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Productivity and phytochemical potential of selected hot pepper varieties cultivated in Tanzania

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Abstract: Hot pepper is a crucial horticultural crop for small-scale farmers in Tanzania, driven by rising demand in domestic and export markets. A study conducted from March to September 2021 evaluated the growth, yield, and bioactive compound concentrations in various hot pepper (*Capsicum* spp.) varieties cultivated at the Botany Department Research Farm, University of Dar es Salaam. The results highlighted significant differences among the varieties. Big Red Cayenne (BRC) was the tallest plant and had the highest yield per hectare (5360 kg). It also had the highest single fruit weight (14.89 g). In contrast, the CCP variety recorded the highest number of fruits per plant (404). Nutritional analysis of ripe-fruit extracts revealed substantial variations in vitamin C, beta-carotene, lycopene, total phenolic content (TPC), and total flavonoid content (TFC). The Orange Bird Eye variety had the highest vitamin C (948.30 ± 22.6 mg/100g) and beta-carotene (0.62 ± 0.006 mg/100 ml) concentrations. BRC exhibited the highest lycopene (0.55 ± 0.0003 mg/100 ml), TPC (454.247 ± 20.9 mg GAE/100g), and TFC (8.92 ± 0.15 mg RE/100g) concentrations, contributing to its highest radical scavenging capacity. Overall, BRC outperformed other varieties in growth and yield, followed by Orange Habanero (OH) and Red Habanero (RH). The study suggests that BRC, OH, and RH varieties are ideal for commercial cultivation in similar ecological conditions. Additionally, BRC's high levels of antioxidants and bioactive compounds make it a promising candidate for developing nutraceuticals and health food products, benefiting the food and pharmaceutical industries, as well as consumers and producers.

Keywords: Hot pepper varieties; Growth and yield performance; Phytochemical, bioactive compounds; antioxidant activity.

Abbreviations: OH_Orange Habanero; RH_Red Habanero; SBH_ Scotch Bonnet Habanero (SBH); BRC_ Big Red Cayenne; ABE1_ African Bird's Eye 1; ABE2_African Bird's Eye; LRC_ Long Red Cayenne; OBE_Orange Bird's Eye hot pepper; CCP_Chiltepin chili peppers; TPC_Total phenolic content; TFC_Total flavonoid content.

Introduction

Hot peppers (chili peppers) are the fruits of herbaceous flowering plants that belong to the family Solanaceae and the genus Capsicum (Othman et al., 2011; Chakrabarty et al., 2017). All Capsicum species originated from the American continents, including northern South America, Central America, the Caribbean islands, Mexico, and the southern United States. Hot peppers have been used as spices to add flavor and spiciness to dishes and as traditional medicines for many centuries, dating back to around 7500 BC (Csillery et al., 2006; Delelegen 2011). Known by various names worldwide, in Tanzania, they are collectively referred to as "pili pili," but they are universally recognized as "hot" or "chili" peppers (Gobie et al., 2019).

Hot peppers thrive in warm seasons and can adapt well to optimal temperatures between 18-30°C, with seeds germinating best at 25-30°C (Chernet and Zibelo, 2019). However, they are sensitive to temperatures below 16°C and above 32°C, and they require moderately high light intensity. They are also sensitive to relative humidity levels below 50% and above 60% (Oh and Koh, 2019). Extreme temperatures and humidity levels can cause the abscission of buds, flowers, and young fruits, significantly affecting growth and yield (Sinha and Petersen, 2011). Suitable agronomic practices, along with favorable genetic and environmental conditions, can lead to optimal growth and high yields of marketable fruits (Quartey et al., 2014). Hot peppers can tolerate a wide range of soil conditions but grow best in sandy loam or clay loam soils rich in organic matter. Proper soil drainage is crucial to prevent water stress, which can lead to bud and flower abscission, thereby reducing yield (Kahsay, 2017).

Hot peppers play a significant role in various aspects of human life, serving as vegetables, spices, and raw materials in various industries worldwide (Andrade et al., 2020). Production and consumption of hot peppers have increased steadily, from 1.4 million tons in 1980 to 4.6 million tons in 2017, with India being the largest producer (FAO, 2019). Other major producers include China, Indonesia, Sri Lanka, Thailand, Japan, Hungary, Spain, and Mexico. In Africa, Ethiopia, Nigeria, and Uganda are notable producers (FAO, 2021). Despite suitable climate and soil conditions, hot pepper production in Tanzania remains low. This may be due to a lack of information on high-yielding, adaptable varieties, poor agronomic practices, and inadequate pest and disease management (Chernet and Zibelo, 2019). Consequently, Tanzania's contribution to global markets is minimal (Maerere, 2014).

To meet the growing global demand for hot peppers and to increase profitability, Tanzanian farmers need to improve production. Key regions for large-scale hot pepper cultivation in Tanzania include Arumeru in Arusha, Muheza in Tanga, Kilolo in Iringa, Mbarali in Mbeya, Mvomero and rural parts of Morogoro, Mkuranga, and Kisarawe in the Coastal region, and Unguja and Pemba in Zanzibar. However, many small-scale farmers grow hot peppers for local markets as a means of income generation (Maerere, 2014). Supporting these small-scale growers with information on high-yielding, adaptable varieties and export market opportunities is essential to overcoming production challenges.

As consumers become more health-conscious, there is a growing preference for natural, plant-based foods over artificial supplements (Chávez-Mendoza et al., 2015). Studies have shown that hot pepper fruits contain high concentrations of bioactive compounds such as vitamin C, beta-carotene, lycopene, total phenolic content, and total flavonoid content, which are powerful antioxidants. However, the levels of these bioactive compounds vary depending on the variety and growing conditions.

Currently, many small-scale farmers in Tanzania use both improved and local varieties, leading to low production of unmarketable fruits. Therefore, more research is needed to provide information that can help improve production. While studies on hot pepper growth and yield have been conducted in countries such as Mexico, Thailand, Bangladesh, Ethiopia, Eritrea, Iran, Ghana, and Nigeria, there has been little research on hot pepper varieties cultivated in Tanzania. Additionally, many studies focus on the nutritional and bioactive compound content in plant foods, with variations attributed to genetics, cultivars, and growing conditions (Chakrabarty et al., 2017). Recent research by Flores-Felix et al. (2021) indicates that phenolic compounds in plant-based foods can inhibit coronavirus from infecting host cells. Understanding the variability in nutrient and antioxidant content among hot pepper varieties can aid farmers, processors, and consumers in selecting varieties with desirable qualities.

