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Heat Tolerance in Field Grown Tomatoes (*Lycopersicon esculentum* Mill.) under Semi-Arid Conditions of West Africa

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Keywords: shading, high temperatures, pollen viability, flower drop, tomato varieties

Abstract

One major reason for extremely low production of tomato in Ghana is that the length of the growing season last only for a few months due to the high temperature influx during the remaining months. The temperatures recorded during these months are above the optimum for tomato flowering and fruiting and this consequently affects yield. To solve this problem a number management practices may be undertaken such has growing heat tolerant tomato varieties or providing shade to mitigate the devastating effect of high temperatures. Therefore the present study was conducted outside the normal growing season from June to October, which has a mean temperature of 23°C. Heat tolerant tomato cultivars were grown from April to July with a mean temperature of 25°C to evaluate their performance under these conditions and to assess the effect of shading on the production of one of the genotypes. Fruiting percentage was significantly lower in exotic hybrids compared to a local variety. Different genotypes showed no differences in the production of viable pollen. Shading decreased final shoot and root biomass by 67 and 47%, respectively, whiles fruit yield was not affected. Also among cultivars yields were similar.

INTRODUCTION

Tomato is widely cultivated in Ghana, however the growing season in most areas lasts for only a few months due to the high temperature influx during the remaining part of the year is period. This makes tomato production in Ghana highly seasonal. For instance in the southern and middle belts of Ghana tomato production is predominantly from May to November whilst in the northern part of Ghana it normally goes from January to May (Robinson and Shashi, 2010). The temperatures recorded outside these months are above the critical for tomato flowering and fruiting and this consequently affects yield. Tomato requires an optimum temperature range within 18-28°C for fruit set and optimum fruit yield (Saeed, 2007).

To solve this problem a number of management practices may be undertaken such as growing heat tolerant tomato varieties or providing shade to mitigate the devastating effect of high temperatures. Advances have been made in the identification and development of heat tolerant genotypes which yield considerably in fruit number and weight over heat sensitive genotypes. However, most heat tolerant tomatoes produce small fruits usually less than 30 g (Dane et al., 1991; Alam et al., 2010), and are undesirable by most Ghanaian farmers and consumers. New heat tolerant hybrids, which have large fruits, have been developed by Monsanto Seed Company. They have however yet to be tested in most agro-ecological zone of the country to assess their growth and yield.

Hybrids bred for heat tolerance have better performance than open pollinated varieties (Villereal and Lai, 1979), however plant response to heat stress is a complex phenotypic and physiological phenomenon that is influenced by other environmental factors (Lin et al., 2006). Heat stress injury, such as low tomato fruit number, low fruit weight, poor fruit set and low yield can be attributed to a combination of several morphological, physiological and biochemical responses such as elongated styles (Lin et al., 2006) and decreased levels of soluble sugars in developing pollen, which reduces their viability (Pressman et al., 2002). It is therefore important to test heat tolerant hybrids under the precise environmental conditions under which targeted farmers are going to subject plants.

The practice of providing shade to control micro climate of the plants, by reducing temperatures and light intensities has been reported to increase yields of tomato (El-Gizawy et al., 1992). This study was therefore conducted to evaluate the performance of two exotic and one indigenous heat tolerant tomato cultivars outside the normal colder – growing season and to assess the effect of shading on the production of one of one these.

