-0.70**	1.00**	-1.00**	-0.55**
FRSI	-0.51**	-0.01	-0.03	-0.52**	-0.52**	-0.52**	-0.52**	-0.52**	0.04	0.39**	0.11		-0.26*	-0.16	-1.00**	0.65**	0.06
FRYP	0.08	0.21	0.13	0.34**	0.36**	0.10	0.16	0.19	0.27*	0.22*	0.26*	-0.02		0.97**	0.90**	-0.26*	0.91**
PFRS	0.06	0.17	0.02	0.09	0.02	0.05	0.02	0.09	0.002	0.16	-0.06	0.16	0.30**		1.00**	0.04	1.00**
LCC	0.18	-0.08	-0.08	-0.06	-0.08	-0.07	-0.08	0.18	0.21	-0.09	0.25*	-0.09	0.17	0.18		1.00**	0.93**
CTD	-0.11	-0.15	0.25*	0.14	-0.02	0.21	0.07	-0.06	-0.08	0.13	-0.54	0.16	0.17	-0.01	0.38**		0.45**
CMT	-0.72**	-0.53**	0.66**	-0.33**	-0.41**	-0.58**	0.03	-0.68**	-0.72**	-0.51**	-0.33**	-0.09	-0.22	-0.67**	-0.73**	-0.31	

PHT = Plant height, DFPFL = Days to 50% flowering, NBPP = Number of branches per plant, NCPP = Number of clusters per plant, NFLPC = Number of flowers per cluster, NFLPP = Number of flowers per plant, NFRPC = Number of fruits per cluster, NFRPP = Number of fruits per plant, AFW = Average fruit weight, FRL = Fruit length, FRD = Fruit Diameter, FRSI = Fruit shape index, FRYPP = Fruit yield per plant, PFRS = Percentage fruit set, LCC = Leaf chlorophyll content, CTD = Canopy temperature depression and CMT = Cell membrane thermostability. ** and * are significantly different at 1% and 5% levels of probability, respectively.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Analysis of Variance

Analysis of variance of the studied traits among the genotypes in Bagauda showed significant differences for all traits except plant height, days to 50% flowering, number of branches per plant, number of flowers per cluster, fruit diameter and canopy temperature, indicating presence of considerable genetic variability in the studied genotypes which is pre-requisite for any crop improvement. Significant variations among studied genotypes in Samaru and combined across locations were recorded for all traits except fruit diameter, depicting sufficient variability exists in the materials used for the study and also indicating possibility for selection of suitable breeding materials for tomato improvement under high temperature. The results were in agreement with findings of Wessel-Beaver and Scott (1992), Hazra and Ansary (2008), Shalini (2009), Kugblenu *et al*. (2013) and Islam *et al*. (2014).

The genotype × location interaction was significant for plant height, number of branches per plant, number of clusters per plant, number of flowers per plant, percentage fruit set and chlorophyll content, indicating that these traits were influenced by the differences in location. Therefore, suitable hybrids could be developed for specific locations. Wessel-Beaver and Scott (1992) reported that expression of genes controlling tomato fruit set was strongly influenced by environmental variation.

5.2 Mean Performance

The mean performance of the genotypes at Bagauda showed significant variations for all traits except days to 50% flowering, number of flowers per cluster, fruit diameter and canopy temperature, revealing that the parents were from diverse origin and can be crossed

effectively to developed good heat tolerant hybrids. Similar results were observed by Abdelmageed and Gruda, (2009a,b), Kamel *et al*. (2010), Kugblenu *et al*. (2013), Akhtar (2014) for leaf chlorophyll content. Roma VF had tallest plant followed by Icrixina. Among the hybrids, Icrixina × Tropimech had shortest days to flowering suggesting that, it can be used as early flowering hybrid that could escape heat stress. Icrixina had the highest performance for number of flowers per cluster, while Icrixina × Rio Grande recorded the highest number of clusters per plant and number of flowers per cluster, suggesting over-dominance gene action for the traits in the cross as supported by the average degree of dominance greater than unity. Regarding the number of fruits per cluster, Icrixina × Petomech exhibited highest number of fruits per cluster followed by Icrixina × Tima and Icrixina × Tropimech. Thorgal F_1 produced heavy fruits among the genotypes. Among the parents Rio Grande exhibited longer fruit, while Rio Grande × Tima had longer fruit size, suggesting the importance of parents for the genetic improvement of heat tolerant tomato regarding fruit size. Among the genotypes, UC82 B had wider fruit size, whereas Petomech × Roma Savana recorded highest fruit shape index, indicating that susceptible genotype had large fruit size than heat tolerant varieties. The traits were negatively correlated with percentage fruit set, indicating that, percentage fruit set under high temperature may increase with a reduction of fruit size. The results were in full agreement with the findings of Dane *et al*. (1991), Wessel-Beaver and Scott (1992), Scott *et al*. (1997), Kamel *et al*. (2010). They observed that, heat tolerant tomato usually produced small size fruits compared to susceptible ones. Icrixina had highest fruit yield per plant whereas Icrixina × Rio Grande recorded highest for these traits among the hybrids depicts over-dominance gene effects for these traits. The results were further supported by the average degree of dominance greater than unity and highly significant positive correlation between the traits. Icrixina ×

Tropimech produced highest canopy temperature depression among the hybrids. Malgorzata *et al*. (2009) and Akhtar (2014) reported significant variation for leaf chlorophyll content in tomato under high temperature while, Gajanayake *et al*. (2011) recorded highest canopy temperature depression in three cultivars of ornamental pepper.