Therefore, this study aims to assess nine selected hot pepper varieties cultivated in Tanzania to identify superior varieties with desirable growth, yield characteristics, and bioactive compound content, as well as antioxidant activity under typical field conditions.

Results

Growth characters

The analysis of variance on the growth performance of hot pepper varieties revealed highly significant differences ($p<0.0001$) among the varieties for plant height, plant canopy diameter, days to 50% flowering, first harvest days, and the number of branches produced per plant (Table 1). Significant variations were also observed in the shoot and root dry weight per plant among the different hot pepper varieties.

Plant height

Significant differences in plant height at maturity ($p<0.0001$) were observed among the hot pepper varieties evaluated. Plant heights ranged from 26.4 ± 1.9 cm to 109.3 ± 11.21 cm, with the lowest height recorded for CCP (26.4 ± 1.9 cm) and the highest for BRC (109.3 ± 11.21 cm) (Table 1). According to Tukey's HSD test, the mean values of LRC and SBH varieties, and the mean values for OH, RH, ABE 1, and ABE 2 were not significantly different (Table 3.1). In *C. chinense*, plant heights ranged from 44 ± 6.9 cm to 63.78 ± 17 cm among OH, RH, and SBH varieties, respectively. In *C. annuum*, plant heights ranged from 26.4 ± 1.9 cm to 109.3 ± 11.21 cm among CCP, LRC, and BRC varieties, respectively. In *C. frutescens*, plant heights ranged from 39.3 ± 3.5 cm to 47.2 ± 8.9 cm in OBE, ABE 1, and ABE 2 varieties, respectively.

Plant canopy diameter

Significant differences in plant canopy diameter ($F = 35.72$, $p<0.0001$, $DF = 8$) were observed among the hot pepper varieties evaluated. The highest and lowest plant diameters at maturity were recorded for BRC (101.4 ± 7.6 cm) and CCP (38 ± 2.3 cm), respectively (Figure 3.1). According to Tukey's grouping, the means of ABE1 and OBE were not significantly different (Table 1). In *C. annuum*, plant diameters ranged from 38 ± 2.3 cm (CCP) to 101.4 ± 7.6 cm (BRC). In *C. chinense*, plant diameters ranged from 78 ± 13 cm (OH) to 88 ± 8 cm (SBH). In *C. frutescens*, plant diameters ranged from 48 ± 4 cm (OBE) to 56 ± 15 cm (ABE 2).

Number of branches per plant

Significant differences in the number of primary, secondary, and tertiary branches produced per plant ($F = 8.27$, $p<0.0001$, $DF = 8$) were observed among the hot pepper varieties. Mean values of the number of branches per plant varied from 13 ± 3 (OBE) to 29 ± 7 (OH). Tukey's HSD test revealed that the mean values of OH, RH, and SBH (denoted by "A") and those of ABE 2, CCP, ABE 1, and LRC (denoted by "B") were not significantly different (Table 3.1). In *C. annuum*, the number of branches per plant varied from 19 ± 4 (BRC) to 24 ± 2 (CCP). In *C. chinense*, the number of branches ranged from 28 ± 6 (RH) to 29 ± 7 (OH). In *C. frutescens*, the number of branches ranged from 13 ± 3 (OBE) to 26 ± 6 (ABE 2).

Shoot and root dry weight (g)

Table 1. General results from analysis of variance on growth traits among hot pepper varieties.

Variety	PL (cm)	PCD (cm)	D-50% FL	FRSD	FHD	NBP
OH	44 ± 6.9^{C}	78 ± 13^{BC}	64 ± 2^{C}	49 ± 3^{D}	93 ± 1^{E}	29 ± 7^{A}
RH	46.9 ± 13^{C}	80 ± 11^{BC}	61 ± 2^{D}	62 ± 4^{C}	95 ± 2DE	28 ± 6^{A}
SBH	63.78 ± 17^{B}	88 ± 8^{BA}	67 ± 2^{C}	65 ± 4^{C}	97 ± 2DE	28 ± 7^{A}
BRC	109.3 ± 11^{A}	101 ± 8^{A}	64 ± 2^{C}	54 ± 5^{D}	99 ± 7^{DC}	19 ± 4^{BC}
ABE 1	47 ± 9.04^{C}	51 ± 16^{FE}	74 ± 1^{B}	96 ± 2^{A}	103 ± 4^{C}	23 ± 6^{BA}
ABE 2	47.2 ± 8.9^{C}	56 ± 15DE	80 ± 2^{A}	64 ± 2^{C}	100 ± 3^{DC}	26 ± 6^{BA}
LRC	68.9 ± 8.9^{B}	69 ± 9^{DC}	74 ± 2^{B}	84 ± 1^{B}	126 ± 3^{A}	23 ± 4^{BA}
OBE	39.3 ± 3.5^{DC}	48 ± 4^{FE}	71 ± 3^{B}	66 ± 2^{C}	119 ± 5^{B}	13 ± 3^{C}
CCP	26.4 ± 1.9^{D}	38 ± 2^{F}	65 ± 2^{C}	63 ± 9^{C}	97 ± 3DE	24 ± 2^{BA}
P value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
F value	53.25	35.72	92.56	111.89	81.39	8.27
DF	8	8	8	8	8	8

PL = plant length at maturity, PCD = plant canopy diameter, D-50% FL = days to 50% flowering, FRSD = fruit setting days, FHD = first harvest days, and NBP = number of branches per plant. OH = Orange habanero; RH = Red habanero; SBH = Scotch Bonnet habanero; BRC = Big red cayenne hot peppers; ABE1&ABE2 = African bird's eye variety 1 and 2; LRC = Long red cayenne; OBE = Orange bird's eye and CCP = Chiltepin pepper hot peppers. Mean values with superscript alphabetical letters represent Tukey's honestly significant difference (HSD); where, the means denoted with similar letters are considered not significantly different at p< 0.05.