MATERIALS AND METHOD

The study was carried out in Anloga in the south eastern part of Ghana.This area is semi-arid coastal savannah zone, which has predominately sandy soils. The soil was Keta series, a sandy soil classified as Arenosols according to ISSS/ISRIC/FAO (1998). A sample of the soil was obtained from 0-15 cm depth. The physio-chemical properties of the soil was as follows; 75% coarse sand, 10% fine sand, 0.5% silt and 2.4% clay, pH: 7.7, Bulk density: 1.5 Mg/m^3, EC: 0.13 dS/m, 0.23% organic carbon, 0.098% N, 123 mg P/kg Olsen. The experiment started from March. Seeds of DV 2962 (DV) and Gandeeva 3993 (GAN) obtained from the Monsanto seed company and a heat tolerant local tomato variety Nkansah (NKA) were sown in seed trays with soilless media (rice husk saw dust 1:1 v/v) for 4 weeks before transplanting unto individual plots of 4.8×3.6 m^2 at a spacing of 60×40 cm. The soil was fertilized with 20 tons cow dung per hectares broad spread before transplanting. Irrigation was performed with sprinklers twice a day to replace actual soil water deficit measured by time domain reflectometry (TDR). The experimental design was a randomized complete block design with 4 replications. Ten plants were used for data collection. The NKA variety was grown both under no shade and shade treatment under 60% shading screen. In shaded plots, 5x4 m black polypropylene net was secured on four poles erected at four corner of each plot, 1 m above the ground surface. The shade screen was applied 1 week after transplanting. Flowers were harvested on non-recorded plants every week for 5 weeks. Pollens were collected and analyzed for viability according to Pressman et al. (2002). Flowers at anthesis were sampled from each treatment. One anther was removed and placed in a microfuge tube containing 0.05 ml germination media (see Pressman et al., 2002). Anthers were crushed with forceps to release pollen grains. Tubes were placed in incubator at 25°C for 8 hours, after which a drop of Alexander dye (Alexander, 1980) was added to the solution. The following data were measured: pollen number, percentage stained and non- stained, germinated and non-germinated, plant height, plant biomass and total number of flowers, flower drop, fruit yield. Data was analyzed using Genstat statistical software.

RESULTS

Table 1 below indicates the prevailing weather conditions during the experiment. The tomato cultivars were grown from April to July with a mean temperature of 25°C. This minimum temperature is above that of the normal growing season, which is rainy and cold with a mean temperature of 23°C.

Plant height differed significantly among cultivars (Fig. 1). Plants heights of DV and GAN were significantly higher than NKA shade and NKA no shade. From the initial weeks NKA shade and NKA produced similar plant height however from the 5th week NKA shade produced significantly higher plants compared to NKA no shade. There was an initial general increase in the weekly elongation rate from week one (Fig. 2) and the peak was recorded in week three for all treatments after which they all started to decline. At final harvest shoot biomass of Monsanto varieties were 50% more than the heat tolerant variety NKA (Fig. 3). However the highest root dry weight was produced by NKA. Shade reduced shoot and root biomass by 67 and 47% respectively (Fig. 3).The root: shoot ratio was significantly different among the tomato genotypes (Table 2). NKA allocated more biomass to the root relative to the shoot compared with the other treatments while DV and GAN invested greater portion of dry matter into shoot production as seen by their low root: shoot ratio. Number of trusses produced was significantly different among the genotypes (Fig. 4a). NKA produced higher number of trusses but was not significantly different from NKA shade. Number of trusses produced by NKA was twice as many as the Monsanto hybrids. Number of trusses produced by DV and GAN were not significantly different from each other. Number of flowers produced per truss (Fig. 4b) followed the same trend as number of trusses. The number of flowers produced ranged from 38 recorded in DV to 100 recorded in NKA (Fig. 4c). NKA shade produced 80 flowers however this was not significantly different from NKA. Figure 4d represents percentage fruit set; fruit abortion and flower drop of tomato genotypes grown under field conditions. Flower drop was least in NKA had compared with the other tomato genotypes however it was not significantly different from the other genotypes. NKA shade showed reduced number of fruits aborted, however this was also not statistically different from the other genotypes. Percentage fruit set was highest in NKA and NKA shade whilst percentage flower drop was higher in NKA shade and GAN. Flower drop was excessive in trusses of the Monsanto varieties where completely empty trusses were observed.

