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Advanced Journal of Plant Biology
Volume 4(2), pages 21-32, April 2023
Article Number: E4D5F9B02
ISSN: 2992-4928
https://doi.org/10.31248/AJPB2022.023
https://integrityresjournals.org/journal/AJPB

Full Length Research

Flower abortion of pepino melon (*Solanum muricatum* Ait.) as influenced by NPK fertilizer rates and growing environment

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Received 28th May 2022; Accepted 27th June 2022

ABSTRACT: Flower abortion is the detachment of flowers from the plant. A study was conducted at Egerton University, Kenya in 2018 to 2020 to investigate the effect of NPK fertilizer rates (0, 100, 200. 300 and 400 kg ha^{-1}) on flower abortion of field and greenhouse grown pepino melons. The experiment was laid out in a randomized complete block design with three replications. Data was collected on number of flowers, number of aborted flowers, viable and non-viable pollen and *in vitro* pollen germination. Data were analysed using analysis of variance with the SAS statistical package. Significant means were separated using Tukey's Honestly Significant Difference at $p \leq 0.05$. Results indicated that field grown plants supplied with 200 and 300 kg NPK ha^{-1} had 10.28 and 11.18 flowers per truss respectively in trial one. In trial two, field grown plants supplied with 300 kg NPK ha^{-1} had 11.32 flowers per truss. Greenhouse grown plants supplied with 300 kg NPK ha^{-1} had 20.61 and 14.19 aborted flowers in trial one and two respectively. High pollen viability was recorded from non-aborted flowers obtained from field grown plants supplied with 300 kg NPK ha^{-1} with a pollen viability of 94.48% and 93.97% in trial one and two respectively. Pollen from non-aborted flowers obtained from field grown plants supplied with 300 kg NPK ha^{-1} had the highest pollen germination of 68.72 and 67.72% in trial one and two respectively. Application of 200 and 300 kg NPK ha^{-1} for field and greenhouse grown pepino melon plants led to reduced flower abortion, high number of flowers per truss, high pollen viability and pollen germination.

Keywords: Aborted, Flowers, non-aborted, pollen germination, pollen viability.

INTRODUCTION

Successful flower development is vital in the production of many horticultural crops (Warner and Erwin, 2005). Abortion is the cessation of development of an organ after which it detaches from the main body of the plant (Wubs *et al*., 2009). Flower buds, flowers and fruits are the main reproductive organs that abort and this leads to reduction in yields of most horticultural crops (Nyoka *et al*., 2015). In an earlier study, Stephenson (1981) reported that flower, fruit and seed abortion is caused by pollination failure, limited photo assimilates, adverse weather conditions, moisture stress and predation. Flower abortion is caused by high temperatures on the male reproductive organs (Kafizadeh *et al*., 2008). Flower abortion causes serious economic problems in horticultural crops. High temperature in pepper causes flower abortion by increasing ethylene production (Huberman *et al*., 1997). Abscisic acid, salicylic acid and ethylene production increases as a result of high temperature (Kotak *et al*., 2007). Taylor and Whitelaw (2001) reported that ABA accelerates abscission by enhancing senescence and hence ethylene climacteric which eventually leads to abscission. Wubs *et al*. (2009) reported that before flower abortion takes place there is reduction of auxin from the flower while ethylene production increases. In sweet pepper, high flower abortion occurred three weeks after anthesis (Wubs *et al*., 2009). Abortion of reproductive organs in sweet pepper occurs even when grown in a greenhouse (Wubs *et al*., 2009).

Reproduction in plants is highly affected by environmental factors such as temperature and may have

significant effects on the reproductive phase hence serious implications in agricultural crops (Thunar, 2010). The reproductive phase in flowering plants is very sensitive to hot or cold temperature stress (Zinn *et al*., 2010). Exposure to high temperatures results to flower and floral bud abortion in many crop species including tomato (Levy *et al*., 1978). Reduction in fruit set at high temperatures is mostly due to poor pollen viability, reduced pollen production and poor pollen tube growth and all result to poor flower fertilization (Prasad *et al*., 2003). Pollen development, fertilization, and asynchrony of stamen and gynoecium's development are sensitive to temperatures during flowering (Prasad *et al*., 1999; Croser *et al.,* 2003; Boote *et al.,* 2005). Sexual reproduction in plants is more delicate to high temperatures than vegetative cycle, and thus reproductive organs will be more sensitive to changes in short periods of high temperatures preceding flowering (Reddy and Kakani, 2007). Low light intensity and shading results to flower abortion in pepper (Heuvelink *et al*., 2004). Growing eggplants at low light intensities in the greenhouse leads to reduced flower development, reduced flower size, small ovaries and short styles and this results to flower abortion (Saito and Ito, 1973). In addition, Gruda (2005) reported that low light intensity reduced sugar accumulation in the flowers and this resulted to flower abortion in pepper. Water stress or drought during the flowering stage in tomato leads to increased flower abortion (Ganova *et al*., 2019).