Table 2. Yield performance of hot pepper varieties on the major attributes assessed.

Variety	NFRP	SFRW (g)	NS/FR	SW (g)
OH	79 ± 16^{D}	13.4 ± 2^{A}	76 ± 9^{B}	0.32 ± 0.03^{DC}
RH	74 ± 19^{D}	11 ± 0.9^{B}	71 ± 6^{B}	0.33 ± 0.04^{C}
SBH	138 ± 27^{C}	5.2 ± 0.8^{C}	46 ± 6^{D}	0.25 ± 0.03^{E}
BRC	72 ± 23^{D}	14.9 ± 2.6^{A}	87 ± 6^{A}	0.67 ± 0.07^{A}
ABE 1	277 ± 48^{B}	0.5 ± 0.07^{E}	26 ± 3^{FE}	0.25 ± 0.04^{E}
ABE 2	315 ± 53^{B}	0.75 ± 0.08^{E}	30 ± 2^{E}	0.27 ± 0.03^{DE}
LRC	89 ± 13^{DC}	3.5 ± 0.2^{D}	57 ± 3^{C}	0.22 ±0.03^{E}
OBE	39.6 ± 4^{D}	6.3 ± 0.4^{C}	85 ± 5^{A}	0.52 ± 0.03^{B}
CCP	404 ± 68^{A}	0.4 ± 0.01^{E}	20 ± 1.4^{F}	0.09 ± 0.01^{F}
P value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
F value	118.85	224.89	239.86	182.99
DF	8	8	8	8

NFRP: number of fruits yield per plant; SFRW: single fruit weight; NS/FR: number of seeds per fruit; SW: seed weight (g) per variety. The mean values with superscript alphabetical letters indicate Tukey's honestly significant difference (HSD); where means with similar letters are not considered significant different at p < 0.05.

Significant differences in shoot and root dry weight (F = 369.81, p<0.0001, DF = 8) were observed among the hot pepper varieties. The highest average weight of dry shoot and root was recorded for BRC (129 g per plant) and the lowest for CCP (26 g). In *C. annuum*, dry weights ranged from 26 g (CCP) to 129 g (BRC). In *C. chinense*, dry weights ranged from 68.3 g (OH) to 91.3 g (SBH). In *C. frutescens*, dry weights ranged from 40.7 g (OBE) to 66 g (ABE 1).

Yield and yield-related parameters

The analysis of variance indicated significant differences (p<0.0001) among hot pepper varieties in terms of the number of fruits yield per plant, single fruit weight, number of seeds per fruit, average seed weight per variety, and total fresh fruit yield per hectare (Table 2).

Number of fruits per plant

Significant differences in the number of fruits yield per plant (F = 118.85, p<0.0001, DF = 8) were observed among the hot pepper varieties. The highest number of fruits per plant was recorded for CCP (404 fruits) and the lowest for OBE (40 fruits). Tukey's HSD test indicated that some varieties (OH, RH, BRC, and OBE; ABE1 and ABE2) were not significantly different. In *C. annuum*, the number of fruits per plant varied from 72 (BRC) to 404 (CCP). In *C. chinense*, the number of fruits per plant ranged from 74 (RH) to 138 (SBH). In *C. frutescens*, the number of fruits per plant varied from 40 (OBE) to 315 (ABE 2).

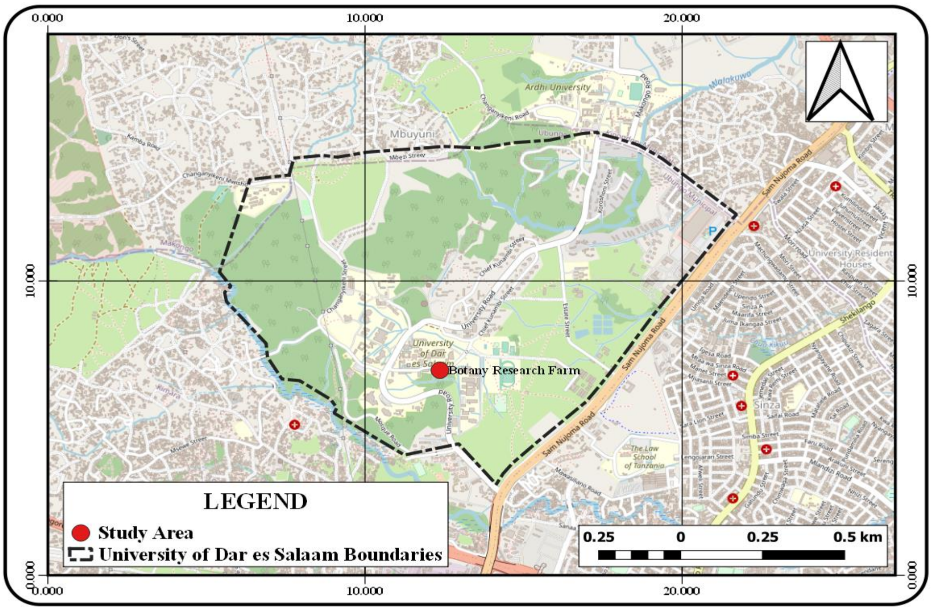

Figure 1. Study area showing Department of Botany Research Farm at University of Dar es Salaam.

Figure 2. Pictures of hot pepper fruits used to extract seeds used for the study. OH = Orange Habanero; RH = Red Habanero; SBH = Scotch Bonnet Habanero; BRC = Big Red Cayenne; ABE1 = African Bird's Eye; ABE2 = African Bird's Eye; LRC = Long Red Cayenne; OBE = Orange Bird's Eye hot pepper and CCP = Chiltepin chili peppers.

Single fruit weight

Significant differences in single fruit weights were observed among the hot pepper varieties. The highest single fruit weight was recorded for BRC and the lowest for CCP. In *C. annuum*, single fruit weights ranged from 0.4 g (CCP) to 14.89 g (BRC). In *C. chinense*, single fruit weights ranged from 5.26 g (SBH) to 13.44 g (OH). In *C. frutescens*, single fruit weights ranged from 0.49 g (ABE1) to 6.32 g (OBE).

