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Effects of hardening off on Growth, Yield and Quality of some Pepper (*Capsicum annuum*) Cultivars

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ABSTRACT

Research findings attribute field performance of crops to factors such as hardening off. As a result, an experiment was conducted at the Department of Horticulture Experimental Field of the University for Development Studies (UDS) Nyankpala Campus to assess the effects of hardening off on the growth, yield and quality of Cayenne chilli, Scotch bonnet and Sweet pepper cultivars. The treatments were: Cayenne chili pepper hardened off (C_1), Cayenne chilli pepper non-hardened off (C_2), Scotch bonnet pepper hardened off (SB_1), Scotch bonnet pepper non-hardened off (SB_2), Sweet pepper hardened off (SW_1) and Sweet pepper non-hardened off (SW_2). These were arranged in a Randomized Complete Block Design (RCBD) using a 2 x 3 factorial combination with three replications. The results indicate that there were significant differences ($p < 0.05$) between the hardened off and non-hardened off pepper cultivars in all the growth and yield parameters studied, except fruit diameter and fruit length. The interactions of the two factors (hardening off and the pepper varieties) produced significant effects in all the growth and yield parameters studied. Hardening off produced taller plants [C_1 (25.56 cm), SB_1 (21.14 cm) and SW_1 (13.64 cm)], broader leaves [C_1 (20.25 cm^2); SB_1 (24.53 cm^2) and SW_1 (26.11 cm^2)], more fruits [SW_1 (39); C_1 (35) and SB_1 (16)], bigger fruits [C_1 (126.21 cm^2), SW_1 (86.54 cm^2) and SB_1 (40.14 cm^2)] and higher yields [C_1 (3.40 t ha^{-1}); SW_1 (3.22 t ha^{-1}); and SB_1 (1.82 t ha^{-1})]. Hardening off also improved fruit quality in terms of freshness/firmness but did not influence colour change of the fruits.

Key words: Hardening off, Pepper, Plant Growth, Yield, Fruit Quality

INTRODUCTION

There are different opinions regarding the place of origin of the species of pepper, *Capsicum spp,* due to the fact that its place of origin is uncertain. It was however believed to be native to the Americas (Acevedo-Rodriguez and Strong, 2012). Some researchers speculate that domestication of *Capsicum spp* started in Mexico; southern and central parts of America where it is believed to have originated from (Basu and De, 2003). Exploratory research by archaeologists led to the discovery of utilization of pepper as spice crop started by human beings as early as 6000 years ago (Hill *et al.,* 2013). Christopher Columbus and other early explorers introduced pepper in the Middle and Southern Europe in the 17th century before its cultivation as spice and medicinal crop (Basu and De, 2003).

Pepper is classified under the family, *Solanaceae*, and the genus name, *Capsicum*.

Pepper is normally a herbaceous and subshrub plant that is grown as an annual or biennial crop (Bolsland and Votava, 2000). Pepper can grow to a height of about 0.5 - 1.5 m tall, erect with many branches, tap root and numerous lateral roots. Flowers emerge singly, terminal pedicel up to 3 cm long in flower. Pepper is behind tomato as the most consumed vegetable in the world (Schipper, 2000). The major constraint affecting the production of the crop was observed to be how to sustain field establishment with low transplant mortality and sub-optimal high plant population (Mavengahama *et al.*, 2008).

Hardening off is a gradual process during which plants modify their physiology to survive the vagaries of an outdoor life or a gradual process of acclimatizing plants grown indoors in a protected environment until they become robust enough to flourish outdoors, that is environmental conditions such as sunlight, temperature, dry air and colder air (UMD, 2020). Pre-conditioning is normally meant for seedlings nursed in sheltered seedbeds, where they would be gradually exposed to direct sunlight with reduced moisture availability. Nutritional pre-conditioning is another method that has been practised to harden sweet pepper seedlings (Dufault and Schultheis, 1994).

The procedure entails withholding macro-nutrients such as nitrogen and phosphorus from seedlings, thereby delaying their growth up to transplanting period. The impact of hardening off includes: it enables plants to withstand adverse weather conditions; it ensures accumulation of starch/carbohydrate in the tissues of the seedlings so far as the seedlings are pre-exposed to external light before finally transplanting them in the permanent field. It also ensures rapid growth in plants, as roots develop quickly because plants transpire less and recovery rate is faster. Growth rate of transplants is slower and root development is affected ranging from top 5 cm of soil, that is if watering is reduced when seedling is half-grown. The practice of hardening off is recommended to withhold water in the first one week (7 or 8 days), 7-10 days or two to three weeks (outdoor for 24 hours per day) before transplanting, depending on the type of plant or ornamental plant, vegetable seedling and other greenhouse plant that is accustomed to external weather conditions (Wanyonyi. 2019). Gopalakrishnan (2000) reports that hardening off of pepper by regulating watering a week prior to transplanting is important for seedling survival and better establishment on the main field.