The mean performance at Samaru showed significant variation among the genotypes for all traits except fruit diameter. These results were in accordance with the finding of Abdelmageed and Gruda, (2009a,b), Kugblenu *et al*. (2013), Islam *et al*. (2014). Icrixina flower early among the parents, while Icrixina × Rio Grande flower early suggesting that the parent can be utilized in breeding programs for developing early maturity varieties. Roma VF had the highest number of fruits per plant followed by Petomech × Roma Savana. The hybrid Icrixina × Roma Savana recorded the highest number of flowers per cluster suggesting that these hybrids could be used under high temperature. The results also indicated that the traits were highly significantly positively correlated with each other. Thorgal F_1 produced heavy average fruit weight followed by Rio Grande × Roma Savana. Among the parents, Rio Grande exhibited big fruit size, whereas, Rio Grande × Tropimech and Rio Grande × Roma Savana showed big fruit size among the hybrids indicating that Rio Grande can be utilized for breeding of large fruit heat tolerant tomato under high temperature. Icrixina × Tima revealed highest fruit yield per plant, and percentage fruit set suggesting over dominance gene action for the traits. The hybrid Tima × Roma Savana expressed highest canopy temperature depression. Similar results were reported by Gajanayake *et al*. (2011), Malgorzata *et al*. (2009) and Akhtar (2014).

Across locations, the mean performance revealed significant differences for all traits, except fruit diameter. Icrixina × Tropimech expressed earlier in flowering. Roma VF among the

genotypes produced the highest number of fruits per plant. The results also revealed that the crosses involving Icrixina recorded the highest mean performance for number of clusters per plant, number of flowers per cluster, number of fruits per cluster, fruit yield per plant, percentage fruit set and leaf chlorophyll content, indicating the parents could be selected for extraction of inbred lines for commercial production of heat tolerant hybrids. The hybrids Rio Grande × Roma Savana and Rio Grande × Tima were the best regarding fruit length and fruit shape index, respectively, showing that, Rio Grande was good combiner for these traits and could be selected for improvement of fruit size under high temperature. The result also revealed that Rio Grande recorded highest gca effects for fruit length, fruit diameter and fruit shape index. Thorgal $F_{1,}$ UC82 B and Tima showed high average fruit weight, fruit diameter and canopy temperature depression.

Genotype × locations interaction, the mean performance revealed significant differences among the genotypes for plant height, number of branches per plant, number of clusters per plant, number of flowers per plant, percentage fruit set and leaf chlorophyll content. Roma VF had tallest plant followed by Icrixina × Petomech at Bagauda, while Petomech × Roma Savana was the tallest plant at Samaru. Roma VF produced the highest number of branches per plant at both locations compared to the parents and hybrids. The result was in accordance with findings of Dane *et al*. (1991), Wessel-Beaver and Scott, (1992), Scott *et al*. (1997). They reported that heat tolerant tomato usually produced few branches compared to susceptible variety. Icrixina had the highest performance for number of clusters per plant and number of flowers per cluster, while Icrixina × Rio Grande recorded the highest number of clusters per plant at Bagauda, suggesting over-dominance gene action for the trait in the cross as supported by the average degree of dominance greater than unity. At Samaru, Roma Savana produced high number clusters per plant, while hybrid Icrixina × Roma Savana

recorded the highest number clusters per plant. Roma VF and Icrixina × Rio Grande have the highest number of flowers per plant at Bagauda and Samaru, respectively. This is because, Roma VF had highest plant height and number of branches per plant. The result also shows the traits were positively correlated. The hybrids Icrixina × Rio Grande and Icrixina × Tima set more fruits at Bagauda and Samaru, respectively. The result also revealed that Icrixina recorded highest gca effects for percentage fruit set and also hybrids recorded highest heterobeltiosis and sca effects suggesting over dominance gene action for the trait in the crosses. Therefore parent Icrixina was good combiner for production of heat tolerant tomato hybrid for both locations. Jaguar F_1 and Tropimech × Petomech recorded highest leaf chlorophyll content at Bagauda and Samaru, respectively. Akhtar (2014) reported significant variation for leaf chlorophyll content in tomato under high temperature.

5.3 Analysis of Combining Ability

Combining ability analysis technique contributes to understanding the genetic potential of parents and their hybrids. It provides information regarding gene action which can be used in formulating an effective breeding strategy. The results of analysis of variance for combining ability at Bagauda and Samaru revealed similar trend and significant differences for parents with regard to plant height, number of clusters per plant, number of flowers per plant, fruit length and fruit shape index indicating genetic variability among the parents for these traits. Parents vs. crosses measures average heterosis which is important for non -additive gene effect. The parent vs. crosses showed significant variation for plant height, number of branches per plant, number of clusters per plant, number of flowers per cluster, number of fruits per cluster and percentage fruit set revealing that the hybrids formed were better than at least one of the parents. The crosses mean squares were significant for days to 50% flowering, number of clusters per plant, number of flowers per plant, , number of fruits

per cluster, number of fruits per plant, average fruit weight, fruit length, fruit shape index, fruit yield per plant, percentage fruit set and canopy temperature depression. This suggests that parents can be used to develop suitable hybrids regarding these traits. GCA and SCA variances were significant for most studied traits, indicating the importance of both additive and non-additive gene actions in the expression of these traits. Despite the fact that both additive and non-additive gene actions were important in the genetic control of most traits, the variance components due to SCA were higher in magnitude than the GCA variances depicting predominance of non-additive gene action for all traits except number of fruits per cluster and fruit length. The predominance of non-additive gene action for all traits in controlling the inheritance of these traits denotes that non-additive gene action largely influence the expression of these traits, hence suggesting development of hybrids for their genetic improvement. Therefore, heterosis could be exploited in improving these traits under heat stress. Similar results were reported by Cheema *et al.* (2003), Hazra and Ansary (2008), Shalini (2009), Sekhar *et al.* (2010), Saleem *et al.* (2013).

The GCA to SCA ratios were less than unity for all traits except number of fruits per cluster and fruit length which depicts the importance of non-additive gene action. The GCA to SCA ratios greater than unity for number of fruits per cluster, number of fruits per cluster and fruit length indicating that additive gene actions were prominent for the traits. Therefore, recurrent selection could be applied to improve the traits under high temperature. Similar result was reported by Yadev *et al.* (2013). The average degree of dominance values were greater than unity except for number of clusters per plant, number of fruits per cluster and fruit length indicating the existence of over-dominance, thus suggesting the importance of non-additive genetic components for the characters. The average degree of dominance values less than unity revealed the existence of partial dominance. The results corroborated

with the finding of Hazra and Ansary (2008) who reported over-dominance and partial dominance for most characters influencing heat tolerance in tomato.