Results showed no differences in the pollen produced by different genotypes or shade treatment (Fig. 5). Number of pollen produced was in the order GAN, NKA shade, DV and NKA. Number of pollen stained as viable was higher than non-stained i.e. non-viable pollen. Marked differences were observed in the fruit number per plant (Fig. 7). NKA grown under shade and no shade produced the highest number of fruits per plant averaging 15 fruits per plant. Fruit yield in terms of number of fruits produced was significantly higher in NKA no shade and NKA shade however, since this variety has very small fruits, fruit yields in terms of total fruit weight (Fig. 8) produced by the genotypes were not significantly different from each other. DV and GAN produced similar number of fruits per plant.

DISCUSSION

The experimental site chosen for the experiment was near Anloga, a coastal town, which is situated on a 1-2 km broad sandpit, bordered by the Bight of Benin to the south and by the 300 km^2 Keta coastal lagoon (Awadzi et al., 2008) to the north. Anloga has an underlying shallow aquifer which provides fresh water all year round and which farmers in this area utilize extensively for irrigation. This means they do not have to depend on rain as is the norm elsewhere in semi-arid regions. Anloga is therefore a good prospective area for all year round tomato production if the adverse effects of heat stress can be mitigated. Tomato production in Ghana is seasonal to avoid periods with low levels of production. All year production of tomatoes may significantly increase production, however lack of varieties able to tolerate the high temperatures is still a major problem that may become aggravated in the future by climate change.

Even though the tomato varieties used in this study were identified as heat tolerant, there was still obvious stress during the growth and development of the plants. Plants were especially wilted and stressed in the afternoons in the non-shaded plots. Insect pests such as whiteflies stayed constantly on plants even with regular insecticide application. Plants were characterized by poor growth and deformed leaves. There was a high incidence of diseases identified as Fusarium wilt and *Tomato yellow leaf curl virus* Disease.

NKA variety produced profuse number of flowers and small fruits. Alam et al. (2010) identified that small sized fruited tomato genotypes that produce a lot of flowers were less affected by heat stress. NKA as well as the two other cultivars dropped a significant number of flowers and this may have been due to high night temperatures recorded during the period of the study. For optimum fruit set, tomatoes require a night temperature of between 15 to 20°C (Lin et al., 2006).

The main aim of providing shade is to control the immediate microclimate of plants by reducing solar radiation and consequently air temperature. Even though air temperature and solar radiation are related such that reducing solar radiation may reduce air temperature, the relationship is however not constant, and may show variations in different seasons and/or locations (Sandri et al., 2003). Abdel-Mawgoud et al. (1996) reported that even though the provision of shade reduced leaf and air temperatures during the day by 2°C, at night however, leaf and air temperature increased in shaded plots. This was because plants in the non -shaded plots emitted long wave radiation to the sky while in the shaded plots this heat exchange was inhibited by the screen. Such effects may be one reason why providing shade increased flower drop in NKA (Fig. 4d) Another reason may be that biomass was greatly reduced in the shaded plots compared to non- shaded, which is similar to the findings of Abdel-Mawgoud et al. (1996) and Sandri et al. (2003) likely to be a result of the reduction in light intercepted by plants under shade. Cockshull et al. (1992) also stated that a 1% reduction in light led to a 1% loss in yield of greenhouse grown tomatoes. Uzun (2007) reported that a higher light intensity increased the number of fruits compared to lower light.Nevertheless, while flower drop was increased in the present study, fruit abortion was diminished and therefore total fruit set in NKA was unaffected by shading (Fig. 8). Also the provision of shade did not increase total fruit yield significantly. Reports of increased yields of tomato under shade treatments can however be found (e.g. El-Gizawy et al., 1992) while Sandri et al. (2003) found a reduction of yield components as a result of shading. In the present study, the different factors and effects may have outweighed each other to produce a very slight and non-significant yield difference. Pollen production, pollen viability and germination under high temperatures have been reported to be important factors which limit fruit set (Hazra and Ansary, 2008). Pollen grain analysis is therefore used as criterion for determining responses of cultivars to high temperatures (Sato et al., 2000). High temperatures reduced to a large extent the germination of pollen grain in tomato (Pressman et al., 2002) and moderately the total number of pollen grains produced and viability of grains (Pressman et al., 2002; Soylu and Çömlekçioğlu, 2009). Marked reduction was observed in the pollen germination (Fig. 6) of tomato treatments compared with the viability stained pollen (Fig. 5). Reduction in the quality of pollen has been attributed to limited availability of carbohydrates during pollen development (Pressman et al., 2002) but in the present study it was difficult to see any relation between pollen germination, viability staining and fruits.