Total yield per hectare (t/ha)

Significant variations in total fresh fruit yield (kg/ha) were observed among the varieties. In *C. annuum*, total yield varied from 5360.4 kg/ha (BRC) to 808 kg/ha (CCP). In *C. chinense*, total yield varied from 5308.8 kg/ha (OH) to 3629.4 kg/ha (SBH). In *C. frutescens*, total yield varied from 1264 kg/ha (OBE) to 676.2 kg/ha (ABE 1). Generally, yield was higher in C. chinense, followed by *C. annuum*, with the lowest yield in *C. frutescens*.

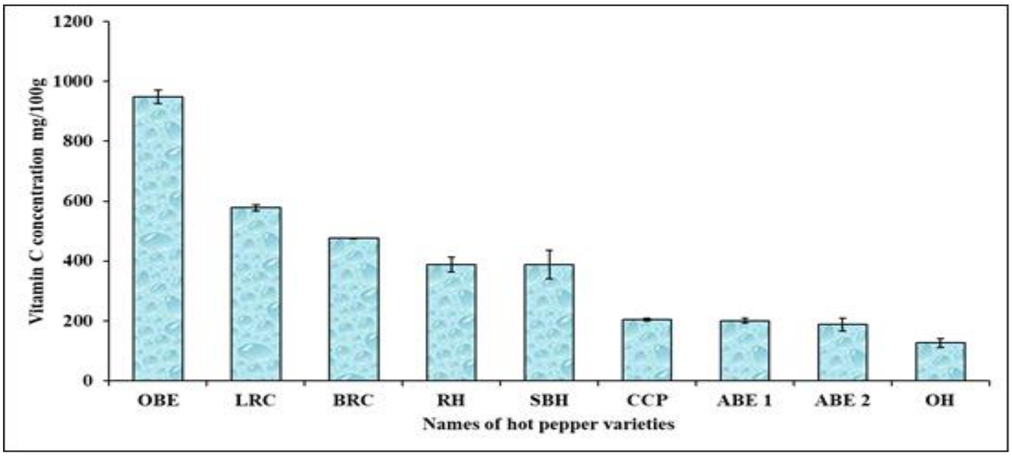

Figure 3. The variation in concentration of vitamin C observed in the hot pepper fruit extracts OH = Orange Habanero; RH = Red Habanero; SBH = Scotch Bonnet Habanero; BRC = Big Red Cayenne; ABE1 = African Bird's Eye; ABE2 = African Bird's Eye; LRC = Long Red Cayenne; OBE = Orange Bird's Eye hot pepper and CCP = Chiltepin chili peppers.

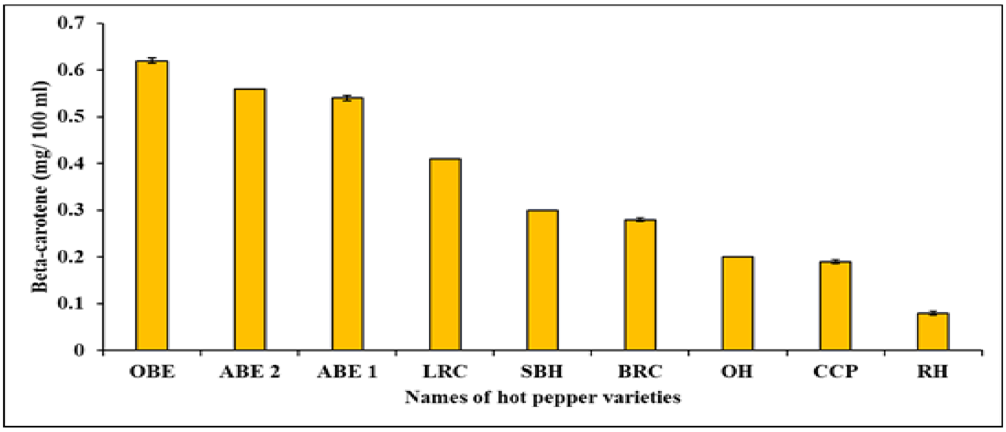

Figure 4. The variation in beta-carotene contents in hot pepper varieties OH = Orange Habanero; RH = Red Habanero; SBH = Scotch Bonnet Habanero; BRC = Big Red Cayenne; ABE1 = African Bird's Eye; ABE2 = African Bird's Eye; LRC = Long Red Cayenne; OBE = Orange Bird's Eye hot pepper and CCP = Chiltepin chili peppers.

Bioactive compounds

Vitamin C

Significant differences in vitamin C concentration ($p<0.0001$) were observed among the hot pepper varieties (Figure 3). In C. annuum, vitamin C concentration ranged from 204.39 ± 5.3 mg/100 g (CCP) to 577.83 ± 10.74 mg/100 g (LRC). In *C. frutescens*, vitamin C concentration ranged from 87.9 ± 20.77 mg/100 g (ABE2) to 948.30 ± 22.6 mg/100 g (OBE). In *C. chinense*, vitamin C concentration ranged from 127.05 ± 14.96 mg/100 g (OH) to 388.73 ± 24.33 mg/100 g (RH). On average, the highest concentration of vitamin C was found in *C. annuum* varieties, followed by *C. frutescens*, with *C. chinense* having the lowest content.

Beta-Carotene

Significant differences in beta-carotene concentration ($p<0.0001$) were observed among the hot pepper varieties (Figure 4). In *C. frutescens*, beta-carotene content varied from 0.54 mg/100 ml (ABE1) to 0.62 mg/100 ml (OBE). In *C. annuum*, beta-carotene content ranged from 0.19 mg/100 ml (CCP) to 0.41 mg/100 ml (LRC). In *C. chinense*, beta-carotene content ranged from 0.07 mg/100 ml (RH) to 0.30 mg/100 ml (SBH).

Lycopene

Significant differences in lycopene concentration ($p<0.0001$) were observed among the hot pepper varieties (Figure 5). The concentration of lycopene decreased from deep-red to light-red and finally to orange fruits. On average, the highest lycopene content was recorded in *C. annuum* varieties, followed by *C. frutescens*, with *C. chinense* having the lowest content.