The combining ability analysis across locations shows highly significant parents vs. crosses × location interaction for plant height and number of branches per plant indicating that the hybrids would be developed and evaluated at individual environments for these traits. GCA × location interaction showed significant variation for the number of branches per plant, number of flowers per plant and canopy temperature, suggesting that different parents behave differently with respect to these traits at the different location. The significant SCA × location interaction for number of flowers per plant, percentage fruit set and leaf chlorophyll content indicate that the hybrids performance for the traits varied with respect to locations. Therefore, specific hybrids would be developed for the specific locations under consideration.

5.3.1 Combining Ability Effects

The combining ability effects for Bagauda revealed that Icrixina recorded highly significant gca effects for all traits except plant height, number of branches per plant, average fruit weight, fruit diameter, leaf chlorophyll content and canopy temperature depression. Significant negative gca effect for days to 50% flowering was observed in Icrixina indicating that, it is good early flowering. Rio Grande recorded significant positive gca effects for fruit length and fruit shape index, suggesting that the traits could be improved using Rio Grande.

The sca effect shows the role of non-additive gene effect in the expression of a trait. Singh and Narayanan (2004) observed that sca effect does not contribute much to the improvement of self-pollinated crops like tomato. However, the sca effects among fifteen hybrids indicate

that none of the hybrids was best specific combiner for all traits indicating differences in genetic variability for the different traits among the hybrids. The hybrids Rio Grande × Tropimech and Tropimech × Petomech exhibited significant positive sca effects for plant height and were good combiners for these traits. Rio Grande × Roma Savana, Tima × Tropimech, Tropimech × Petomech and Petomech × Roma Savana showed significant negative sca effects for days to 50% flowering indicating that, they are good crosses for early flowering which could escape heat stress. The results were further supported by negative heterobeltiosis recorded for these hybrids. With regard to number of branches per plant, only Tropimech × Roma Savana among the hybrids had significant negative sca effects. Icrixina × Rio Grande and Petomech × Roma Savana expressed significant positive sca effects, while Icrixina × Petomech, Rio Grande and Petomech and Tima × Roma Savana recorded significant negative sca effects for number of clusters per plant. These results corroborate the findings of Mahendrakar (2004) and Saleem *et al.* (2013). The hybrid Tropimech × Roma Savana recorded significant negative sca effect for number of flowers per cluster among the crosses. The sca effects for number of flowers per plant were significant in the hybrids Icrixina × Rio Grande and Petomech × Roma Savana, whereas, Icrixina × Roma Savana recorded significant negative sca effect. Positive sca effect for number of fruits per plant was observed in Rio Grande × Tima while negative sca effects were found in Rio Grande × Roma Savana and Tima × Roma Savana. Significant positive sca effect for fruit length was observed in Rio Grande × Tima among the crosses. Saleem *et al.* (2013) reported significant positive sca effect for number of fruits per plant in only one cross. Petomech × Roma Savana was a good specific combiner as indicated by significant positive sca effects for fruit shape index, while Tima × Petomech and Tropimech × Roma Savana expressed significant negative sca effects for this trait. In case of fruit yield per

plant, crosses Icrixina × Rio Grande and Petomech × Roma Savana exhibited significant positive sca effects, whereas Rio Grande × Petomech showed significant negative sca effect. The fruit yield per plant for Icrixina × Rio Grande and Petomech × Roma Savana were higher compared to Thorgal F_1 and Jaguar F_1. The high fruit yield per plant recorded for Icrixina × Rio Grande and Petomech × Roma Savana might be due one of heat tolerant parent in the crosses. The crosses Icrixina × Rio Grande, Tima × Tropimech and Petomech × Roma Savana revealed significant positive sca effects for percentage fruit set, indicating that the crosses were good combiners for heat tolerance compared to Thorgal F_1 and Jaguar F_1. With regard to leaf chlorophyll content, only Rio Grande × Tima showed significant negative sca effect. The high sca effects manifested by these crosses involved one of parents with high × low or low × low gca effects. Therefore, these hybrids could be developed and improved for production of commercial hybrids under high temperature environment. Similar results were reported by Brar *et al.* (2005), Kavitha *et al.* (2007), Singh *et al.* (2008) and Saleem *et al.* (2013). The results of sca effects for number of fruits per cluster, average fruit weight, fruit diameter, canopy temperature depression and cell membrane thermostability were non-significant among the hybrids. Singh and Narayanan (2004) reported that sca effect do not contribute much to the improvement of self-pollinated crops like tomato and sca effects of hybrids did not always coincide with percent hybrid vigor (Kalloo *et al.,* 1974).

The gca and sca effects for Samaru showed that Icrixina recorded highly significant positive gca effects for all traits except plant height, fruit diameter and fruit shape index and significant negative gca effects were observed for days to 50% flowering, average fruit weight, fruit length and canopy temperature depression. This parent could be hybridized and selection practiced in segregating generations to develop advance generations lines having

heat tolerance ability. Negative gca effect observed for Icrixina for days to 50% flowering suggests that Icrixina is a good combiner for early flowering. Significant positive and negative gca effects of these traits have been reported by Gaikwad *et al.* (2009), Izge *et al.* (2012) and Saleem *et al.* (2013). Rio Grande had significant positive gca effects for average fruit weight and fruit length but negative significant gca effects for number of branches per plant, number of clusters per plant, number of flowers per plant and number of fruits per plant, suggesting that Rio Grande was good combiner for average fruit weight and fruit length which could be used as valuable donor to develop big fruit size, but with the reduction of number of branches per plant, number of clusters per plant, number of flowers per plant and number of fruits per plant as supported by highly significant negative correlations between the traits. Tima expressed significant positive gca effect for percentage fruit set and canopy temperature depression. Roma Savana had significant positive gca effect for days to 50% flowering and fruit length, while negative significant gca effects were observed for percentage fruit set.