Pepper is an important commodity in terms of its exportation and domestic utilization (Parthasaranthy *et al.*, 2008). According to Mavengahama *et al*. (2008), small-scale farmers face many challenges with regards to the production of this valuable cash crop and thus producers are unable to take full advantage of the market demand. Production of *Capsicum spp* is successful on a good field after transplanting (Chivinge and Mariga, 1998). Farmers experience challenges such as high transplant mortality, sub-optimal plant population and serious weed threats which can result in the loss of the entire crop in the field. These can be attributed to poor Capsicum transplant establishment in the field. Various factors cause poor establishment of transplanted seedlings in the field, and these include inadequate or lack of hardening off of the transplanted seedlings (Dhaliwal, 2017). In the past, sub-Saharan local farmers in Africa adopted strategies to mitigate the impact of climate variability through farming systems such as shifting cultivation (Ajani, 2013). These strategies were however not adequate to curb adverse effects of temperature to ensure good establishment of crops in the field (Owusu,

2016). Research findings suggest that farmers do not usually understand hardening off regime; they rather subject their seedlings to alternate watering and hardening off (Mavengahama *et al.*, 2008). In spite of the huge potential for pepper production in Ghana, most farmers do not adhere to good agricultural practices, such as hardening off seedlings of their crops, which improve yield. Therefore, this research was conducted to find out the effect of hardening off on the growth, yield and quality of Cayenne chilli, Scotch bonnet and Sweet pepper cultivars.

MATERIALS AND METHODS

Location of the Experiment

The study was conducted at the Plant House, Department of Horticulture, Faculty of Agriculture, University for Development Studies (Nyankpala Campus). Nyankpala is located in the Tolon District of Northern Guinea Savannah Zone of Ghana. The district lies between latitudes 9^0 25' N and 10^0 02' N and between longitudes 0^0 58' W and 1^o 25' W at an altitude of 183 m above sea level in the Northern Guinea Savannah Zone of Ghana (SARI, 2004). The area shares boundaries to the north with the Kumbungu District, the North Gonja District to the west, the Central Gonja District to the south and the Sagnarigu District in the east (Tolon District Assembly, 2015).

Soils on the experimental field is an alfisol under the USDA system of classification; also known as Nyankpala series or Plinthic Acrisol. The soil is brown, moderately drained sandy loam, thinly developed from the Voltain sandstone, free from compaction and shallow with a hard pan beneath the top in few centimetres (NAES, 1984). The soil is a black sandy-loamy soil which is good for supporting plant growth. The study area experiences unimodal rainy season. Rainfall starts from April or May to September or October and increases in July or August with an estimated annual rainfall of 1100 mm (MoFA, 2004). The dry season usually starts from November and ends in March, which is characterized by the North-Eastern Trade winds.

Experimental Design

The pepper seeds were bought at Wumpini Agro-Chemicals Limited shop, a recognized and licensed agro-chemical shop in Tamale. The experiment was a 2 x 3 factorial one, involving two factors, *hardening off* and *pepper cultivars*. The first (main) factor consisted of 2 treatments (hardening off and non-hardening off) while the second factor was made up of 3 treatments (Cayenne chilli, Scotch bonnet and Sweet pepper cultivars). These gave rise to six treatment combinations which were used in the experiment. These were: C_1 = Cayenne chili pepper hardened off; C_2 = Cayenne chili pepper not hardened off; SW_1 = Sweet pepper hardened off; SW_2 = Sweet pepper not hardened off; SB_1 = Scotch bonnet chili pepper hardened off; and SB_2 = Scotch bonnet chili pepper not hardened off. These were arranged in a Randomized Complete Block Design (RCBD) using a 2 x 3 factorial combination with three replications.

The experimental land (the Department of Horticulture Experimental Field) near the Plant House, was divided into two fields; for hardening off and non-hardening off. For each field, the total area was 116 m^2 with eighteen plots of which each plot measured 2 m x 2 m. Distance between replicates was 1 m and distance between plots was 0.5 m. The total land area of the two fields was 232 m^2.

Experimental Procedure

River sand and top soil were mixed in a ratio of 1:2, meaning one part of river sand and two parts of top soil were thoroughly mixed, and the mixture was used as the medium for raising the pepper seedlings. Seeds were nursed in a tray on 17th September, 2018,

using the broadcasting method in the Plant House. The seeds started germinating from the 7th to 14th day after planting. Thinning out was done on the 18th and 19th days, after the appearance of the true leaves of the seedlings. This was to ensure that healthy seedlings were selected prior to transplanting. The seedlings stayed in the nursery for six weeks (after sowing), after which hardening off was done to reduce transplanting shock as well as ensure good establishment of seedlings. Transplanting was done during the cooler period of the day (late afternoon). The seedlings were transplanted on to the seedbed in the main field using 60 cm x 60 cm spacing between plants. Immediately after transplanting, five plants were tagged on each experimental unit. Nine (9) plants occupied each experimental unit. The nursery management practices carried in the field included shading, organic fertilizer application, mulching, weeding, pricking out, thinning out and watering.

The Hardening Off Process

The following were the steps of the hardening off process used in the experiment:

I. The hardening off process took 7 days prior to the transplanting date. On the first day, the seedlings were placed in a shady spot outdoors under a tree for about 2-4 hours, and gradually increased the time spent outside by 1-2 hours per day on the second day.
II. The seedlings were brought back indoors in the glasshouse each night.
III. After 2–3 days, the seedlings were moved from their shady spot in to the sun but returned to the shade in the afternoon because too much sunlight could scorch the leaves.
IV. After 7 days the seedlings were transplanted in the open field.

The non-hardened off seedlings were however kept indoors in the glasshouse from sowing till they were transplanted in the open field (without going through the hardening off process).