Total phenolic content (TPC)

High variations were observed on the content of TPC ($p<0.0001$) among the hot pepper varieties evaluated (Figure 6). At species level, the amount of TPC found in the hot pepper fruits extracts decreased in the following manner: in *C. annuum,* the concentration ranged from 454.247 ± 20.9 (BRC) >447.880 ± 14.6 (CCP)>301. 417 ±12.08 (LRC)mg GAE/ 100g of extracts. In *C. chinense*, the content varied from 374.98 ± 23.5 (RH) >296.807 ± 1.84 (OH) > 260.35 ± 1.32 (SBH) mg GAE/ 100g of extracts. In *C. frutescens*, the concentration varied from 288.13 ± 21.98 (ABE 2) > 271.99 ± 3.79(ABE 1 > 236.197 ± 7.81 (OBE) mg GAE/ 100g of extracts.

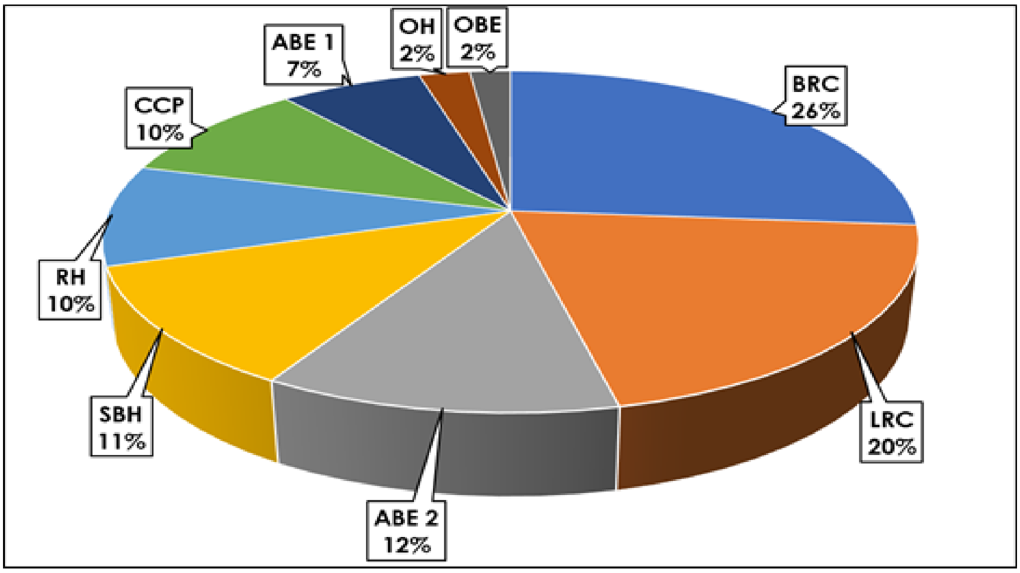

Figure 5. Variation in concentration of lycopene in hot pepper extracts. OH = Orange Habanero; RH = Red Habanero; SBH = Scotch Bonnet Habanero; BRC = Big Red Cayenne; ABE1 = African Bird's Eye; ABE2 = African Bird's Eye; LRC = Long Red Cayenne; OBE = Orange Bird's Eye hot pepper and CCP = Chiltepin chili peppers.

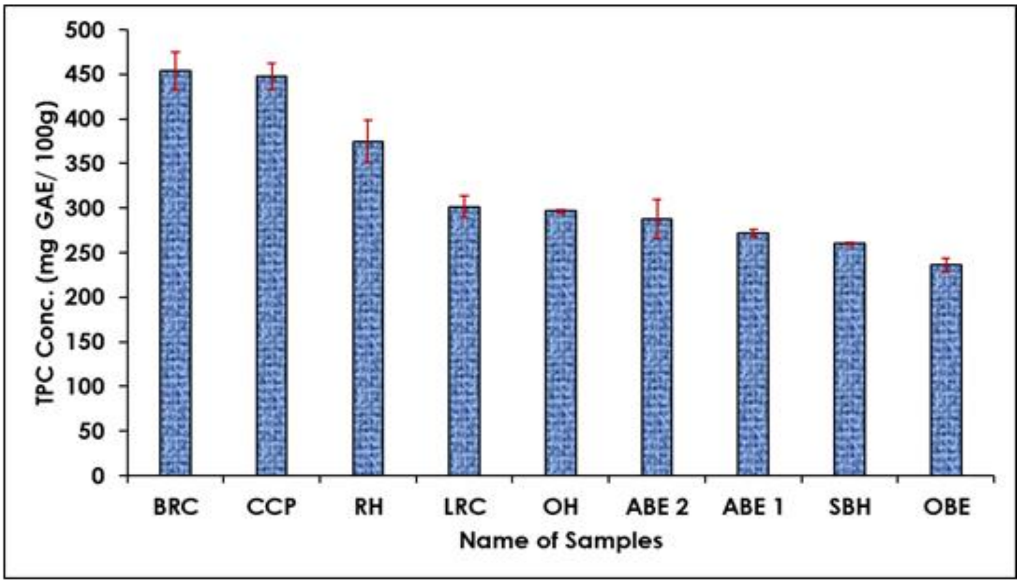

Figure 6. Total phenolic contents in hot pepper fruits extract solutions OH = Orange Habanero; RH = Red Habanero; SBH = Scotch Bonnet Habanero; BRC = Big Red Cayenne; ABE1 = African Bird's Eye; ABE2 = African Bird's Eye; LRC = Long Red Cayenne; OBE = Orange Bird's Eye hot pepper and CCP = Chiltepin chili peppers.