The specific combining ability effects revealed that Tropimech × Petomech had significant sca effects for plant height, while Icrixina × Tropimech and Tima × Petomech expressed significant negative sca effects for days to 50% flowering which is preferable for possible early maturity variety that can escape heat stress. Similar result was reported by Singh *et al.* (2008). Positive significant sca effects for plant height, number of clusters per plant and number of flowers per plant were observed for Tropimech × Petomech and Petomech s× Roma Savana while significant negative sca effects was found for Rio Grande × Roma Savana regarding number of clusters per plant, number of flowers per plant, number of fruits per plant and percentage fruit set, suggests that the hybrids were good combiners for the traits. Among the hybrids, only Tropimech × Roma Savana exhibited sca effect for a number

of flowers per cluster. For number of flowers per plant, hybrids Icrixina × Rio Grande, Tima × Tropimech and Petomech × Roma Savana recorded significant positive sca effects. The hybrids manifested high sca effects, because they involved either parent with high × low or low × low gca effects. Out of fifteen crosses, only Icrixina × Rio Grande and Petomech × Roma Savana revealed significant positive sca effect for number of fruits per plant. These results corroborated with findings of Premalakshmi *et al.* (2006). Izge *et al.* (2012) and Saleem *et al.* (2013). Rio Grande × Roma Savana showed significant positive sca effect for average fruit weight. The result revealed that Rio Grande was good combiner regarding average fruit weight for the cross. Hybrids Icrixina × Roma Savana and Rio Grande × Tropimech exhibited significant positive sca effects for fruit length. The high positive sca effects manifested by these crosses were due to the fact that parents Rio Grande and Roma Savana were good combiners (high × high gca effects) for fruit length. Significant positive sca effects regarding fruit shape index were found in Icrixina × Roma Savana and Rio Grande × Tropimech. Out of fifteen hybrids, only Icrixina × Petomech revealed significant negative sca effect for fruit yield per plant suggesting that the parents were not good combiners for fruit yield per plant as supported by non-significant heterotic response showed by all crosses. Hannan *et al.,* (2007a,b,) reported high non-significant sca effect for fruit yield per plant. Significant positive effects for percentage fruit set were observed in Icrixina × Rio Grande, Icrixina × Tima, Tima × Roma Savana and Petomech × Roma Savana. These hybrids involved one or both parents with high or low gca effects that can be effectively utilized for hybrid breeding as well as pure line breeding for heat tolerance. Negative sca effects were recorded in Icrixina × Petomech and Tropimech × Petomech for leaf chlorophyll content, while significant positive sca effect was observed in Tima × Roma Savana. Number of branches per plant, number of fruits per cluster, fruit diameter and cell

membrane thermostability showed non-significant sca effects among the hybrids. (Kallo *et al.*, 1974) observed that sca effects of hybrid did not always coincide with percent hybrid vigor.

The gca and sca effects across locations show that none of the parents was general combiner for all traits indicating differences in genetic variability for traits among the parents. However, Icrixina exhibited high gca effects for all traits except plant height, average fruit weight, fruit diameter, leaf chlorophyll content and canopy temperature depression. Among the parents, Rio Grande was found to be a good combiner for average fruit weight, fruit length, fruit diameter and fruit shape index, whereas significant negative gca effects were observed for the number of clusters per plant, number of fruits per cluster and number of fruits per plant. The Icrixina and Rio Grande were good combiner for days to 50% flowering, number of branches per plant, number of clusters per plant, number of flowers per clusters, number of flowers per plant, number of fruits per cluster, number of fruits per plant fruit yield per plant, percentage fruit set and average fruit weight, fruit length, fruit diameter and fruit shape index, respectively. The parents could be used for hybrid breeding in individual locations.

Plant height recorded significant positive sca effects for Tropimech × Petomech and negative sca effects for Petomech × Roma Savana. The hybrids Icrixina × Tropimech, Tima × Petomech, Tropimech × Petomech and Petomech × Roma Savana expressed significant negative sca effect for days to 50% flowering which is desirable for early flowering. The results were further supported by negative heterotic effects shown by the hybrids. Among the crosses, only Petomech × Roma Savana exhibited significant positive sca effect for number of clusters per plant while Rio Grande × Roma Savana and Tima × Tropimech

showed significant positive sca effects for number of flowers per cluster and negative significant sca effects for number of flowers per cluster were observed in Icrixina × Tima, Rio Grande × Tropimech and Tropimech × Roma Savana. Out of fifteen hybrids, only Tima × Tropimech showed significant positive sca effect for number of fruits per cluster, indicating that Tima was good combiner for the trait as supported by significant heterobeltiosis observed in the cross. Regarding number of fruits per plant, Petomech × Roma Savana and Rio Grande × Roma Savana recorded significant positive and negative sca effects respectively. The results corroborated the findings of Kulkani (2003), Mahendrakar (2004), Yashavantakumar (2008) and Saleem *et al.* (2013). The cross Rio Grande × Roma Savana showed significant positive sca effect for average fruit weight, while Rio Grande × Tima exhibited significant positive sca effect for fruit length, suggests Rio Grande was good combiner for both average fruit weight and fruit length which could be used as valuable donor in breeding programme for developing big fruit size under heat stress. Petomech × Roma Savana and Tropimech × Roma Savana showed significant positive and negative sca effects for fruit shape index respectively. The high sca effects manifested by these crosses were due to one of the best general combiner parents (Rio Grande and Roma Savana). The results are further supported by heterotic response shown by most of the crosses for the traits. Number of branches per plant, number of flowers per plant, fruit diameter, fruit yield per plant, fruit yield per hectare, leaf chlorophyll content, canopy temperature depression and cell membrane thermostability recorded non-significant sca effects. The results were in agreement with the finding of (Kallo *et al.,* 1974). Hannan *et al.,* (2007a) reported high non-significant sca effect for fruit yield per plant.