Other agronomic practices

A hand hoe was used to control weeds at the second and sixth (2nd and 6th) weeks after transplanting. Reshaping of beds and loosening of soil were carried out at the fourth and eighth weeks after transplanting using a hoe. Mulching was also carried out on 15th October, 2019 (4 weeks after transplanting) to conserve moisture in the soil and as well as reduce soil temperature to conducive levels. Grasses were used as the mulching materials. Staking was done by using sticks to support the pepper plants with weaker stems or lodged ones for upright growth. When there was drought as a result of low/absence of rainfall, supplementary irrigation was done using watering cans to supply water to the pepper plants throughout the growing period of the plants. The pepper fruits were harvested by hand (manually) when they reached maturity and ripened. Fruits of mature sweet pepper were harvested when they were green, shiny and firm while matured fruits of Cayenne Scotch bonnet were harvested when they were red.

Data collection

Data collection started at two weeks after transplanting (2WAT) of seedlings in the field. Using similar methods outlined by Shu-aib Jakpa *et al*. (2019) and Shu-aib Jakpa *et al*. (2020), data was gathered on growth, yield and quality parameters of the pepper plants:

Data on Growth parameters

Data was gathered on the following growth parameters: plant height, stem diameter, number of branches and leaf area.

Plant height
For each treatment plot, the heights of five tagged plants were taken from the ground level to the stem apex of each plant. The average was used to represent that plot. The measurements were taken in centimetres (cm) and the data was computed accordingly.

Stem diameter
The stem diameter of each plant was measured using a pair of calipers. An average from five plants was used to represent each pepper treatment plot. The measurement was taken in centimetres (cm).

Number of branches
For each treatment plot, the number of branches on individual tagged plants was counted manually and calculated as the number of branches for the treatment plot.

Leaf Area
The leaf area of individually tagged plants was determined by multiplying the length by the width of each leaf and the average was calculated for five tagged plants per plot.

Data on Yield Parameters
Data was gathered on the following yield parameters: fruit length, fresh fruit weight, fruit diameter and number of fruits.

Fruit length
The lengths of five fruits per plant on each plot were measured from the pedicel attachment to its apex and the average was used to represent fruit length of that treatment plot. Fruit length was measured in centimetres (cm).

Fresh fruit weight
The fruits were weighed with an electronic weighing scale. The weight of five fruits of each treatment plot was measured in grammes (g) and the average was taken to represent the weight of the treatment plot.

Fruit diameter
Five fruits were measured and the average was used to represent the fruit width of that treatment. The measurement was taken in centimetres (cm).

Number of Fruits
For each treatment plot, an average of the sum of five sampled plants was computed as the number of fruits for the treatment plot.

Data on Fruit Quality
On fruit quality, data was taken on fruit colour and freshness/firmness of fruits

Fruit Colour
Changes in colour (from fruit set up to time of harvesting) were noted and recorded in all the treatments used. The colours were then matched with a colour chart (Figure 1).

Figure 1. A colour cart
(Source: Segmation.wordpress, 2012)

Freshness/Firmness of Fruits
Changes in freshness/firmness (from fruit set up to time of harvesting) were also noted and recorded in all the treatments applied. Firmness of fruits was determined at 3 places laterally along the diameter of each sampled fruit.

Pulp firmness of fruits was also determined along 3 flanks of the sampled fruits, at the equatorial part, by means of a penetrometer (Bertuzzi FT 011) fitted with an 8-mm diameter probe (Cheng *et al.*, 2008 and Rubio *et al.*, 2010).

Data analysis

The data collected was subjected to analysis of variance (ANOVA) using GenStat statistical package (10.3DE) and the means were separated using LSD at 5 % level of significance.

RESULTS

Effect of Hardening Off on The Growth Parameters of Pepper

Plant Height

The analyzed experimental results, in terms of the main and interactive effects, showed significant differences ($p < 0.05$) among the various treatments of pepper from the second to the sixth week after transplanting (Tables 1, 2 and 3). There was significant difference in terms of the main effects of hardening off on plant height of pepper at 2, 4 and 6 weeks after transplanting (WAT), with hardening off treatment producing taller plants than those of non-hardening off. Performances in height of the various varieties of pepper were also significantly different ($p < 0.05$) from 2WAT to 6WAT, with Cayenne (C_1 and C_2) recording the tallest plants, followed by Scotch Bonnet (SB_1 and SB_2) and Sweet pepper (SW_1 and SW_2) recording the shortest plants. The interactions between hardening off and pepper varieties (Table 3) also had significant effects ($p < 0.05$) on height of the pepper plants 2WAT to 6WAT, with C_1 producing the tallest plants while SB_1 recorded the shortest plants.

Generally, C_1 (Cayenne hardening off) recorded the highest values in terms of plant height from 2WAT to 6WAT, followed by SB_2, with the lowest values recorded by SW_2.