CONCLUSION

In conclusion, the study revealed that yields of Monsanto hybrids were comparable to yields of the heat tolerant variety NKA and may be recommended for cultivation by farmers during the off season, due to their higher fruit weight. Providing shade did not increase yields and the cost of using shade as a management practice may therefore not be justified as well as it may be beyond the reach of many poor-resource farmers in semi-arid regions.

ACKNOWLEDGMENTS

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Tables

Table 1. Climatic conditions during the experiment.

Month	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Global radiation	Wind speed		Average daily sunshine hours
	Min	Max	Min	Max	Monthly total	MJ/m^2	Min	Max	
Apr-11	26.3	31.0	67	85	85.00	20.93	0.64	4.03	12.26
May-11	25.5	30.2	69	88	228.00	17.35	0.47	3.98	12.41
Jun-11	25.1	28.6	74	87	190.20	14.95	0.95	4.28	12.46
Jul-11	23.9	27.2	78	91	7.80	18.14	1.66	5.33	12.48

Table 2. Root:shoot ratio of tomato genotypes grown under field conditions. Significant level at P<0.01. Numbers with same letter are not significantly different.

Tomato genotypes	Root:shoot ratio
DV 2962	0.07c
Gandeeva	0.07c
Nkansah	0.15 a
Nkansah Shade	0.11b

Figures

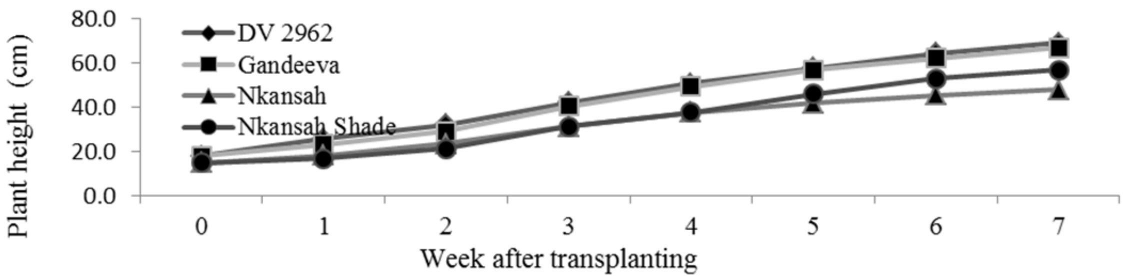

Fig. 1. Weekly measured plant height of tomato genotypes grown under field conditions.

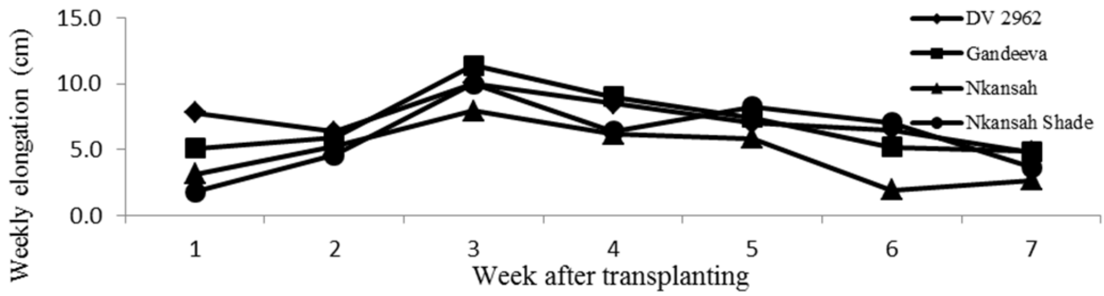

Fig. 2. Rate of change of plant height (cm/week) of field grown tomatoes.