5.4 Heterosis

The estimates of heterobeltiosis for Bagauda, Samaru and combined across locations show that the degree and magnitude of heterobeltiosis varied from hybrid to hybrid and from trait to trait. However, both positive and negative heterotic values were observed among traits. Negative heterobeltiosis were recorded for days to 50% flowering which is desirable because of their breeding value for developing early flowering tomato hybrids which can escape heat stress. In this study, the results showed a similar trend for both locations. In general, most of the crosses recorded significant positive heterobeltiosis for number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant and percentage fruit set indicating the prevalence of non-additive gene action for the majority of traits. This is further supported by the average degree of dominance greater than unity and selection for hybrids with suitable traits would be possible. Icrixina × Tima, Tima × Petomech and Icrixina × Tropimech showed significant negative heterosis for plant height, number of branches per plant, number of flowers per plant, average fruit weight, fruit length, fruit diameter, fruit shape index, leaf chlorophyll content and canopy temperature depression over better parent. This could be attributable to similar genetic base of the materials used for the development of the parent. The results corroborated the findings of Fageria *et al.* (2001), Sharma *et al.* (2001), Radiša *et al.* (2010), Rahmani *et al.* (2010), Ahmad *et al.* (2011), Patwary *et al.* (2013) and Amaefula *et al.* (2014). Rio Grande × Roma Savana and Rio Grande × Petomech expressed significant positive heterosis for cell membrane thermostability over better parent. Therefore, heat tolerant hybrid could be developed using the parents. No hybrids exhibited significant heterobeltiosis for fruit yield per plant, but the hybrids Icrixina × Rio Grande, Icrixina × Roma Savana, Icrixina ×

Petomech and Petomech × Roma Savana expressed positive heterosis over better parent. Amaefula *et al.* (2014) also reported non-significant heterobeltiosis for fruit yield per plant.

5.5 Cell Membrane Thermostability

Membrane thermal stability measures leakage of electrolytes when cellular membrane exposed to high temperature. Electrical conductivity has been used as an index of membrane stability to identify genetic variation for heat tolerance in tomato (Kuo *et al.,* 1993). The results of cell membrane thermostability and heat injury at Bagauda, Samaru and combined across locations indicate that the majority of the genotypes were heat tolerant at 30^{o}C. This is optimum temperature required for tomato cultivation as reported by Camejo *et al.* (2005). The cell membrane thermostability and heat injury at 40^{o}C indicate that most of the genotypes were moderately to slightly heat tolerant. The significant variation among genotypes for electrolyte leakage at flowering stage and heat tolerance shows that the trait can be improved through breeding. The results corroborated the findings of Kuo *et al.* (1993), Alsadon *et al.* (2006), Saeed *et al.* (2007a,b) and Islam *et al.* (2014). At 50^{o}C, the cell membrane thermostability and heat injury among the genotypes indicated that hybrids Icrixina, Icrixina × Tropimech, Rio Grande × Tropimech, Rio Grande × Roma Savana and Rio Grande × Petomech were slightly heat tolerant. These hybrids were crosses involving one or both heat tolerant parents and can be utilized for yield improvement in high temperature locations. The significant variation observed among the genotypes for electrolyte leakage at flowering stage shows that flowering stage is an optimum stage for selecting heat tolerant tomato. The results were in accordance with findings of Kuo *et al.* (1993), Alsadon *et al.* (2006) and Hilali (2011). They observed that flowering stage is an optimum stage for evaluating heat tolerance of tomato in-vitro. Vegetables with low heat

injury were more stable than the ones with high heat injury in different growing seasons (Kuo *et al.,* 1993).

5.6 Heritability

The results of broad sense and narrow sense heritabilities for Bagauda, Samaru and combined across locations showed similar trend. The estimates of broad sense heritability were high for all the traits. The high broad sense heritability for number of branches per plant, number of clusters per plant, number of flowers per plant, number of fruits per plant, average fruit weight, fruit yield per plant, percentage fruit set, leaf chlorophyll and cell membrane thermostability indicates the existence of additive genes in the expression of the traits and the traits were heritable and can be transferred to the progeny for improvement by simple selection under heat stress. Similar results were reported by Wessel-Beaver and Scott (1992), Kamel *et al.* (2010), Kaushik *et al.* (2011), Manna and Paul (2012), Shankar *et al.* (2013) and Nwosu *et al.* (2014).

Narrow sense heritability measures the proportion of phenotypic variance among individuals in a population which is due to heritable genetic effects. The results of narrow sense heritability were generally low to moderate for the majority of the traits. At Bagauda, low narrow sense heritability estimates were recorded for all the traits except number of fruits per cluster and fruit length, which recorded moderate narrow sense heritability values. Low narrow sense heritability values were observed for plant height, days to 50% flowering, number of flowers per plant, number of fruits per plant, average fruit weight, fruit diameter, fruit yield per plant, percentage fruit set, leaf chlorophyll content and cell membrane thermostability and moderate values for number of branches per plant, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, fruit length, fruit shape index and canopy temperature depression. The estimates of narrow sense heritability values

for combined across locations were low for plant height, days to 50% flowering, number of branches per plant, average fruit weight, fruit diameter, fruit yield per plant, percentage fruit set, leaf chlorophyll content, canopy temperature depression and moderate for number of clusters per plant, number of flowers per cluster, number of flowers per plant, number of fruits per plant and fruit shape index while high estimate values were found for number of fruits per cluster and fruit length. Low narrow sense heritability values indicate non-additive gene influence, whereas, moderate narrow sense heritability shows both additive and non-additive gene actions are important in influencing the expression of these traits under high temperature locations. Low narrow sense heritability values indicate that selection of these traits is difficult in early generations. Selection should be delayed to later segregating generations. The relatively low to moderate values of narrow sense heritability were observed as a result of large environmental effects on the expression of traits at high temperature and confounded effects of Biotic (Septoria leaf spot) and abiotic (heat, drought and minerals imbalance) factors. These results were in accordance with findings of Dane *et al.* (1991), Peter *et al.* (2002). Hussein *et al.*, (2014) reported low narrow sense heritability for number of branches per plant, days to 50% flowering, number of fruits per plant and high values for fruit length (65.17%) and fruit shape index (83.64%). Low narrow sense heritability values were observed for number of branches per plant, number of flowers per plant, days to 50% flowering, fruit yield per plant and moderate values were recorded for plant height, number of fruit per plant and fruit diameter (Welegama *et al.*, 2015).