Table 1. Effects of Hardening off on Growth Parameters of some Pepper (*Capsicum annuum*) Cultivars

	Plant Height			Stem Diameter (cm)	Number of branches	Leaf area (cm^2)
Hardening	*2WAT*	*4WAT*	*6WAT*			
Hardening off	13.38*	15.35*	16.98*	5.26*	21.00*	23.63*
Non hardening off	11.46*	13.29*	14.63*	6.23*	26.67*	21.67*
LSD	0.545	0.723	0.878	0.324	1.655	0.711
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	11.0	10.2	10.5	11.9	16.8	6.1

WAT: Weeks after transplanting
* Along a column means 'significant difference'
LSD: Least significant difference
CV: Coefficient of variation

Table 2. Varietal Effects of Pepper on Growth Parameters of some Pepper (*Capsicum annuum*) Cultivars

	Plant Height									Stem Diameter (cm)			Number of branches			Leaf area (cm^2)		
	2WAT			*4WAT*			*6WAT*											
Hardening	**Pepper Variety**			**Pepper Variety**			**Pepper Variety**			**Pepper Variety**			**Pepper Variety**			**Pepper Variety**		
	CC	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*
	13.39*	14.06*	9.81*	16.65*	15.15*	11.16*	19.05*	16.43*	11.92*	5.68*	6.43*	5.13*	25.00*	27.50*	19.00*	22.56*	21.82*	23.57*
LSD	0.667			0.886			1.075			0.397			2.027			0.871		
P-value	<0.001			<0.001			<0.001			<0.001			<0.001			<0.001		
CV (%)	18.4			19.8			22.8			11.4			18.3			3.9		

WAT: Weeks after transplanting
CC: Cayenne Chili
SB: Scotch Bonnet
SW: Sweet pepper
* Along a column means 'significant difference'
LSD: Least significant difference
CV: Coefficient of variation

Table 3. Interaction of Hardening off on Growth Parameters of some Pepper (*Capsicum annuum*) Cultivars

Hardening	Plant Height									Stem Diameter (cm)			Number of branches			Leaf area (cm^2)		
	2WAT			*4WAT*			*6WAT*											
	Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety		
	CC	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*
Hardening off	19.13*	18.52*	11.41*	22.56*	19.96*	13.16*	25.56*	21.14*	13.64*	4.50*	4.11*	7.18*	25.00*	24.00*	14.00*	20.25*	26.11*	24.53*
Non-hardening off	7.65*	9.60*	8.20*	10.74*	10.34*	9.17*	12.54*	11.73*	10.21*	5.69*	6.86*	6.14*	41.00*	25.00*	14.00*	24.88*	17.53*	22.61*
LSD	0.944			1.253			1.520			0.561			2.867			1.231		
P-value	<0.001			<0.001			<0.001			<0.001			<0.001			<0.001		
CV (%)	58.4			53.6			50.4			26.2			56.8			20.6		

WAT: Weeks after transplanting
CC: Cayenne Chili
SB: Scotch Bonnet
SW: Sweet pepper

* Along a column means 'significant difference'
LSD: Least significant difference
CV: Coefficient of variation

Stem Diameter

Hardening off had significant effect ($p < 0.001$) on the stem diameter of the pepper plants, with non-hardening off producing larger stems (6.23 cm) of pepper plants than those that were hardened off (5.26 cm (Table 1). The interactions of hardening off and varieties of pepper (Table 3) generally also had significant effects ($p < 0.05$) on stem diameters of the pepper plants with the non-hardening off treatment mostly producing plants with higher values for their stem diameters [C_2 (5.69 cm); SB_2 (6.86 cm) and SW_2 (6.14 cm)] than the hardened off pepper plants [C_1 (4.50 cm); SB_1 (4.11 cm) and SW_1 (7.18 cm)]. There was significant difference ($p < 0.05$) among the varieties of pepper in terms of the stem diameter. Sweet pepper recorded the largest stem diameters [SW_1 (7.18 cm) and SW_2 (6.14 cm)], followed by Scotch bonnet [SB_1(4.11 cm) and SB_2 (6.86 cm]. Cayenne recorded the smallest stem diameter [C_1 (4.50 cm) and C_2 (5.69 cm)]

Number of Branches

Analysis of the results indicate that hardening off and varieties of pepper (Tables 1 and 2) and the interactions (Table 3) of the two parameters (hardening off and pepper varieties) had significant effects on the number of branches of the pepper plants with the non-hardening off recording a higher number of branches [C_2 (41); SB_2 (25) and SW_2 (14)] than the hardening off pepper plants [C_1 (25); SB_1 (24) and SW_1 (14)], except the sweet pepper (SW) which recorded the same number of branches (14) under hardening off and non-hardening off treatments. There was significant difference ($p < 0.05$) among the varieties of pepper in terms of the number of branches. In general, Cayenne recorded the highest number of branches [C_1 (25) and C_2 (41)], followed by Scotch bonnet [SB_1(24) and SB_2 (25)] with Sweet pepper recording the lowest number of branches [SW_1 (14) and SW_2 (14)].

In overall terms, C_2 recorded the highest number of branches (41), followed by C_1 (25) and SB_2 (25), with SW_1 and SW_2 recording the fewest number of branches (14 each).

Leaf Area

Hardening off significantly influenced leaf area of the plants, with hardened off plants producing larger leaf area (23.63 cm^2) than non-hardened off plants (21.67 cm^2) (Table 1). Generally, the interactions between hardening off and varieties of pepper had significant effects ($p < 0.05$) on the leaf area of the pepper plants, with the hardening recording broader leaves [C_1 (20.25 cm^2); SB_1 (24.53 cm^2) and SW_1 (26.11 cm^2)] than the non-hardening off pepper plants [C_2 (17.53 cm^2); SB_2 (24.88 cm^2) and SW_2 (22.61 cm^2)]. There was also significant difference ($p < 0.05$) among the varieties of pepper in terms of the leaf area. Sweet pepper recorded the broadest leaves [SW_1 (26.11 cm^2) and SW_2 (22.61 cm^2)], followed by Scotch bonnet [SB_1(24.53 cm^2) and SB_2 (24.88

cm^2]. Cayenne recorded the narrowest leaves [C_1 (20.25 cm^2) and C_2 (17.53 cm^2)]

In overall terms, Sweet pepper hardening off recorded the broadest leaves SW_1 (26.11 cm^2), followed by Scotch bonnet non-hardening of SB_2 (24.88 cm^2] while Cayenne non-hardening off recorded the narrowest leaves C_2 (17.53 cm^2).