Reproductive processes such as pollen grain development, pollen tube growth, and fruit set are adversely affected by temperature than any other environmental factor when water is not a limiting factor (Thunar, 2010). In addition, environmental stress during pollen development, germination and pollen tube growth affect the functioning of pollen and eventually fruit and seed set (Thunar, 2010). Once pollen grains are released from the anthers they are exposed to environmental factors and thus high temperatures during flowering adversely affect pollen more compared to the ovules (Thunar, 2010). High temperatures inhibits pollen germination and pollen tube growth but the sensitivity differs between different crops (Huan *et al.,* 2000; Kakani *et al.,* 2005). Temperatures above 33°C in tomato inhibit pollen formation, reduce pollen viability and eventually leads to reduced fruit set (Adams *et al*., 2001; Dominguez *et al*., 2005). High temperature will accelerate the production of reactive oxygen species (ROS) which at high levels can lead to oxidative damage and even cell death (Apel and Hirt, 2004). Exposure of sweet pepper to a temperature of 33°C for four days led to 100% abortion of flower buds and flowers (Marcelis *et al*., 2004). Several studies have reported abortion of flower buds, flowers and young fruits due to high temperatures above 30°C (Aloni *et al*. (1991); Huberman *et al*. (1997); Erickson and Markhart 2001; 2002). Pepino grows well within a temperature range of 10-30°C and the optimum temperature for growth is between 15 and 25°C (Lim, 2015). If the temperatures are below 10°C or above 30°C fruit set is reduced (Prohens *et al*., 2000). High temperatures interfere with pollination and fruit set (Burge, 1989).

Nitrogen, phosphorous and potassium (NPK) fertilizers have been reported to have an effect on flower abortion in many crops. Application of 200 and 300 kg NPK ha^{-1} reduced flower abortion in okra compared to the control and application of 100 kg NPK ha^{-1} (Iyagba *et al*., 2013). On the contrary, Makinde *et al*. (2016) reported that NPK fertilized tomato plants had more flower abortion compared to the control which had the lowest flower abortion. Low nutrient supply will increase abortion (Wubs *et al*., 2009). There is insufficient information on the effect of NPK fertilizer and temperature on flower abortion of pepino melon. The present study sought to investigate the effect of NPK fertilizer rates and temperature on flower abortion of field and greenhouse grown pepino melons.

MATERIALS AND METHODS

Experimental site description

The experiment was conducted at the Horticulture Research and Teaching Field, Egerton University, Kenya. The field lies at a latitude of 0º 23′ South, longitudes 35º 35′ East in the Lower Highland III Agro Ecological Zone (LH3) at an altitude of approximately 2,238 m above sea level. Average maximum and minimum temperatures range from 19 ºC to 22 ºC and 5 ºC to 8 ºC, respectively, with a total annual rainfall ranging from 1200 to 1400 mm. The soils are predominantly mollic andosols (Jaetzold and Schmidt, 2006). The greenhouse used was 8 by 60m and the covering material was polythene with a thickness of 12 × 150 microns purchased from Amiran Kenya Ltd.

Determination of experimental field and greenhouse temperature

Temperature in the greenhouse was determined by use of a thermometer which was placed in each experimental plot. Temperature readings were taken on daily basis and later converted to mean monthly temperatures. Field temperature readings were obtained from the Department of Agricultural Engineering, Egerton University. The temperatures were recorded on daily basis and converted to mean monthly temperatures. The mean monthly temperatures in the greenhouse and field during the experiment are presented in Table 1.

Experimental design and treatment application

The experimental design was randomized complete block design (RCBD) with five treatments and three replications. The five treatments included (0, 100, 200, 300 and 400 NPK (17:17:17) kg ha^{-1}). Pepino seedlings (Ecuadorian Gold variety) were obtained from Garlic and Pepino Farm, Nakuru. For the field experiment, each experimental plot

Table 1. Average monthly field and greenhouse temperature (°C) in trial one and two.

Trials	Environment	2018		2019					
		Nov	Dec	Jan	Feb	Mar	Apr	May	June
Trial one	Field	20.9	19.7	20.9	21.7	22.8	22.6	21.2	18.9
	Greenhouse	30.3	21.0	33.4	30.2	29.4	34.0	35.8	28.0

Trials	Environment	2019						2020	
		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Trial two	Field	19.1	19.2	20.5	19.3	19.3	18.9	19.1	22.6
	Greenhouse	18.5	29.4	30.0	28.0	32.0	28.0	35.3	36.7

Table 2. Effect of NPK fertilizer rates on pollen viability of field and greenhouse grown pepino melon non-aborted flowers in trials one and two.

Environment	Fertilizer (kg ha^{-1})	Pollen viability (%)	
		Trial 1	Trial 2
Field	0	87.44ef*	86.30d
	100	90.20bc	89.34bc
	200	91.22b	90.37b
	300	94.48a	93.97a
	400	89.45cd	88.65c
Greenhouse	0	83.39g	82.29f
	100	88.40de	85.33de
	200	89.37cd	88.12c
	300	89.19cd	86.41d
	400	87.23f	84.47e

*Means followed by the same letter (s) within a trial are not significantly different according to Tukey's test at ($p \leq 0.05$).

was 3.2 m × 3.2 m and the seedlings were planted in rows 80 cm apart and 50 cm (FAO, 1994) within the plants to give a total of 24 plants per plot. In the greenhouse experiment, each experimental plot was 2 m × 5 m at the same spacing as in the field experiment to give a total of 25 plants per plot. The NPK fertilizer was applied and thoroughly mixed with the soil before placing the seedlings in the transplanting holes. Weeding was done uniformly to all experimental units. Field capacity was determined as described by Cong *et al*. (2014) thereafter tensiometers were placed in two experimental units in each block. Irrigation was done when the field capacity fell below 60% since pepino requires a field capacity of 60-65% (Lim, 2015). Drip irrigation was used in the greenhouse experiment. Trial one was carried out from November 2018 to June 2019 and trial two from July 2019 to February 2020.