5.7 Correlations

Correlation provides information regarding associations among various traits. It gives an opportunity for selection of genotypes having desirable traits simultaneously (Ali *et al.*, 2009). Adequate knowledge about the magnitude and degree of association between fruit

set, fruit yield and yield attributing components would assist the breeder in the decision process for simultaneous improvement of more than one trait in a breeding program (Sivaprasad, 2008; Monomadi *et al.,* 2013). Yield is a quantitative trait controlled by many genes. Therefore, Selection for yield based on multiple traits is usually better than selection based on yield alone. The best way of improving yield indirectly is to select for traits that are highly correlated with yield and possess high heritability. Significant positive phenotypic correlation between traits shows that they can be predicted from each, while, genotypic correlation provides a measure of genetic association that will determine whether the relationship will be passed on to the offspring or not (Aghughu, 2001). The genotypic and phenotypic correlation coefficients for Bagauda, Samaru and combined across locations showed that, the estimates of genotypic correlations were higher than their corresponding phenotypic correlations, indicating strong genetic association between the traits studied and their phenotypic expression was hindered by environmental influences. Similar results were reported by Islam *et al.* (2012), Dar and Sharma (2011), Al-Aysh *et al.* (2012) and Meena and Bahadur (2015). The results for Bagauda, Samaru and combined across locations revealed that correlation coefficients of a trait at the genotypic level could be significant, while the same traits at the phenotypic level could be non-significant. This finding was in conformity with Kumari and Sharma (2013) and Meena and Bahadur (2015). At Bagauda, fruit yield per plant had significant positive correlation at genotypic and phenotypic levels with number of clusters per plant, number of flowers per cluster, number of fruits per cluster, average fruit weight and percentage fruit set. Fruit yield per plant was also significantly positively associated with plant height, number of branches per plant, number of flowers per plant, leaf chlorophyll content, canopy temperature depression and cell membrane thermostability, while it was significantly negatively correlated with days to 50%

flowering, fruit length and fruit diameter. The significant positive correlations observed between fruit yield and these traits show that fruit yield per plant under high temperature will increase with selection of plant height, number of branches per plant, number of clusters per plant, number of flowers per plant, number of flowers per cluster, number of fruits per cluster, average fruit weight, percentage fruit set, leaf chlorophyll content, canopy temperature depression and cell membrane thermostability. The significant negative indicate that as fruit yield per plant increases the days to flowering and fruit size will reduced under high temperature. The results were in agreement with findings of Wessel-Beaver and Scott (1992), Hazra and Ansary (2008) Al-Aysh *et al.* (2012), Kumari and Sharma (2013), Kumar *et al.* (2013) and Meena and Bahadur (2015). Percentage fruit set showed significant positive association with number of flowers per cluster, number of flowers per plant and fruit yield per plant both at genotypic and phenotypic levels. The results corroborated the findings of Wessel-Beaver and Scott (1992), Hazra and Ansary (2008) but contradicted the finding of Meena and Bahadur (2015) who reported significant negative correlations between percent fruit set and number of flowers per plant at both genotypic and phenotypic levels. Percentage fruit set also expressed significant positive genotypic correlation with plant height, number of branches per plant, number of clusters per plant, number of fruits per cluster, number of fruits per plant and cell membrane thermostability, but significant negative correlation with fruit diameter, suggesting that percentage fruit set under high temperature would increase with selection for these traits, but with a reduction in fruit size. Dane *et al.* (1991) also reported a negative correlation between fruit set and fruit size.

The estimates of genotypic and phenotypic correlations for Samaru revealed that, fruit yield per plant expressed significant positive correlations with number of flowers per cluster, number of flowers per plant, number of fruits per cluster, number of fruits per plant and

percentage fruit set at both genotypic and phenotypic levels, indicate that selection of the traits will indirectly increase fruit yield per plant under heat stress. This could occur when the genes governing two traits were linked, pleiotropy and environmental factors played small role in the expression of the traits. Fruit yield per plant also exhibited significant positive correlations with plant height, number of branches per plant, number of clusters per plant, average fruit weight and cell membrane thermostability. Significant negative relationships observed with days to 50% flowering, fruit length, fruit diameter and fruit shape index at genotypic level suggest that selection for the traits under high temperature environment would increase fruit yield per plant, but reduces days to flowering and fruit size as reported by Kaushik *et al.* (2011), Kugblenu *et al.* (2013), Nwosu *et al.* (2014) and Sherpa *et al.* (2014). The percentage fruit set show significant positive genotypic and phenotypic correlations with fruit yield per plant. It also indicated significant positive genotypic correlations with number of branches per plant, number of clusters per plant, number of fruits per cluster, number of fruits per plant and cell membrane thermostability. Significant negative correlations with days to 50% flowering, fruit length, fruit diameter and fruit shape index at genotypic level indicates percentage fruit set increases with selection of the traits. The negative association indicated that, earliness in flowering results in decrease of percentage fruit set and fruit size.

The genotypic and phenotypic correlations combined across locations show that fruit yield per plant had significant positive genotypic association with number of flowers per cluster, number of flowers per plant, number of fruits per cluster, number of fruits per plant and leaf chlorophyll content suggest that selection for the traits under high temperature environment would increase fruit yield per plant. fruit yield per plant significantly negatively correlated with days to 50% flowering, average fruit weight, fruit length, fruit diameter and fruit shape

index at genotypic level indicate selection of fruit yield per plant under heat stress result in decrease for days to 50% flowering, average fruit weight, fruit length, fruit diameter and fruit shape index . Percentage fruit set showed significant positive correlation with fruit yield per plant at both genotypic and phenotypic levels. It also positively correlated with plant height, number of branches per plant, number of clusters per plant, number of fruits per cluster, number of fruits per plant and cell membrane thermostability. The Significant negative association with days to 50% flowering, average fruit weight, fruit length, fruit diameter and fruit shape index at genotypic level indicate that as fruit set under high temperature increases days to 50% flowering, fruit weight and fruit size decrease. Wessel-Beaver and Scott (1992) also observed significant negative correlations between percentage fruit set and average fruit weight and suggested that as fruit set under high temperature increases, a reduction in fruit weight would be expected.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The study was conducted to estimate combining ability, heterosis, cell membrane thermostability, heritability and correlation in tomato under field conditions. The parental materials used comprised two heat tolerant and four heat susceptible tomato, which were crossed in a half diallel excluding reciprocals. The resultant 15 crosses, 6 parents and 4 checks were evaluated at Bagauda and Samaru during 2014 rainy season using 5 × 5 partial balanced lattice design with three replications.