Total flavonoid content (TFC)

The analysis of variance indicated that there were high significant differences on the TFC content ($p<0.0001$) among hot pepper varieties evaluated (Figure 7). The observation at species level indicated that *C. annuum* varieties: BRC, LRC and CCP the TFC content varied from 8.92 ± 0.15 mg RE/ 100g,5.27 ± 0.08 mg RE/ 100g and 4.46 ± 0.08 mg RE/ 100grespectively. In *C. chinense*varieties: SBH, OH and RH the TFC concentration varied from 7.2 ± 0.06 mg RE/ 100g, 6.25 ± 0.07 mg RE/ 100g and 4.04 ± 0.17 mg RE/ 100g as recorded, respectively. In *C. frutescens* varieties: OBE, ABE 2 and ABE 1 the TFC concentration varied from 6.55 ± 0.3 mg RE/ 100g), 5.95 ± 0.04 mg RE/ 100g to 4.40 ± 0.06 mg RE/ 100g respectively.

DPPH radical scavenging activity

The results obtained from DPPH radical scavenging activity assay were expressed in terms of the lowest concentration of antioxidant required to scavenge 50% of DPPH free radicals (LC_{50}). The sample extracts with the lowest LC_{50} value were considered as varieties with the greatest antioxidant capacity. The findings from this study revealed that BRC variety had the smallest LC_{50} value and followed by CCP, OBE, OH, LRC and SRH compared to the ascorbic acid (AA) used as antioxidant standard (Figure 8).

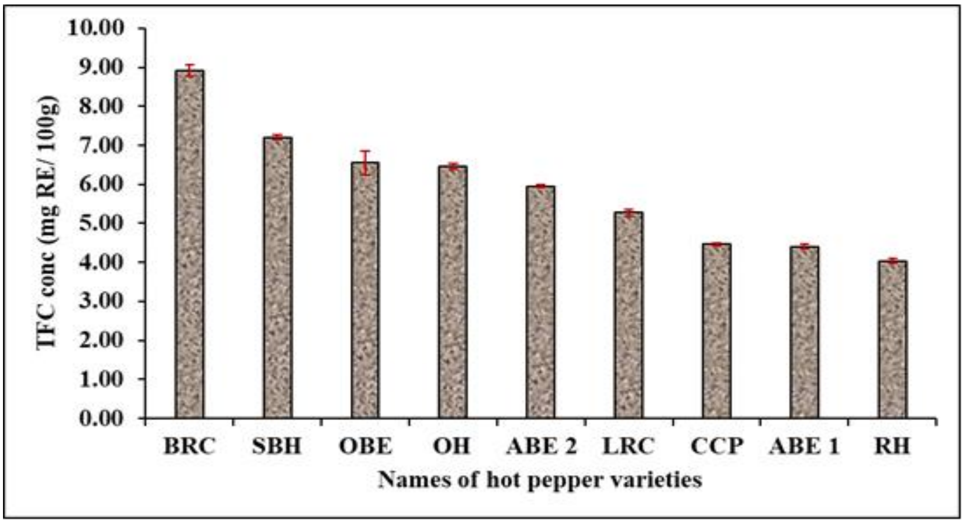

Figure 7. Total flavonoid contents in the hot pepper fruits extract solutions. OH = Orange Habanero; RH = Red Habanero; SBH = Scotch Bonnet Habanero; BRC = Big Red Cayenne; ABE1 = African Bird's Eye; ABE2 = African Bird's Eye; LRC = Long Red Cayenne; OBE = Orange Bird's Eye hot pepper and CCP = Chiltepin chili peppers.

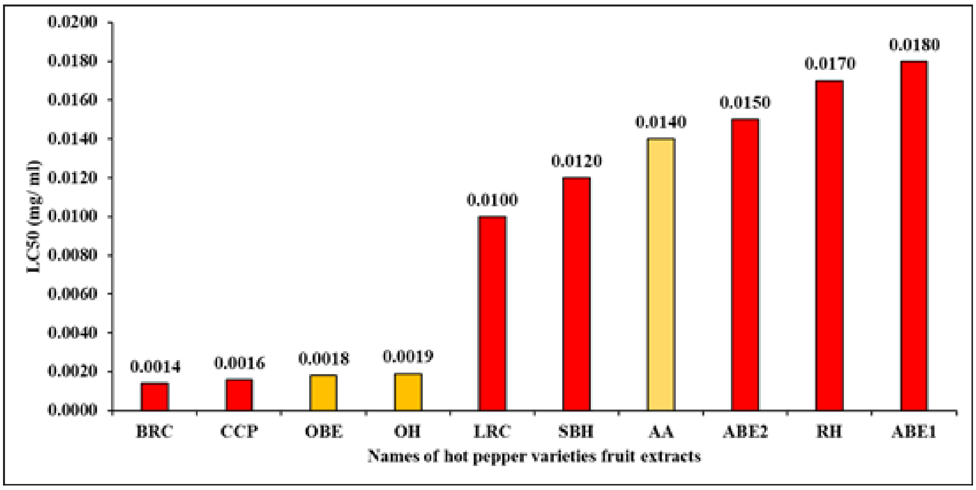

Figure 8. Variation in LC_{50} values for hot pepper fruit extracts. AA OH = Orange Habanero; RH = Red Habanero; SBH = Scotch Bonnet Habanero; BRC = Big Red Cayenne; ABE1 = African Bird's Eye; ABE2 = African Bird's Eye; LRC = Long Red Cayenne; OBE = Orange Bird's Eye hot pepper and CCP = Chiltepin chili peppers.

Discussion

Growth characters

High significant differences were observed on plant height (cm) and plant canopy diameter (cm) among hot pepper varieties could be due to inherited traits and availability of nutrients, moisture in the soil and temperature at the growing area. Plant height and diameter are associated with vegetative growth and yield performance of plants. The plant height and canopy diameter are associated with high yield because taller and wider plants are connected with an increase of the number of branches per plant, which increase the number of reproductive nodes at which fruits are produced. These findings are parallel with results reported by Fanwoua et al. (2014) and Herison et al. (2015) that greater number of branches per plant provides greater chances for higher number of flowers per plant and greater opportunity for a higher number of fruits yield per plant. The number of branches per plant depends on the varieties which indicate that their variations are due to genetic differences among the varieties. A study conducted by Andrade et al. (2020) showed that variabilities observed in *C. annuum, C. chinense* and *C. frutescens* species are difficult to separate because they share many features including plant height and canopy diameter. Therefore, taller and wider plants due the dynamic vegetative growth provide strong sources to support high yield, although major variations in growth and yield are under genetic control of each variety.