Effect of Hardening Off on the Yield of Pepper Cultivars

Number of Fruits

In terms of the main effects, hardening off significantly influenced ($p < 0.001$) the number of pepper fruits produced (Table 4). Hardening off produced more fruits (30) than non-hardening off (24). The interactions also had significant effects ($p < 0.001$) on the number of fruits produced, with the hardening off recording more fruits [SB_1 (39); C_1 (35) and SW_1 (16)] than the non-hardening off pepper plants [SB_2 (31); C_2 (28) and SW_2 (12)]. There was significant difference ($p < 0.05$) among the varieties of pepper in terms of the number of fruits produced. Generally, Scotch bonnet recorded the highest number of fruits [SB_1 (39) and SB_2 (31)], followed by Cayenne [C_1 (35) and C_2 (28)], with Sweet pepper recording the fewest fruits [SW_1 (16) and SW_2 (12)]. Largely, Scotch bonnet hardening off SB_1 produced the most fruits (39), the next was Cayenne hardening off (C_1) which recorded 35 fruits, and Sweet pepper non-hardening off SW_2 recorded the least number of fruits (12) (Tables 4 and 5).

Table 4. Effects of Hardening off on Yield of some Pepper (*Capsicum annuum*) Cultivars

	Number of Fruits	Fruit diameter (cm)	Fruit length (cm)	Fruit size (cm^2)	Fruit weight (g)	Fruit yield (t ha^{-1})
Hardening off	30.00*	5.89	13.70	76.64*	37.32*	2.81*
Non-hardening off	23.67*	5.68	13.11	66.20*	30.96*	1.90*
LSD	1.498	0.447	0.614	2.415	0.648	0.297
P-value	<0.001	0.351	0.058	<0.001	<0.001	<0.001
CV (%)	16.7	2.6	3.1	10.3	13.2	27.3

WAT: Weeks after transplanting
CC: Cayenne Chili
SB: Scotch Bonnet
SW: Sweet pepper

* Along a column means 'significant difference'
LSD: Least significant difference
CV: Coefficient of variation

Table 5. Varietal Effects of Pepper on Yield of some Pepper (*Capsicum annuum*) Cultivars

Hardening	Number of Fruits			Fruit diameter (cm)			Fruit length (cm)			Fruit size (cm^2)			Fruit weight (g)			Fruit yield (t ha^{-1})		
	Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety		
	CC	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*
	33.00*	22.00*	25.50*	5.40*	5.74*	6.21*	15.11*	13.28*	11.84*	78.78*	66.15*	69.33*	35.64*	33.55*	33.22*	2.99*	2.00*	2.09*
LSD	1.834			0.548			0.752			2.958			0.794			0.364		
P-value	<0.001			0.017			<0.001			<0.001			<0.001			<0.001		
CV (%)	20.9			7.0			12.2			9.2			3.9			23.2		

WAT: Weeks after transplanting
CC: Cayenne Chili
SB: Scotch Bonnet
SW: Sweet pepper

* Along a column means 'significant difference'
LSD: Least significant difference
CV: Coefficient of variation

Table 6. Interaction of Hardening off on Yield of some Pepper (*Capsicum annuum*) Cultivars

Hardening	Number of Fruits			Fruit diameter (cm)			Fruit length (cm)			Fruit size (cm^2)			Fruit weight (g)			Fruit yield ($t\ ha^{-1}$)		
	Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety			Pepper Variety		
	CC	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*	*CC*	*SB*	*SW*
Hardening off	35.00*	16.00*	39.00*	7.47*	4.03*	6.16*	17.08*	14.05*	9.98*	126.21*	40.14*	86.54*	38.46*	37.58*	35.91*	3.40*	1.82*	3.22*
Non-hardening off	31.00*	28.00*	12.00*	6.25*	3.33*	7.45*	16.17*	9.47*	13.69*	101.06*	31.34*	97.51*	32.83*	29.52*	30.53*	2.58*	2.18*	0.95*
LSD	1.294			0.775			1.063			4.184			1.123			0.515		
P-value	<0.001			<0.001			<0.001			<0.001			<0.001			<0.001		
CV (%)	51.7			46.3			32.3			90.5			3.1			39.5		

WAT: Weeks after transplanting
CC: Cayenne Chili
SB: Scotch Bonnet
SW: Sweet pepper

* Along a column means 'significant difference'
LSD: Least significant difference
CV: Coefficient of variation

Fruit Diameter

Analysis of the results of the main effects of hardening off on fruit diameter of the pepper plants (Table 4) indicate that there was no significant difference ($p = 0.351$) between the hardening and non-hardening off, although the varietal effects differed significantly ($p = 0.017$), with SW recording the largest fruit diameter of 6.21 cm (Table 5). The interactions of hardening off and the pepper varieties had significant effects ($p < 0.001$) on fruit diameter with hardening off recording higher fruit diameters [C_1 (7.47 cm); SB_1 (4.03 cm) and SW_1 (6.16 cm)] than the non-hardening off pepper plants [SW_2 (7.25 cm); C_2 (6.25 cm) and SB_2 (3.33 cm)]. In terms of the varieties of pepper, Cayenne produced fruits with largest diameter [C_1 (7.47 cm) and C_2 (6.25 cm)], followed by Sweet pepper [SW_1 (6.16 cm) and SW_2 (7.25 cm)] while Scotch bonnet produced fruits with the smallest diameter [SB_1 (4.03 cm) and SB_2 (3.33 cm].