The results of analysis of variance revealed highly significant differences for agronomic, heat tolerance and physiological traits indicating presence of considerable genetic variability in the genotypes and also showing the scope for selection of suitable initial breeding materials for tomato improvement under high temperature. The significant genotype × location interaction recorded for most of the measured traits indicate that the traits were influenced by the difference in locations. Therefore, suitable hybrids could be developed for specific locations. The mean performance of the genotypes showed significant variations for most of the traits, depicting the parents were from diverse origin and could be crossed to develop good heat tolerant hybrids. The hybrids Icrixina × Rio Grande and Icrixina × Roma Savana performed well and are suitable for fruit yield per plant and percentage fruit set in Bagauda; Icrixina × Rio Grande and Icrixina × Tima performed well in Samaru, whereas Icrixina × Rio Grande and Icrixina × Roma were the best across locations regarding fruit yield per plant and percentage fruit set (heat tolerance).

The combining ability analysis at both locations revealed that, both additive and non-additive gene actions were important for the inheritance of most traits. The variance

components due to SCA were higher in magnitude than the GCA variance indicating predominance of non-additive gene effects in controlling the inheritance of most traits. The prevalence of non-additive gene action for the majority of the traits in the present work was further supported by heterotic response shown by some of the crosses for these traits. Therefore, heterosis breeding could be applied for improving the traits under heat stress for selection of suitable hybrids. The mean squares of parents vs. crosses were significant for most of the traits. This measures average heterosis which is important for non-additive gene action. The GCA to SCA variance ratios were less than one for all traits except number of fruits per cluster and fruit length indicating the importance of non-additive gene action. The average degree of dominance values were greater than unity for all traits except number of clusters per plant, number of fruits per cluster, and fruit length suggesting the existence of over-dominance for the traits influencing heat tolerance. The average degree of dominance values less than unity for number of fruit per cluster and fruit length revealed the existence of partial dominance. Therefore heterosis breeding could be exploited for developing heat tolerant tomato. The GCA × location interaction variance was significant for number of branches per plant, number of flowers per plant and canopy temperature depression, indicating that different parental varieties behaved differently in the two locations. Therefore, selection of different parents for hybrid production should be applied differently in the two locations. The significant SCA × location interaction variance for number of flowers per plant, percentage fruit set and leaf chlorophyll content showed that hybrids performance varied with regard to the locations, therefore specific hybrids could be developed for each specific locations. The gca effects for the traits at both locations showed that, Icrixina recorded highly significant positive values for the majority of the traits while highly significant negative values were observed for days to 50% flowering. The parent

Icrixina would be useful in hybrid breeding with regard to heat tolerance, fruit yield and yield attributing traits. Sca effects exhibited that, Icrixina × Rio Grande had significant positive sca effects for a number of clusters per plant, number of flowers per plant, fruit yield per plant and percentage fruit set, while Petomech × Roma Savana recorded significant positive sca effects for number of clusters per plant, number of flowers per plant, fruit shape index, fruit yield per plant and fruit yield per hectare. These hybrids were from high × low general combiners, Icrixina (high gca effect), Rio Grande and Roma Savana (low gca effect). Therefore, the parent Icrixina produced hybrids with highest sca effect (Icrixina × Rio Grande) for fruit yield per plant and percentage fruit set. The result of sca effect in Samaru, indicate that Petomech × Roma Savana had highest positive sca effects for fruit yield per plant followed by Icrixina × Rio Grande and Icrixina × Tima. Whereas Icrixina × Rio Grande and Icrixina × Tima recorded highly significant sca effects for percentage fruit set, these hybrids (Icrixina × Rio Grande and Icrixina × Tima) were from parents of high × low general combiners, Icrixina (high gca effect) and Rio Grande and Tima (low gca effect). The sca effects for combined across location show that Icrixina × Rio Grande and Petomech × Roma Savana recorded the highest sca effects for fruit yield per plant, while Icrixina × Rio Grande exhibited the highest sca effect for percentage fruit set.

The hybrids Icrixina × Rio Grande, Icrixina × Roma Savana, Icrixina × Petomech and Petomech × Roma Savana expressed highly significant heterobeltiosis for fruit yield per plant and percentage fruit set in Bagauda. In Samaru, Icrixina × Rio Grande and Icrixina × Tima showed non-significant heterobeltiosis for fruit yield per plant. Icrixina × Rio Grande, Icrixina × Tima and Icrixina × Roma Savana recorded highly significant percentage fruit set over the better parent. Icrixina × Rio Grande, Icrixina × Petomech, Icrixina × Tima, and Icrixina × Roma Savana recorded non-significant and highly significant heterobeltiosis

for fruit yield per plant and percentage fruit set across locations. These hybrids also recorded highly significant heterobeltiosis for heat tolerance related traits like number of clusters per plant, number of flowers per cluster, number of fruits per cluster and number of fruits per plant. The parents of these hybrids could be used for the improvement of tomato fruit yield and adaptation to high temperature. However, it was observed that no single hybrid was consistent for all traits in this study. Therefore, specific hybrids could be utilized for specific purposes at specific locations.

The percent of cell membrane thermostability and heat injury at 30^0C, 40^0C and 50^0C revealed significant variations among genotypes at flowering stage. The results indicate that the majority of the genotypes were heat tolerant at 30^0C and it is optimum temperature required for tomato cultivation. The cell membrane thermostability and heat injury at 40^0C revealed that most of the genotypes were moderately to slightly heat tolerant, whereas at 50^0C, Icrixina, Icrixina × Tropimech, Rio Grande × Tropimech, Rio Grande × Roma Savana and Rio Grande × Petomech were slightly heat tolerant. These hybrids were crosses from one or both of the heat tolerant parents. Therefore, cell membrane thermostability can be used as a selection criterion for heat stress tolerance.