The variation in days to 50% flowering, fruit setting and first harvest days could also be due to genetic background of the hot pepper varieties and ecological conditions at the growing area. The findings are in line with Delelegn et al. (2014) report that high significant different on days to 50% flowering, days to first harvest, number of fruits per plant could be due to differences in genotypes among the hot pepper varieties involved in the study. The earliness or lateness to attain days to 50% flowering, fruit setting and first harvest days might be due to genetic which control the time required to familiarize to the growing area before initiating growth and development (Oh and Koh, 2019). Also, the variations could occur due to high abscission of buds and flowers due to high temperatures; particularly, during daytime. Oh and Koh (2019) stated that fruit formation can be late due to high abscission rates of buds and flowers caused by high temperatures above the optimum levels for the crop. The information for days to 50% flowering and first days to harvest are important attributes in determining the early maturity of the crop and in the selection of suitable varieties for commercial cultivation (Nsabiyera et al., 2012).

Significant differences observed on shoot and root dry weights among the varieties of hot pepper varieties could be due to genetic background of the varieties and availability of nutrients, moisture and other conditions at the growing area. From this study, it was observed that varieties with high shoot and root dry weights have high yielding capacity than those with low shoot and root dry weights. That is, plants with high shoot and root dry weights showed high vegetative growth during development and high yield because they had ability to compete more efficiently for soil nutrients, minerals and water. These outcomes were in consistent with Khaitov et al. (2019) results reported that high proportion of shoots help plants to capture more sunlight-energy and increase photosynthetic reactions and are more resistant to stresses such as drought and low level of nutrients in the soil. The differences in plant shoot and root dry weights could be due to genetic variations of hot pepper varieties that are influenced by environmental conditions such assoil type, nutrients, light, temperature and humidity. Therefore, plant shoot and root dry weights are among the parameters for important selection of varieties for sustainable cultivation.

Yield parameters

The significant variation observed on yield could be due to genetic differences among the hot pepper varieties and due to environmental conditions. In this study, it was observed that varieties with small fruits produced large numbers of fruits while varieties with large fruits produced low numbers of fruits. Yield is attributed to various components such as number of fruits per plant, single fruit weight (a function of fruit size, seed number per fruit and seed weight). The number of seeds and seed weight per fruits directly affect the single fruit weight. The results conform to the results reported by Abdul-Rafiu et al. (2019) that the size and number of fruits produced per plant cannot go beyond the plant fruit carrying capacity. Thus, the differences on the number of fruits yield per plant and total yield per hectare among the hot pepper varieties could be due to genetic make-up as well as the effect of environmental conditions. The associated traits such as plant height and diameter, number and size of branches could have associated with the number of flowers produced per plant and fruits yield. Similar results were reported by Kahsay et al. (2017) and Herison et al. (2015) that greater number of branches might provide opportunity for a higher number of fruits yield per plant.

The total yield per plant and per hectare were determined by using number of fruits yield per plant and single fruit weight which is the result of seed number per fruit and seed weight. The variations on single fruit weights could be due to the difference in the abilities of plants to absorb the nutrients from the soil, particularly when the nutrients are inadequate amounts; that might affect seed number per fruit and seed weight. The findings supported results reported by Delelegen (2011) that seeds of high weight could be those received higher proportion of photosynthetic assimilate. Also, the results are in line with the findings reported by Tesfaw et al. (2013) that larger sized fruits are directly related to the amount of nutrients taken from the soil. The seed number and weight are important components as they contribute to single fruit weight and fruit yield is determined by the quantities of fruits produced per plant. This indicates that number of fruit yield per plant and single fruit weight are the most important yield components. Therefore, any improvement in agronomic practices related to the increase in fruit numbers, number of seeds and seeds weight might increase yield in the hot pepper varieties per hectare.

Vitamin C (Ascorbic acid)

The results obtained from this study suggest that hot peppers are an excellent source of vitamin C. Highest amount of vitamin C was recorded from OBE variety and followed by LRC and BRC varieties. However, all varieties evaluated contained higher amounts indicating that the some of the selected hot pepper varieties cultivated in Tanzania are composed of higher amounts of vitamin C. Even the lowest amount (127.05 ± 14.96 mg/100g) recorded from OH variety exceeded the recommended daily amount of 60 mg/100g (Chaves-Mendoza et al. 2015). These results are consistent with the findings reported by Korkutata and Kavaz (2015) and Hamed et al. (2019). Also, the results are in line with findings reported by Palma et al. (2014) who stated that hot peppers contained higher amounts of vitamin C compared to many other types of fruits. Kantar et al. (2016) stated that some hot pepper varieties have higher amount of vitamin C as twice as the concentration found in tomatoes, apples and oranges per gram of fruit weight.

Vitamin C is an essential dietary nutrient for various biological functions in human health and well-being. It is a powerful antioxidant; an excellent free radical scavenger molecule. It can act as a cofactor for several important biosynthesis numerous enzymes involved in plant and human metabolism (Chaves-Mendoza et al., 2015). Increasing consumption of vitamin Crich foods and spices would help to strengthen body’s immunity and prevent the development of many diseases (Slowianek and Leszczynska, 2016; Desai et al., 2019). High intake of vitamin C rich food has been linked with reduced risk of several types of cancer in the laboratory tests in animals (Groso et al., 2013). Therefore, high concentration of vitamin C found in the selected hot pepper varieties indicated that the crop can be used to improve nutritional qualities of hot pepper consumers in the society.

Beta-carotene (Pro-vitamin A)

The results obtained from this study, showed that beta-carotene content in the hot pepper varieties depends strongly on the variety. The varieties of hot peppers evaluated indicated that on average, a greater content of beta-carotene was found in *C. frutescens* varieties and followed by the content found in *C. annuum* and the *C. chinense* varieties had the lowest beta-carotene content. The concentration of beta-carotene was higher in orange and bright red peppers - bird eye varieties. These results conform with findings reported by Aremu and Nweze (2017) and Villa-Rivera et al. (2020) that levels of beta-carotene in hot peppers depends on the variety and environmental conditions at the growing area, experimental conditions, extraction procedures and method used. The main purpose of studying beta-carotene is due to its properties, such as provitamin A, immune improvement agent and powerful antioxidant, which help to neutralize a wide range of free radicals through electron transfer process. Beta-carotene molecules also have been extensively investigated as possible cancer preventive agents; however, the greatest benefits are obtained when these compounds are consumed along with other phytochemicals in whole foods and not from expensive dietary supplements (Chávez-Mendoza et al., 2015).