Fruit Length

As indicated in Table 4, hardening off did not have any significant effects ($p = 0.058$) on fruit length of pepper. The main varietal effects on fruit length (Table 5) however differed significantly ($p < 0.001$), with CC producing the longest fruits (15.11 cm) while SW produced the shortest fruits (11.84 cm). The interactive effects (Table 6) of hardening off and pepper varieties on fruit length differed significantly ($p < 0.001$), with hardening off producing longer fruits [C_1 (17.08 cm); SB_1 (14.05 cm) and SW_1 (9.98 cm)] than the non-hardening off [C_2 (16.17 cm); SB_2 (9.47 cm) and SW_2 (13.69 cm)].

Fresh Fruit Size

With reference to the main effects, hardening off had a significant influence ($p < 0.001$) on fruit size (Table 4), with non-hardened off plants producing bigger fruits (76.64 cm^2) than hardened off fruits (66.20 cm^2). The varietal effects on fruit size also differed significantly with CC producing the biggest fruits (78.78 cm^2) while SB produced the smallest fruits (66.15 cm^2). The interactions of hardening off and the pepper varieties (Table 6) also significantly influenced fruit size, with hardening off generally producing bigger fruits [C_1 (126.21 cm^2); SB_1 (40.14 cm^2) and SW_1 (86.54 cm^2)] than non-hardening off [C_2 (101.06 cm^2); C_2 (31.34 cm^2) and SW_2 (97.51 cm^2)] (Table 6).

Fresh Fruit Weight

There was significant difference ($p < 0.001$) in the main effects of the hardening of the pepper plants with regards to the fresh weight of the fruits (Table 4). Hardening off produced heavier fruits (37.32 g) than non-hardening off (30.96 g). The varietal effects (Table 5) also significantly influenced the weight of fruits produced, with CC recording the heaviest pepper fruits produced (35.64 g), while SW lowest values (33.22 g) in the terms of fruit weight. The interaction of hardening off and pepper varieties (Table 6) also

had significant influence on fresh weight of the fruits, with hardening off generally producing heavier fresh fruits [C_1 (38.46 g); SB_1 (37.58 g) and SW_1 (35.91 g)] than non-hardening off [C_1 (32.83 g); SB_1 (29.52 g) and SW_1 (30.53 g)].

Yield of Pepper

Hardening off also significantly influenced yield of pepper. An analysis of the main effects of hardening off (Table 4) indicates that hardening off produced higher yields of pepper (2.81 t ha^{-1}) compared non-hardening off (1.90 t ha^{-1}). In addition, significant influence was observed in the varietal effects (Table 5), where CC produced the highest yield of pepper (2.99 t ha^{-1}) while SB produced the lowest yield (2.00 t ha^{-1}). The interaction of the two factors (hardening off and varietal effects of pepper) also significantly impacted on the yield of pepper produced (Table 6). Hardening off generally recorded a higher yield [C_1 (3.40 t ha^{-1}); SB_1 (1.82 t ha^{-1}) and SW_1 (3.22 t ha^{-1})] than the non-hardening off pepper plants [C_2 (2.58 t ha^{-1}); SB_2 (2.18 t ha^{-1}) and SW_2 (0.95 t ha^{-1})].

The Effect of Hardening Off on Quality of Fruits of Pepper

Colour Change

In terms of colour, hardening off had no effect on colour change within the varieties. At 6WAT, when the pepper plants had started producing fruits, both C_1 and C_2 were greenish in colour. The colour then changed from green to red at 7WAT, to deep red at 8WAT and to 10WAT (Table 7). The changes in colour were determined by comparing the colours of the fruits with the colours in a colour chart (Figure 1).

The trend was similar in the other two varieties (SB and SW). In the case of SB (SB_1 and SB_2), the colour changes were: green, red, yellow/red, red and red at 6WAT, 7WAT, 8WAT, 9WAT and 10WAT respectively. For SW (SW_1 and SW_2). the colour changes were: green, green/light yellow, yellow/orange, orange and orange at 6WAT, 7WAT, 8WAT, 9WAT and 10WAT respectively.