The estimates of broad-sense heritability were higher for all studied traits indicating that the traits are heritable and can be transferred to the progeny and improvement by simple selection to improve tomato under heat stress. The estimates of narrow-sense heritability were generally low to moderate for the majority of the traits. The relatively low narrow sense heritability of most traits indicates non-additive gene influence on the expression of the traits. It might be as a result of large environmental effects on the expression of traits at

high temperature and confounded effects of Biotic (Septoria leaf spot) and abiotic (drought) factors.

The estimates of genotypic and phenotypic correlation coefficients, reveal that genotypic correlations were higher than their corresponding phenotypic correlations, suggesting strong genetic associations between the studied traits and the possibility that their phenotypic expression was impeded by environmental influences. Fruit yield per plant had significant positive correlation with most traits while it had significant negative correlations with days to 50% flowering, fruit length and fruit diameter at either genotypic level, phenotypic level or both levels. The significant positive associations observed between fruit yield per plant and these traits indicate that fruit yield per plant under high temperature will increase as a results of selection of these traits. Significant negative correlation indicates that as fruit yield per plant increases the days to flowering and fruit size will be reduced under high temperature. The percentage fruit set also recorded significant positive association with most of the traits and significantly negatively correlated with days to 50% flowering, average fruit weight, fruit length, fruit diameter and fruit shape index at either genotypic level or both levels, suggesting that, percentage fruit set under high temperature would increase with selection of these traits, but with a reduction of days to 50% flowering, average fruit weight and fruit size.

6.2 Conclusions

The study show genetic variability for the traits among the genotypes and also show scope for selection of suitable initial breeding materials for tomato improvement for heat tolerance. The prevalence of non-additive gene action for the majority of the traits suggested the possibility of selection for hybrids with suitable traits, which was further supported by the heterotic response shown by some of the crosses regarding these traits. GCA × location

interaction shows the need to select different parents for hybrid production for specific locations. Significant SCA × location interaction indicated that specific hybrids would be developed for specific location under consideration. Parent Icrixina recorded highest significant gca effects for most of the traits across locations. It was good a combiner and could be crossed to concentrate desirable genes through recurrent selection. The hybrids, Icrixina × Rio Grande, Icrixina × Tima and Petomech × Roma Savana show highest sca effects and could be regarded as the most desirable hybrids for fruit yield per plant and percentage fruit set across locations. The cell membrane thermostability and heat injury at 30^{o}C, 40^{o}C and 50^{o}C exhibited significant variations among the genotypes for electrolyte leakage at flowering stage, showing that, cell membrane thermostability could be used to screen and evaluate tomato genotypes for heat tolerance. The hybrids, Icrixina × Rio Grande, × Rio Grande, × Roma Savana, Rio Grande × Tropimech, Icrixina × Tima and Petomech × Roma Savana were moderately to slightly heat tolerant at 40^{o}C and 50^{o}C. The broad-sense heritability of the traits was high indicating mass selection could be employed to improve tomato fruit yield under high temperature conditions. The narrow sense heritability for the traits was relatively low, suggesting reciprocal recurrent selection for improving heat tolerance in tomato. The significant positive correlation of fruit yield per plant/ percentage fruit set with other traits and significant negative correlations with days to 50% flowering, average fruit weight, fruit length, fruit diameter and fruit shape index at either genotypic level, phenotypic level or both levels, suggested that, the traits would be considered as selection criteria for tomato fruit yield improvement under high temperature environments. Therefore, considering the prevalence of non-additive gene effects for the traits and large negative genetic association between percentage fruit set and fruit size,

heterosis breeding could be employed as a technique for developing heat tolerant tomato with acceptable fruit size.

6.3 RECOMMENDATIONS

Based on the results of this study, it is recommended that, Icrixina was the best combiner for percentage fruit set, fruit yield and yield contributing traits. Considering mean performance, heterosis, sca effects and cell membrane thermostability, the hybrids Icrixina × Rio Grande, Icrixina × Roma Savana, Icrixina × Tima, Rio Grande× Roma Savana and Petomech × Roma Savana were recommended for further testing under high temperature conditions. The parents Rio Grande, Tima and Petomech with large fruit size, vigorous vine growth and resistance to Septoria leaf spot should be used for developing heat tolerant tomato under rainy season condition. Molecular markers should be considered for further studies to fast track selection for heat tolerant genotypes under heat stress.

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APPENDICES

Appendix i: Meteorological data for Bagauda and Samaru during 2014 rainy season.

Month	Bagauda			Samaru		
	Maximum Temperature (^oC)	Minimum Temperature (^oC)	Rainfall (mm)	Maximum Temperature (^oC)	Minimum Temperature (^oC)	Rainfall (mm)
July	32.2	22.6	24.06	30.9	22.38	11.71
August	31	24.13	30.86	29.83	22.43	26.74
September	32.67	27.11	14.07	31.17	21.72	11.04
October	32.92	24	45.2	33.73	21.23	2.33

Source: National Horticultural Research Institute, Bagauda and Institute for Agricultural Research, Samaru, Zaria, meteorological data units.

Appendix ii: Septoria leaf spot severity scores at Bagauda and Samaru during 2014 rainy season

Genotype	Bagauda	Samaru
Icrixina	4	5
Rio Grande	3.5	4
Tima	0.5	1.5
Tropimech	1.5	2.5
Petomech	2	3
Roma Savana	4	5
Icrixina × Rio Grande	2.5	4
Icrixina × Tima	2	3
Icrixina × Tropimech	1.5	2
Icrixina × Petomech	4.5	5
Icrixina × Roma Savana	3	5
Rio Grande × Tima	2.5	3.5
Rio Grande × Tropimech	3.5	5
Rio Grande × Petomech	3.5	4.5
Rio Grande × Roma Savana	4	5
Tima × Tropimech	2.5	4
Tima × Petomech	0.5	0.5
Tima × Roma Savana	0.5	0.5
Tropimech × Petomech	2.5	2.5
Tropimech × Roma Savana	1.2	1
Petomech × Roma Savana	3.5	2.5
Roma VF	1.5	2.5
UC82 B	3.5	2.5
Thorgal F_1	1.5	3
Jaguar F_1	2.5	4