Soil analysis

Soil samples were collected from the experimental plots in the field and greenhouse and analysed for total N, P, K and pH before the experiment was carried out. Soil sampling was done at a depth of 0-40cm with a soil auger, bulked to form a composite sample and taken for selected analysis. Sub soil samples were air dried and crushed to pass through a less than 1mm sieve. Analysis was carried out using the method described by (Okalebo *et al*., 2002) and the results are presented in Table 2.

Data collection and analysis

Data was collected and recorded on number of flowers per truss, number of aborted flowers, pollen viability and pollen germination. Number of flowers per truss was determined by counting the number of flowers per truss from the 8 selected plants in each treatment. Number of aborted flowers was determined by counting aborted flowers on the surface of the soil in the field and greenhouse. Pollen viability was determined by use of the iodine-potassium iodide test as described by Rathod *et al*. (2018). The number of viable pollen grains (darkly stained) and non-viable pollen grains were examined under a light microscope (Motic Type 102 M) and images were taken using Moticam X camera. Pollen viability was then

calculated using the formular:

$$\text{Pollen viability (\%)} = \frac{\text{Number of stained pollen grains}}{\text{Total number of pollen grains on slide}} \times 100$$

In vitro pollen germination was determined using Brewbacker and Kwack's (1963) medium (10% sucrose, 100 mg l^{-1} boric acid, 300 mg l^{-1} calcium nitrate, 200 mg l^{-1} magnesium sulfate and 100 mg l^{-1} potassium nitrate). Pollen was collected from fresh open flowers and aborted flowers from the field and greenhouse at 7.00 to 8.00 a.m. A drop of the medium was placed on a microscope slide, pollen grains were then dusted onto the medium using a brush and the slide covered with a cover slip and its periphery sealed with Vaseline to maintain the required humidity. The slide was then placed inversely over a petri dish lined with moist filter paper. Germination of pollen was counted after 24 hours at 25°C on germination medium. Pollen grains were considered to have germinated only if the length of the pollen tube was at least equal to the diameter of the pollen tube. Germinated pollen were examined and counted under an electron microscope. This was done in three replications for the five NPK fertilizer treatments in the field and greenhouse. Percentage pollen germination was computed using the formula below:

$$\text{Pollen germination (\%)} = \frac{\text{Number of germinated pollen}}{\text{Total number of pollen grains on slide}} \times 100$$

Data collected was subjected to Analysis of Variance (ANOVA) and significant means separated using Tukey's honestly significant difference (Tukey's HSD) test at $p \leq 0.05$. The SAS statistical package (SAS Institute, 2005) was used for data analysis.

RESULTS

Number of flowers per truss

NPK fertilizer rates and growing environment had a significant effect at p≤0.05 on the number of flowers per truss in both trials. In trial one, field grown plants supplied with 200 and 300 kg NPK ha^{-1} had 10.28 and 11.18 flowers per truss respectively. The lowest flowers per truss was recorded in both field and greenhouse grown plants supplied with 400 kg NPK ha^{-1} and they had 4.53 and 4.2 flowers per truss respectively. In trial two, field grown plants supplied with 300 kg NPK ha^{-1} had 11.32 flowers per truss and this was significantly different from the other fertilizer rates in both growing environments. The lowest number of flowers per truss was recorded in both field and greenhouse grown plants supplied with 400 kg NPK ha^{-1} which had 4.26 and 4.14 flowers per truss respectively. Generally, it was observed that field grown plants had more number of flowers per truss compared to greenhouse grown plants (Figure 1).

Number of aborted flowers

NPK fertilizer rates and growing environment had a significant effect (p≤0.05) on the number of aborted flowers in both trials. In trial one, greenhouse grown plants supplied with 300 kg NPK ha^{-1} had the highest number of aborted flowers (20.61) while field grown plants not supplied with NPK fertilizer (control) had 5.42 aborted flowers although this was not significantly different from field grown plants supplied with 100 and 200 kg NPK ha^{-1} with 6.29 and 7.54 aborted flowers respectively. In trial two, greenhouse grown plants supplied with 300 kg NPK ha^{-1} had 14.19 aborted flowers and this was significantly different from all the other treatments. The lowest number of aborted flowers was recorded in field grown plants not supplied with NPK fertilizer with 5.24 aborted flowers but this was not significantly different from field grown plants supplied with 100, 200 and 400 kg NPK ha^{-1}. It was noted that the number of aborted flowers increased as the fertilizer rates increased and reached a peak at 300 kg NPK ha^{-1} after which the number dropped in both growing environments and trials. Trial one had the highest number of aborted flowers compared to trial two in both environments. Generally, greenhouse grown plants had the highest number of aborted flowers compared to filed grown plants (Figure 2).

Pollen viability of non-aborted flowers

NPK fertilizer rates and growing environment had a significant effect on pollen viability of pepino melon flowers. In trial one, non-aborted flowers from field grown plants supplied with 300kg NPK ha^{-1} had the highest pollen viability of 94.48% while the lowest pollen viability of 83.39% was recorded in flowers from greenhouse grown plants not supplied with NPK fertilizer (control). Flowers from field grown plants supplied with 200 kg NPK ha^{-1} had a pollen viability of 91.22% but this was not significantly different from flowers obtained from field grown plants supplied with 100 kg NPK ha^{-1}. In trial two, flowers from field grown plants supplied with 300 kg NPK ha^{-1} had the highest pollen viability of 93.97% while the lowest pollen viability was recorded in flowers from greenhouse grown plants not supplied with NPK fertilizer. Flowers from field grown plants supplied with 100 and 200 kg NPK ha^{-1} had a pollen viability of 89.34 and 90.37% respectively. Pollen viability of flowers from plants supplied with 100 kg NPK ha^{-1} was not significantly different from flowers obtained from field grown plants supplied with 400 kg NPK ha^{-1} and greenhouse grown plants supplied with 200 kg NPK ha^{-1} with a viability of 88.65% and 88.12% respectively. Generally, pollen viability increased as the NPK fertilizer rates increased but reached a peak at 200 and 300 kg NPK ha^{-1} for flowers from greenhouse and field grown plants respectively. Flowers from field grown plants had a higher pollen viability compared to flowers from greenhouse