Table 7. The Effect of Hardening Off on the Colour of Cultivars of Pepper Fruits

Treatment	***6WAT***	***7WAT***	***8WAT***	***9WAT***	***10WAT***	
C_1	Green	Red	Deep red	Deep red	Deep red	
C_2	Green	Red	Deep red	Deep red	Deep red	
SB_1	Green	Red	Yellow/Red	Red	Red	
SB_2	Green	Red	Yellow/Red	Red	Red	
SW_1	Green	Green/Light yellow	Yellow/Orange	Orange	Orange	SW_2
Green	Green/Light yellow	Yellow/Brown	Orange	Orange		

WAT: Weeks after transplanting SB: Scotch Bonnet
CC: Cayenne Chili SW: Sweet pepper

Table 8. Freshness/firmness of Pepper Fruits from Week 6 to Week 10 After Transplanting

Treatment	***6WAT***	***7WAT***	***8WAT***	***9WAT***	***10WAT***
C_1	firm	firm	soft	soft	very soft
C_2	firm	firm	soft	very soft	very soft and slightly watery
SB_1	firm	firm	soft	soft	very soft
SB_2	firm	firm	soft	soft	very soft and watery
SW_1	firm	firm	firm	soft	very soft and slightly watery
SW_2	firm	firm	firm	soft	very soft and watery

WAT: Weeks after transplanting SB: Scotch Bonnet
CC: Cayenne Chili SW: Sweet pepper

Freshness/Firmness

The research results show that, for freshness/firmness, hardening off had some effect on the pepper fruits. At 6WAT, when the pepper plants had started producing fruits, both C_1 and C_2 were firm. The pepper fruits remained firm at 7WAT but C_1 became soft, soft and very soft at 8WAT, 9WAT and 10WAT respectively, while C_2 became soft, very soft and very soft and slightly watery respectively at 8WAT, 9WAT and 10WAT (Table 8). The changes followed similar patterns in the other two varieties (SB and SW). For SB (SB_1 and SB_2), changes in the freshness/firmness were: firm, firm, soft and soft at 6WAT, 7WAT, 8WAT and 9WAT respectively. At 10WAT, however, while SB_1 became very soft, SB_2 turned into very soft and watery fruits. In the case of SW (SW_1 and SW_2). changes in the freshness/firmness were: firm, firm, firm and soft at 6WAT, 7WAT, 8WAT and 9WAT respectively but at 10WAT, while SW_1 developed into very soft and slightly watery fruits, SW_2 became very soft and watery (Table 8).

DISCUSSION

Effect of Hardening Off on the Growth Parameters of Pepper

Generally, the main effects of hardening off and varietal main effects as well as the interactions of hardening off and the varietal effects of pepper significantly influenced the growth in height of the pepper plants. Pepper plants that were hardened off significantly grew taller than the non-hardened off ones due to the early exposure of the pepper plants to relatively higher intensity of light and higher temperatures during the period of hardening off compared to those that were not hardened off which could have accelerated physiological activities and stimulated faster growth to give the plants a 'heads start' to produce taller plants. Similar results were obtained by Masrufa *et al.* (2016) who reported that hardened off rice plants generally produced taller plants than the non-hardened ones as their early exposure to field conditions during the hardening off process enabled them to adapt and establish better to such conditions when they were eventually transplanted in the field.

Performances in height of the three varieties of pepper were also significantly different ($p < 0.05$) throughout the experiment, with Cayenne recording the tallest plants, followed by Scotch Bonnet and Sweet pepper producing the shortest plants. Generally, C_1 (Cayenne hardening off) recorded the highest values in terms of plant height from 2WAT to 6WAT, followed by C_2. SB_2 recorded the lowest value at 2WAT but gradually performed better at 4WAT and 6WAT than SW_2 which ended up with the lowest values at 4WAT and 6WAT. SW_2 produced the shortest plants probably due to the adverse effects of lower intensity of light and lower temperatures as they were not hardened off. This is in line with an assertion by Rylski and Spigelman (1986b) that Sweet pepper responds well to favourable growth conditions such as relatively higher intensities of light and temperature by producing taller plants. Conversely, under relatively lower intensities of light and temperature, Sweet pepper tends to perform poorly and results in stunted growth by producing rather shorter plants.

Significant difference ($p < 0.05$) was observed between the hardening and non-hardening off with regards to stem diameter of the pepper plants in both the main effects and the interactive effects of the two factors (hardening off and the varietal effects of pepper), with the non-hardening off mostly recording higher values for their stem diameters than the hardening off pepper plants. This could be due to the non-hardened off plants not being exposed to relatively higher intensities of light and higher temperatures at the initial stages of their growth (the hardening off period) and therefore developed shorter but sturdier stems with wider diameters compared to those exposed to higher intensities of light and temperature which developed taller but narrower stems. This could

be as a result of the relatively lower temperatures and other unfavourable growth conditions that constrained the initial growth of the pepper plants (Díaz-Pérez 2010).

With regards to number of branches, there was significant difference ($p < 0.05$) between the hardening and non-hardening off in the main effects and interaction, with the non-hardening recording a higher number of branches than the hardening off pepper plants. The non-hardened off pepper plants developed more branches most probably to produce more leaves to 'capture' the least available light under the given relatively lower intensities of light and temperature as the plants were not hardened off. Similar results were obtained by Hunter *et al*. (2012) who said pepper and other vegetables grown under limited growth factors tend to make maximum use of such conditions by exhibiting vigorous growth patterns. There was significant difference ($p < 0.05$) among the varieties of pepper in terms of the number of branches. In general, Cayenne recorded the highest number of branches [C_1 (25) and C_2 (41)] perhaps due to its rapid growth habits as it tends to develop more branches to maximize fruit yields (Sinnadurai, 1992).