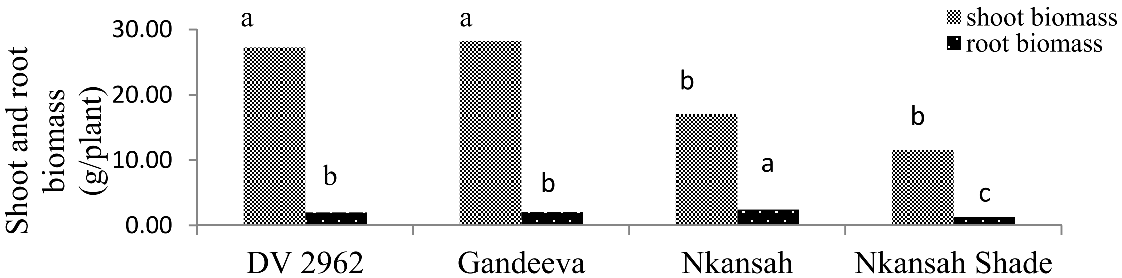

Fig. 3. Final shoot and root dry weight of tomato genotypes grown under field conditions. Significant level at P<0.001. Bars with same letter are not significantly different.

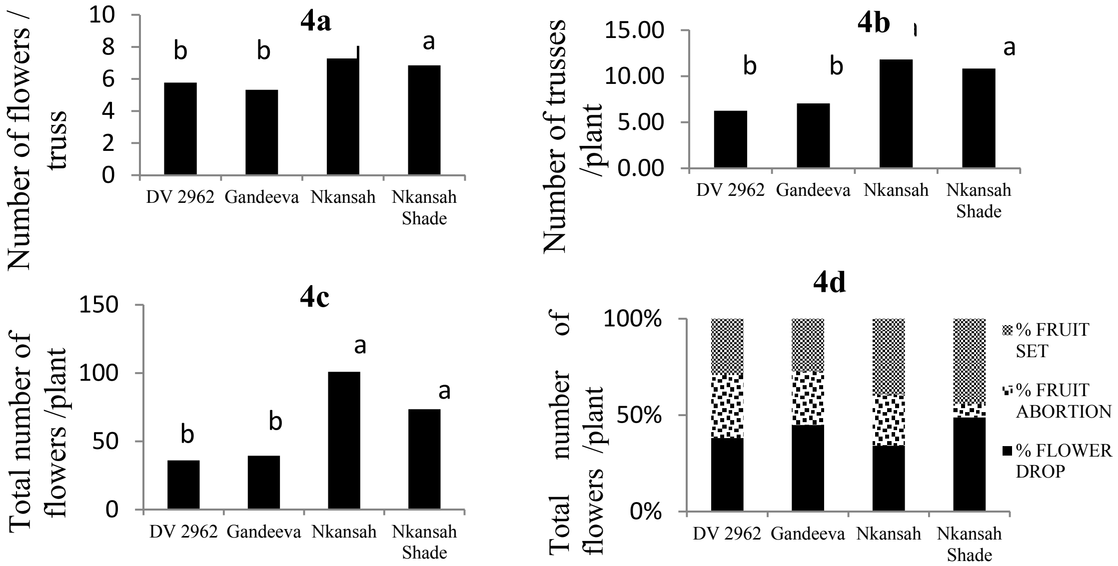

Fig. 4. (a) Number of trusses per plant, (b) number of flowers per truss, (c) number of flowers per truss, (d) fruit set, fruit abortion and flower drop as percentage of total number of flowers produced for tomato genotypes grown under field conditions. Significant level at P< 0.001.Bars with same letter are not significantly different. Figure represents absolute values however ANOVA was performed on log transformed data.