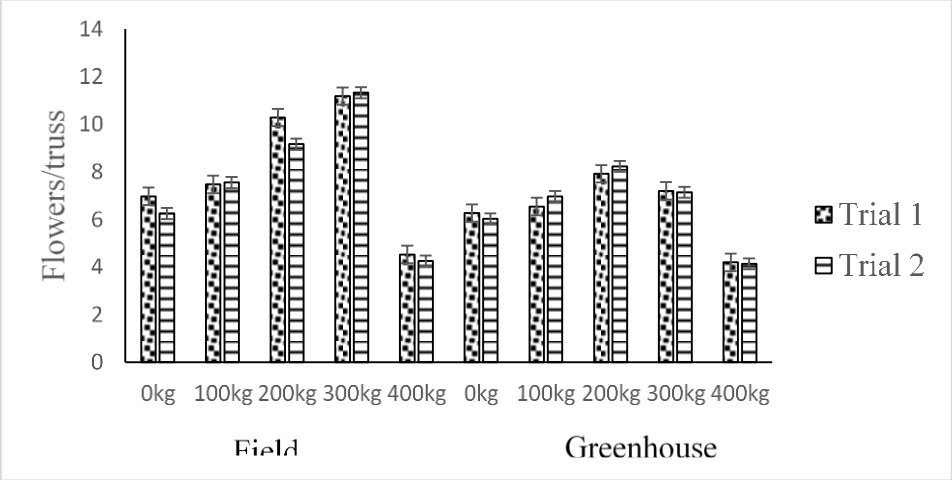

Figure 1. Effect of NPK fertilizer rates and growing environment on number of flowers per truss of pepino melon in trial one and two.

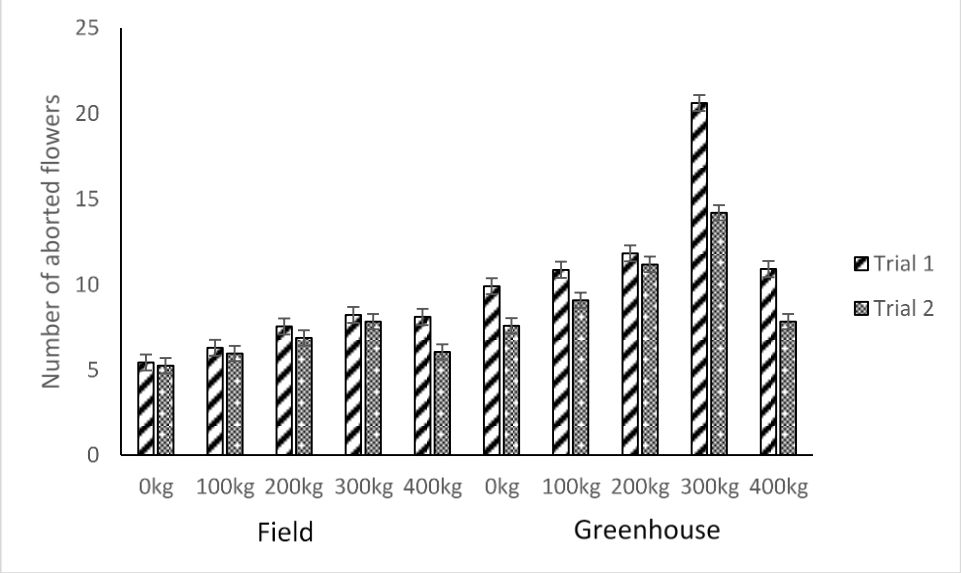

Figure 2. Effect of NPK fertilizer rates and growing environment on flower abortion of pepino melon in trial one and two.

grown plants in both trials. Viable pollen grains were darkly stained while non-viable pollen were lightly stained (Plate 1).

Pollen viability of aborted flowers

NPK fertilizer rates and growing environment had a significant effect at p≤0.05 on pollen viability of field and greenhouse grown pepino melon aborted flowers. In trial one, the highest pollen viability of 58.25% was recorded in aborted flowers from field grown plants supplied with 300 kg NPK ha^{-1} while the lowest pollen viability of 38.70% was in aborted flowers from greenhouse grown plants not supplied with NPK fertilizer. Aborted flowers from field grown plants supplied with100 and 200 kg NPK ha^{-1} had a pollen viability of 53.68 and 54.99% which was not significantly different. Pollen viability of aborted flowers from field grown plants supplied with 100 and 400 kg NPK ha^{-1} was also not significantly different.