There was significant difference ($p < 0.05$) between the hardening and non-hardening off with regards to leaf area of the pepper plants with the hardening recording broader leaves than the non-hardening off pepper plants. This could be as a result of the hardened off plants making us of the early exposure to high levels of light and temperature to produce more and broader leaves. This confirms the assertion by Holttum and Enoch (1997) who reported that plants that have access to such favourable growth conditions tend to produce more and broader leaves. There was significant difference among the varieties of pepper in terms of the leaf area with Sweet pepper recording the broadest leaves. The findings support similar ones obtained by Singh *et al*. (2010) who indicated that Sweet pepper thrives best in warm climate during the growing seasons.

Effect of Hardening Off on the Yield Parameter of Pepper Cultivars

Hardened off pepper plants produced more pepper fruits than the non-hardened off ones probably due to early exposure to field conditions which resulted in the hardened off plants getting well-adapted when they were eventually transplanted in the open environment with similar conditions. This might have enabled the plants to grow more vigorously and produce more fruits. Although the results confirm those of Saha *et al*. (2010) who reported that pepper plants could produce different numbers of fruits as a result of variation in the genotype as well as changes in other environmental conditions, they contradict findings of Dhaliwal *et al.* (2017) who asserted that the number of pepper fruits rather increased at lower intensities of light and temperatures.

With regards to the effect of hardening and non-hardening off on fruit diameter, hardening off had greater impact on the diameter of fruits. This is in contrast with research findings of Ryiski and Spigelman (1986a) who obtained shortest fruit diameter (7.1 cm) in screen house and 6.70 cm under the open field conditions. Significant difference was also noticed between the hardening and non-hardening off, with hardening off recording longer fruits. The variation may have occurred as a result of good field establishment of the hardened off pepper plants which falls in line with an assertion by Ajani (2013) that various factors cause good establishment of transplanted seedlings in the field, and these include hardening off of the transplanted seedlings. There was significant difference among the varieties of pepper with respect to fruit length with Cayenne producing the longest fruits, followed by Sweet pepper, while Scotch bonnet recorded the shortest fruits. This could be due to certain superior morphological traits in the Cayenne pepper

plants that enhanced the production of longest fruits when hardened off. This is in agreement with the findings of Ali and Kelly (1982) who stated that fruit weight, length, and diameter were the greatest at the temperature of 25 °C during daytime and 18 °C at night.

The main effects of hardening off and interaction with the pepper varietal effects significantly influenced fruit size of the pepper plants, with hardening off producing bigger fruits than those of the non-hardening off. This could be due to the hardened pepper plants adapting well to field conditions and growing vigorously as well as producing bigger fruits. This confirms results obtained by Jovicich *et al.* (2004) who indicated that pepper plants exposed to favourable field conditions performed optimally in terms of growth and production of larger fruits. There was significant difference ($p < 0.05$) among the varieties of pepper with respect to fruit size. Cayenne produced the biggest fruits, followed by Sweet pepper, and Scotch bonnet recorded the smallest fruits.

Significant differences were noticed between the hardening off and non-hardening off with regards to the fruit weight and yield of pepper in the main and interactive effects, with the hardening recording a heavier and more yields of pepper fruits. This may be due to favourable field conditions which the plants were adapted to when they were transplanted. This is in support of an assertion by Nyarko *et al.* (2011) that higher yields of pepper can be obtained under well-adapted favourable field conditions. There was significant difference ($p < 0.05$) among the varieties of pepper in terms of fruit yield. Cayenne produced the highest fruit yields This could be due to good morphological traits in the Cayenne pepper variety that enhanced its growth and yield under the adapted field conditions. This falls in line with an assertion by Akinfasoye et. *al.* (2018) that Cayenne has the potential of producing high fruit yields of up to 13.07 t ha^{-1} when given the right field treatments. In contrast, In-Kyung *et al*., 2007) identified Scotch bonnet as the pepper variety which, although originated from Mexico, does well under good conditions in Africa, Asia, and countries along the Mediterranean. Delfine *et al*. (2001) also found Sweet pepper to be a higher-yielding variety when subjected to drought and temperature stress.

The Effect of Hardening Off on Quality of Harvested Pepper Fruits

The research findings show that hardening off did not have any effect on the quality of the pepper fruits produced with respect to the colour change, but affected their freshness/firmness. Hardened off pepper fruits performed better and had lower deterioration rate plants beyond 9WAT, with the potential of a longer shelf life, than the non-hardened off pepper plants. The positive impact of hardening off on freshness/firmness suggests that probably the pepper plants that were hardened off got used to the external weather conditions (Masrufa *et al.* 2016 and Wanyonyi, 2019), grew more vigorously and produced healthier fruits with slower rate of spoilage. It also could also be probably due to the fact that hardening off enhanced the field adaptability and morphological features of the pepper plants which led to the improvement in the fruit quality (in terms of freshness/firmness) of the fruits. This supports the research findings of Mavengahama *et al*. (2008) who reported that good field establishment of plants in the field increases their vegetative growth and fruit quality.

CONCLUSION

The results indicate that there were significant differences ($p < 0.05$) between the hardened off and non-hardened off pepper cultivars in all the main effects on growth and yield parameters studied, except fruit diameter and fruit length, as well as the interactions of hardening off and the pepper varieties, with hardening off performing better in almost all the parameters studied. Hardening off also improved fruit quality with

respect to freshness/firmness but did not influence colour change of the fruits. Based on the results of the experiment, hardening off of pepper is recommended for farmers to adopt since it impacts significantly on the growth, yield and quality of the pepper cultivars.

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