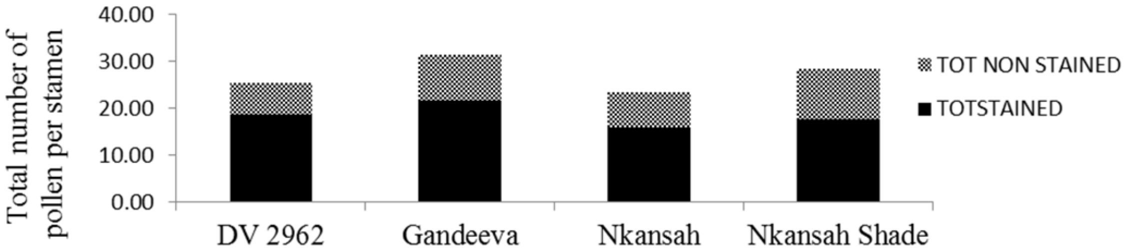

Fig. 5. Number stained and non-stained pollen of tomato genotypes grown under field conditions. Figure represents absolute values however ANOVA was performed on log transformed data.

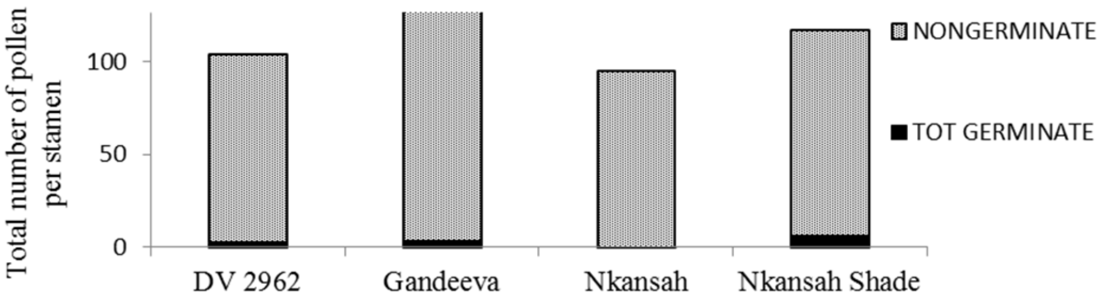

Fig. 6. Number germinated and non-germinated pollen of tomato genotypes grown under field conditions. Figure represents absolute values however ANOVA was performed on log transformed data.

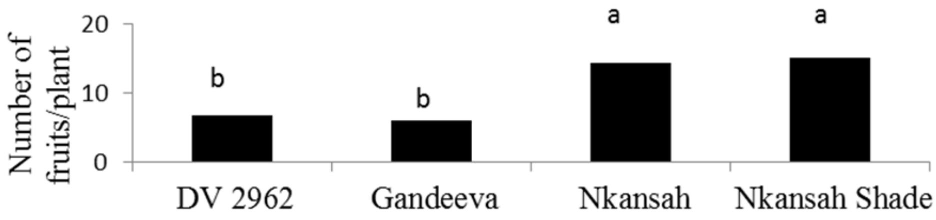

Fig. 7. Number of fruit per plant of tomato genotypes grown under field conditions. Significant level at P<0.001. Bars with same letter are not significantly different. Figure represents absolute values however ANOVA was performed on log transformed data.

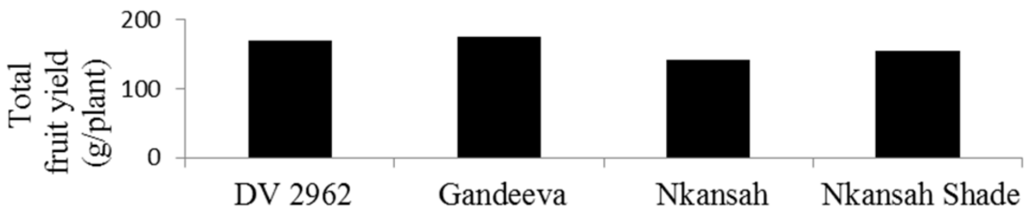

Fig. 8. Total fruit yield per plant of tomato genotypes grown under field conditions.