In trial two, aborted flowers from field grown plants supplied with 300 kg NPK ha^{-1} had the highest pollen viability of 58.44%. Aborted flowers from field grown plants supplied with 100 and 200 kg NPK ha^{-1} were not significantly different at $p \leq 0.05$ with a pollen viability of 53.2 and 54.56% respectively. However, the pollen

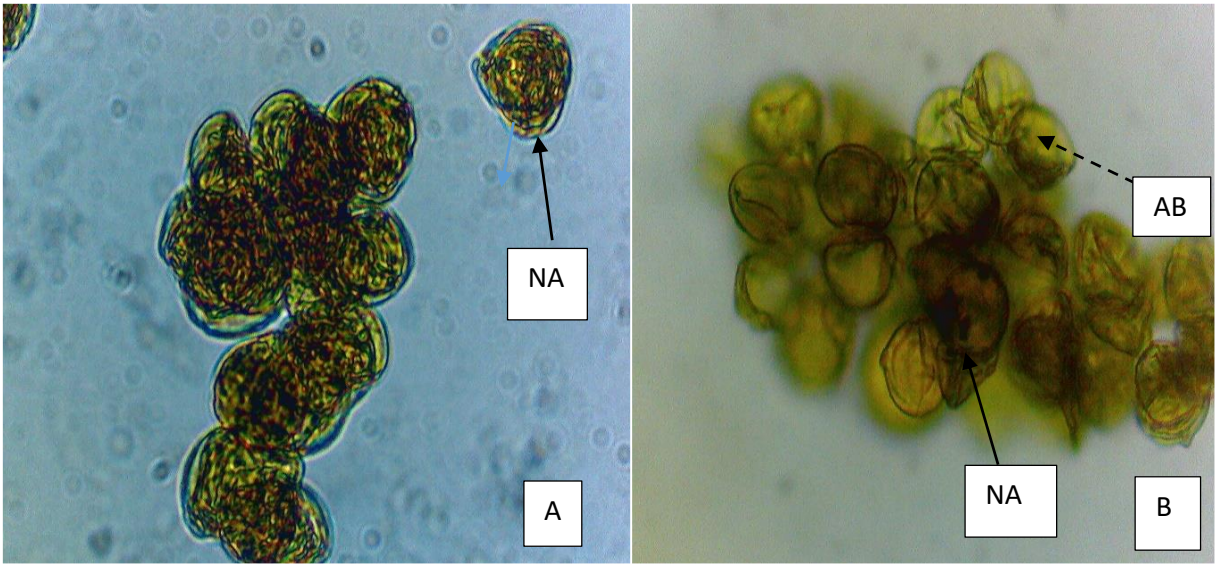

Plate 1. Pollen viability of non-aborted flowers: A- non-aborted (NA) pollen grains of flowers from field grown plants and B-Aborted (AB) and non-aborted (NA) pollen grains of flowers from greenhouse grown plants. Magnification ×400.

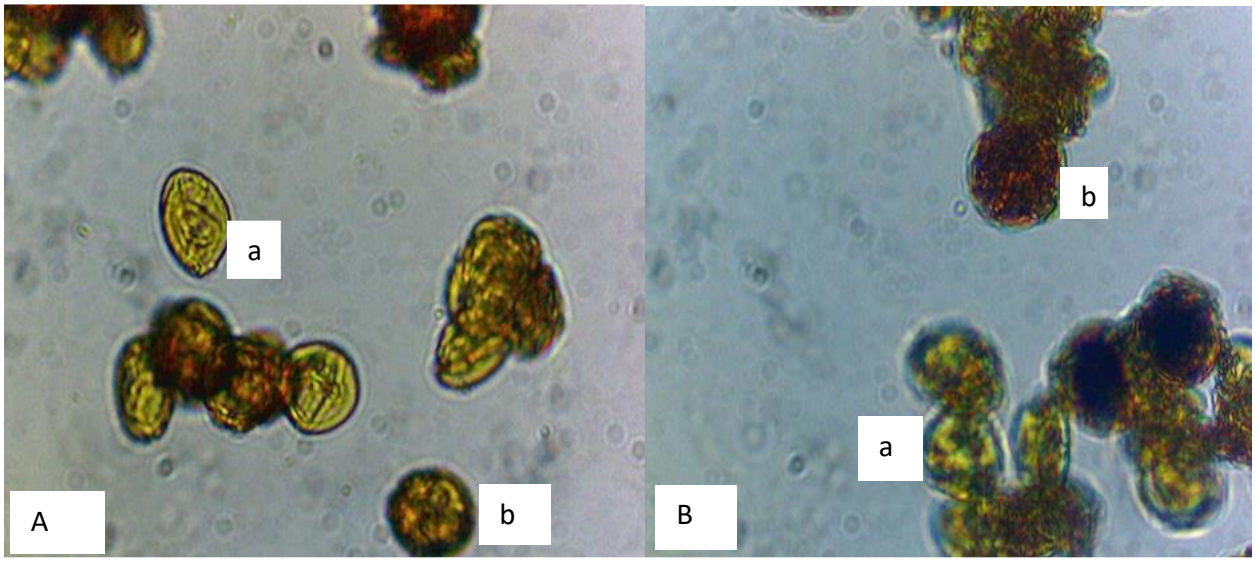

Plate 2. Pollen viability of aborted flowers: A- pollen from aborted flowers from greenhouse grown plants, B-pollen from aborted flowers from field grown plants. a-lightly stained non-viable pollen and b-darkly stained viable pollen. Magnification ×400.

viability of 53.2% recorded in aborted flowers from field grown plants supplied with 100 kg NPK ha^{-1} was not significantly different from that of aborted flowers from field grown plants supplied with 400 kg NPK ha^{-1} which had a pollen viability of 51.83%. The lowest pollen viability of 38.92% was recorded in aborted flowers from greenhouse grown plants not supplied with NPK fertilizer (Table 3). Generally, aborted flowers from greenhouse grown plants had the lowest pollen viability in both trials (Plate 2).

In vitro pollen germination of non-aborted flowers

NPK fertilizer rates and growing environment had a significant effect on pollen germination of non-aborted pepino melon flowers. In trial one, the highest pollen germination of 68.26% was recorded in flowers from field grown plants supplied with 300 kg NPK ha^{-1} and this was significantly different from all the other treatment combinations. Flowers from field grown plants supplied

Table 3. Effect of NPK fertilizer rates on pollen viability of field and greenhouse grown pepino melon aborted flowers in trials one and two.

Environment	Fertilizer (kg ha^{-1})	Pollen viability (%)	
		Trial 1	Trial 2
Field	0	46.38d*	48.33d
	100	53.68bc	53.20bc
	200	54.99b	54.56b
	300	58.25a	58.44a
	400	52.02c	51.83c
Greenhouse	0	38.70g	38.92g
	100	42.82ef	41.61f
	200	44.54de	43.45e
	300	46.29d	47.16d
	400	42.21f	41.19f

*Means followed by the same letter (s) within a trial are not significantly different according to Tukey's test at ($p \leq 0.05$).

Table 4. Effect of NPK fertilizer rates on pollen germination of non-aborted flowers of field and greenhouse grown pepino melons in trials one and two.

Environment	Fertilizer (kg ha^{-1})	Pollen germination (%)	
		Trial 1	Trial 2
Field	0	57.66d*	56.61de
	100	61.70b	60.65b
	200	63.00b	62.07b
	300	68.26a	67.72a
	400	60.63bc	59.83bc
Greenhouse	0	52.61f	51.71g
	100	55.80de	54.90ef
	200	58.50cd	57.59cd
	300	54.63ef	53.36fg
	400	52.73f	51.64g

*Means followed by the same letter (s) within a trial are not significantly different according to Tukey's test at ($p \leq 0.05$).

with 100, 200 and 400 kg NPK ha^{-1} were not significantly different with a pollen germination of 61.7%, 63% and 60.63% respectively. The lowest pollen germination of 52.61% was recorded in flowers from greenhouse grown plants not supplied with NPK fertilizer although the pollen germination was not significantly different from flowers of greenhouse grown plants supplied with 300 and 400 kg NPK ha^{-1} with a pollen germination of 54.63 and 52.73% respectively (Table 4).

In trial two, the highest pollen germination of 67.72% was recorded in flowers from field grown plants supplied with 300 kg NPK ha^{-1} and this was significantly different from all the other treatments. Pollen germination of flowers from field grown plants supplied with 100, 200 and 400 kg NPK ha^{-1} were not significantly different and it was 60.65, 62.07 and 59.83% respectively. However, pollen germination of flowers from field grown plants supplied with 400 kg NPK ha^{-1} was not significantly different from that of flowers from greenhouse grown plants supplied with 200 kg NPK ha^{-1} with a pollen germination of 57.59%. The lowest pollen germination of 51.64% was recorded in flowers from greenhouse grown plants not supplied with 400 kg NPK ha^{-1} although this was not significantly different from pollen germination of flowers from greenhouse grown plants not supplied with NPK fertilizer and those supplied with 300 kg NPK ha^{-1} with a pollen germination of 51.71 and 53.36% respectively (Table 4). Generally, flowers from field grown plants had the highest pollen germination percentage in both trials.

In vitro pollen germination of aborted flowers

NPK fertilizer rates had a significant effect at p≤0.05 on pollen germination of aborted flowers of field and greenhouse grown pepino melon. In trial one, aborted

Table 5. Effect of NPK fertilizer rates on pollen germination of aborted flowers of field and greenhouse pepino melon plants in trials one and two.

Environment	Fertilizer (kg ha^{-1})	Pollen germination (%)	
		Trial 1	Trial 2
Field	0	39.95de*	38.75de
	100	43.33bc	42.37bc
	200	44.60b	43.69b
	300	48.14a	48.39a
	400	41.69cd	40.43cd
Greenhouse	0	32.06fg	30.89g
	100	34.34f	33.30f
	200	38.29e	36.95e
	300	33.00fg	31.95fg
	400	30.92g	29.98g

*Means followed by the same letter (s) within a trial are not significantly different according to Tukey's test at ($p \leq 0.05$).

flowers from field grown plants supplied with 300 kg NPK ha^{-1} had the highest pollen germination of 48.14% and this was significantly different from the other treatment combinations. Aborted flowers from field grown plants supplied with 100 and 200 kg NPK ha^{-1} had a pollen germination of 43.33 and 44.6% respectively and this was not significantly different. In addition, the pollen germination of aborted flowers from field grown pepino plants supplied with 400 kg NPK ha^{-1} was not significantly different from that of aborted flowers from field grown plants not supplied with NPK fertilizer. The lowest pollen germination of 30.92% was recorded in aborted flowers from greenhouse plants supplied with 400 kg NPK ha^{-1} but this was not significantly different from greenhouse grown plants not supplied with NPK fertilizer and those supplied with 300 kg NPK ha^{-1} with a pollen germination of 32.06% and 33% respectively (Table 5).

In trial two, aborted flowers from field grown plants supplied with 300 kg NPK ha^{-1} had the highest pollen germination of 48.39% and this was significantly different from all the other treatment combinations. Aborted flowers from field grown plants supplied with 100 and 200 kg NPK ha^{-1} had a pollen germination of 42.37 and 43.69% respectively and this was not significantly different. The lowest pollen germination of 29.98% was recorded in aborted flowers from greenhouse grown plants supplied with 400 kg NPK ha^{-1} although this was not significantly different from that of aborted flowers not supplied with NPK fertilizer and those supplied with 300 kg NPK ha^{-1}. Generally, aborted flowers from field grown pepino melon plants had a higher pollen germination compared to aborted flowers from greenhouse grown plants (Table 5).

DISCUSSION

In the present study, NPK fertilizer rates and growing environment had a significant effect on number of flowers per truss of pepino melon in both trials. Application of 400 kg NPK ha^{-1} in both field and greenhouse grown plants had the lowest number of flowers. This could be attributed to high nitrogen from the NPK fertilizer which favored the vegetative phase at the expense of flowering. Field grown plants had higher number of flowers per truss compared to greenhouse grown plants. This could be due to low temperature recorded in the field compared to the high temperature in the greenhouse High temperature has been reported to cause flower abortion in tomato and pepino plants (Sato *et al*., 2000). There were more flowers aborted in the greenhouse compared to the field and this led to reduced number of flowers in greenhouse grown plants. The number of flowers per truss increased as the NPK fertilizer rates increased. Similarly, Khetran *et al*. (2016) also reported an increase in the number of flowers of okra plants as the NPK fertilizer rates increased. Results of the current study are also in harmony with the findings of Iyagba *et al*. (2013) who reported that application of 100, 200 and 300 kg NPK ha^{-1} to okra plants produced the highest number of flowers compared to the control. Cavusoglu *et al*. (2009) stated that air temperatures above 25°C cause a negative effect on flower formation of pepino melon.

Greenhouse grown plants had the highest number of aborted flowers. This could be attributed to the high temperature in the greenhouse. Similarly, Ascough *et al*. (2005) reported that abortion of reproductive organs in sweet pepper occurred even when they were grown in a controlled environment. Abortion of reproductive organs is mainly caused by temperature (Huberman *et al*., 1997). Temperature has a direct effect on respiration even when plants have adequate supply of water and nutrients (Ascough *et al*., 2005). High temperature leads to increased metabolism resulting to an increase in use of energy reserves and this leads to abortio n (Guinn, 1974).

Similarly, Marcelis *et al*. (2004) reported that exposure of sweet pepper to a temperature of 33°C resulted to 100% abortion of buds and flowers.

Several studies have also reported increased abortion of flowers by high temperatures above 30°C (Aloni *et al*., 1991; Huberman *et al*., 1997; Erickson and Markhart (2001; 2002). Increase in temperature from 33 to 35°C led to a decrease in respiration and sugar accumulation in buds and flowers (Aloni *et al*., 1997) and it was concluded that abortion was caused by decrease in dry matter partitioning rather than a decrease in photosynthesis. At high temperatures auxin concentration and transport to the pedicels of flowers and fruitlets is decreased (Huberman *et al*., 1997). Consequently, the levels of ethylene precursor 1-aminocyclopropane-1-carboxylic acid (ACC) increase after long exposure to high temperatures (Wien *et al*., 1993) resulting to an increase in ethylene concentration in buds and flowers and this increases susceptibility to abortion (Wubs *et al*., 2009). High temperature causes a decrease in photosynthesis and consequently a decrease in availability of carbohydrates (Sato *et al*., 2000). Carbohydrate content affects the expression of flower abortion genes through hexokinases which play a role in sugar metabolism and signal transduction to other genes (Jang and Sheen, 1997). Flower abortion in chilli pepper was caused by high temperatures when chilli was planted at different times of the year (Mends-Cole *et al*., 2019). Similarly, Van and Stead (1997) reported that flower retention was highly sensitive to environmental factors particularly temperature.

Pollen production is a significant stage in plants and fertile pollen is critical for plant multiplication. Abiotic stresses decrease synthesis of photosynthates and genotypes likewise reduce mobilization of reserves to the tapetum cells and this decreases pollen fertility (Razzaq *et al*., 2019). The low pollen viability recorded in flowers from greenhouse grown plants could be due to high temperature. High temperature affects reproductive growth, flower growth, fertilization and fruit maturity (Prasad et , 1999). Prasad *et al*. (2002) reported that the number of pollen grains in kidney bean reduced from 2000 to almost zero when the air temperature increased from 28/18°C to 40/30°C day/night temperature. Similarly, in tomato the number of pollen grains per flower reduced from 700,000 to less than 400,000 when temperature increased from 28/22°C to 32/26°C day/night temperature (Pressman *et al*., 2002). In addition, flower and fruit development is sensitive to high temperature but the response depends on the stage of flower growth and plant genotype (Kafizadeh *et al*., 2008). Most crops do not respond in a similar manner to high temperature but lack of viable pollen is the major cause for fruit formation failure (Abdul-Baki, 1992; Atherton and Rudish, 1986). Both male and female gametophytes are sensitive to high temperatures but the male gametophyte is more vulnerable because at high temperature, pollen germination and tube growth are greatly reduced (Kakani *et al*., 2005). Several studies have indicated that high temperature on male reproductive organ leads to flower abortion and subsequent yield reduction (Kafizadeh *et al*., 2008). Similarly, Pressman *et al*. (2002) reported decreased pollen production per flower and decreased pollen viability in tomato when the temperatures were increased to 32°/26°C day/night temperatures.

The high pollen viability recorded in flowers from field grown plants could be due to the low temperatures in the field during the growing season. Low temperature favored the male gametophyte and thus reduced flower abortion, increased viability and increased yield for field grown plants. Increase in pollen viability as the fertilizer rates increased could be attributed to increase in absorbed nutrients which had a positive effect on photosynthesis, flowering and consequently pollen viability. The low pollen viability in flowers from plants not supplied with NPK fertilizer could be due to reduced absorption of nutrients which led to reduced photosynthesis, flowering and pollen viability. Lau and Stephenson (1993) also reported that zucchini plants supplied with high nitrogen produced 1.15 times more pollen than plants supplied with low nitrogen levels. Pollen grains are packed with inorganic nutrients and energy reserves such as lipids and starch which are utilized during germination and pollen tube growth (Lau and Stephenson, 1993). Pollen grains from *Cucurbita pepo* plants supplied with high nitrogen levels were larger compared to pollen grains from plants supplied with low nitrogen levels (Lau and Stephenson, 1993). Therefore, pollen grains from plants supplied with high nitrogen levels had more reserves compared to those from low nitrogen plants and this had an effect on pollen viability and germination. On the other hand, flowers from plants which were supplied with 400 kg NPK ha^{-1} had low pollen viability because most of the absorbed nutrients were directed towards vegetative growth rather than to the flowers. In addition, the reduction in pollen viability could also be attributed to low soluble sugar content in the developing pollen grains (Pressman *et al*., 2002). Sucrose protects pollen grains from dessication thus pollen grains which have high sucrose levels do not dehydrate and are therefore viable. Hoekstra *et al*. (1989) reported that pollen dehydration survival rate had a positive association with sucrose concentration. Pollen viability is important because pollen should be viable at the time of pollination for fruit set to occur.

Flower abortion is mainly caused by high temperature and the pollen grains are extremely sensitive to high temperature. The low pollen viability in the aborted flowers could be due to damage of pollen grains as a result of high temperature especially in the greenhouse. The high pollen viability of aborted flowers from field grown plants could be due to low temperature in the field. The low pollen viability in aborted flowers from plants not supplied with NPK fertilizer could be due to reduced absorption of nutrients which led to reduced photosynthesis, flowering and pollen viability. On the other hand, aborted flowers from plants

supplied with intermediate nutrients had high pollen viability because of the availability of nutrients which led to increased photosynthesis, flowering and pollen viability. Aborted flowers from plants supplied with 400 kg NPK ha^{-1} had the lowest pollen viability probably due to allocation of most of the photosynthates for vegetative growth rather than to the flowers. Pollen viability tests using dyes are easier and faster but they tend to overestimate viability. Therefore, truly viable pollen can be quantified by use of *in vitro* pollen germination tests.

Flowers from greenhouse grown plants had a low pollen germination compared to flowers from field grown plants. The low pollen germination in flowers from greenhouse grown plants could be due to the high temperatures in the greenhouse. Similarly, Kafizadeh *et al*. (2008) reported reduced pollen germination of pepper when plants were grown in 38°C compared with pepper plants grown at 25°C. Findings of the current study are in harmony with those of Kakani *et al*. (2005) who reported that temperature above 28°C for 12 hours during flowering in tomato led to reduced pollen germination. High temperatures lead to reduced pollen production, pollen viability and pollen tube growth (Kafizadeh *et al*., 2008). The low pollen germination in flowers from greenhouse grown plants could be attributed to reduction in pollen moisture due to the high temperature (Kafizadeh *et al*., 2008). When the relative humidity is normal, pollen grains perform their metabolic activities normally but at low relative humidity due to high temperature, pollen desiccation occurs and thus affect metabolic activities and membrane integrity (Kafizadeh *et al*., 2008). The low pollen germination under high temperature conditions in flowers obtained from greenhouse grown plants could also be due to under-utilization or unavailability of carbohydrates in pollen grains during pollen formation (Kakani *et al*., 2005). In addition, Pressman *et al*. (2002) reported a reduction in starch and soluble sugars in the anther walls and pollen grains of tomato when exposed to 32/26°C day/night temperatures. Therefore, the low pollen germination in flowers from greenhouse grown plants could be due to reduced starch and soluble sugars in the pollen grains. Pollen tube growth and development are energy requiring processes and carbohydrates act as the main energy sources and thus a reduction in the two will lead to low pollen germination. In addition, high temperatures have a negative impact on pollen development and this leads to decreased *in vitro* pollen germination percentage. High temperatures also lead to formation of reactive oxygen species (ROS) in the pollen grains and this may have led to reduced pollen viability for pollen from greenhouse grown flowers and hence the reduced *in vitro* pollen germination percentage. The low pollen germination in flowers from plants not supplied with NPK fertilizer could be due to reduced absorption of nutrients which led to reduced photosynthesis, flowering and pollen germination. On the other hand, flowers from plants supplied with intermediate nutrients had high pollen germination because of the availability of nutrients which led to increased photosynthesis, flowering and pollen germination. Flowers from plants supplied with 400 kg NPK ha^{-1} had the lowest pollen germination probably due to allocation of most of the photosynthates for vegetative growth rather than to the flowers.

Conclusion

Based on the foregoing results, we conclude that application of 300 kg NPK ha^{-1} for field grown pepino melon plants lead to reduced flower abortion, increased the number of flowers per truss, increased pollen viability and pollen germination while application of 200 kg NPK ha^{-1} for greenhouse grown pepino melon plants led to low number of aborted flowers, high number of flowers per truss, increased pollen viability and pollen germination.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation and thanks to World Bank through the Centre of Excellence in Sustainable Agriculture and Agribusiness Management (CESAAM), Egerton University for the financial support of this research. Thanks to the Biotechnology Laboratory and Department of Crops, Horticulture and Soils of Egerton University- Kenya for hosting this research.

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