Lycopene

The results showed that dark-red hot pepper fruits contain higher amount of lycopene than medium red fruits and orange hot pepper fruits evaluated (Figure 3). These results are parallel with findings reported by Adebisi et al. (2014) that concentration of lycopene was high in red hot peppers. The compound is mostly present in most red fruits such as tomatoes and contributes to antioxidant activities and maintenance of human health (Martinez-Ispizua et al. 2021).The variation observed in the content of lycopene could be due to genetic differences among the hot pepper varieties, agronomic practices and influence of environmental conditions at the growing area. The knowledge of the variability of bioactive contents among hot pepper cultivated in Tanzania is necessary because it might help farmers, processors and consumers in the identification and selection of high-quality varieties to improve production and nutrition in the society. The increased interest in lycopene, has grown rapidly due to many studies which suggest that the compound has important role in the human health and disease. Lycopene is said to be non-toxic and has antioxidant, anti-inflammatory and chemotherapeutic effects, in cardiovascular or neurodegenerative disease and in some cancer. Lycopene seems to be the most efficient in neutralizing singlet oxygen free radicals compared to the other common carotenoids due to its unique chemical properties. It cannot be converted to vitamin A; therefore, it is completely available for other properties such as antioxidant activities (Chaves-Mendoza et al., 2013).

Total phenolic content (TPC)

The results obtained in this study showed that on average, a greater content of TPC was recorded from *C. annuum* varieties then followed by *C. chinense* and the lowest average was recorded from *C. frutescens* varieties. These results agree with the findings reported by Aryal et al. (2019) that TPC content depended on the variety; that is the variations in the TPC in the hot pepper fruit extracts evaluated could be due to genetic difference of the varieties. But also, climatic and soil conditions at the growing area could affect the concentration of the bioactive compounds. During preparation, the extraction solvent used and method used for analysis could also contribute to the variations in the quantity obtained from each variety. The amount of TPC in the extract is directly related to the antioxidant properties which allow the extracts to act as antioxidants (Phuyal et al., 2020). Thus, if significant amount of TPC is present, the plant extract might be suitable to be used as herbal medicine (Johari and Khong 2019).

Total phenolic contents (TFC)

The TFC amounts obtained from this study showed greater variation among the hot pepper varieties evaluated. On average, a greater content of TFC was recorded in *C. annuum* varieties and followed by the concentration obtained from *C. chinense* varieties and *C. frutescens* varieties had the lowest concentration. These results supported findings by Pavun et al. (2018) and Phuyal et al. (2020) who stated that the variation on the content of bioactive compounds could be due to genetic variability among the varieties; but also, other factors such as soil type, fertilization, climatic conditions, geographic origin, preparation and determination method used. The results revealed that there are fluctuations in the levels of TFC and the levels of TPC are always higher than that of TFC. Maisuthisakul et al. (2005) described these differences in concentrations between TPC and TFC in extracts that flavonoid levels are always lower because they are part or portion of the TPC. Flavonoids are important compounds synthesized by plants as secondary metabolites and have properties such as antioxidant, anticancer, anti-inflammatory, anti-allergic, antiviral, anticarcinogenic and antibacterial, pharmacological, therapeutic and cytotoxic properties among others. They are powerful antioxidants and have free radical scavenging capacities and can prevent coronary heart diseases, inflammatory diseases and various types of cancer. Recently, flavonoid compounds have been proved that they can prevent possible antiviral activities (Annunziata et al. 2020).

Antioxidant activity

The results obtained from DPPH RSA test showed that antioxidant activity of hot pepper fruit extracts depended on the variety and concentration of TPC, TFC and vitamin C. On average, at species level, *C. annuum* varieties have a lowest LC_{50} value, followed by *C. chinense* varieties and *C. frutescens* varieties have the highest LC_{50}value.Higher LC_{50} indicate that the extract has lower the antioxidant capacity and lower LC_{50}value showed that the extract has greater antioxidant capacity. On the other hand, hot pepper fruit extracts contained lower concentrations of both TPC, TFC and vitamin C such as ABE1 had the lowest radical scavenging capacity. Presence of higher amounts of TPC, TFC and vitamin C, directly related with higher antioxidant capacities of hot pepper fruit extracts assessed. These results supported the findings reported by several researchers such as Phuyal et al. (2020) who stated that presence of total phenolic content (TPC) in any plant extract, directly related to their antioxidant properties. Maisuthisakul et al. (2007) and Chavan et al. (2013) also stated that the presence of significant amount of TPC in fruit extracts contributed to high antioxidant activity of the plant materials sample extracts.

Growth characteristics

The analysis of variance on the growth performance of hot pepper varieties revealed highly significant differences (p<0.0001) among the varieties for plant height, plant canopy diameter, days to 50% flowering, first harvest days, and the number of branches produced per plant (Table 1). Significant variations were also observed in the shoot and root dry weight per plant among the different hot pepper varieties.

Materials and Methods

Study area
This study was conducted at the Department of Botany Research Farm, University of Dar es Salaam (UDSM), Tanzania. The study was conducted from March to September, 2021. The field is located at latitude 6°46'50" S and longitude 39°12'12" E (www.udsm.ac.tz). The area has tropical climate with high temperatures and relative humidity ranging from 19°C to 32.5°C and 74% to 84%, respectively (https://www.udsm.ac.tz). It normally receives average rainfalls above 1000 mm per year which occurs in short and long rainy seasons from October to December and March to May respectively with some fluctuations.

Experimental materials
The hot pepper varieties were collected from local farmers at different places; they included: Orange Habanero (OH) variety obtained from Kigamboni, Dar es Salaam and Mbulu, Manyara; Red Habanero (RH) from Mazinde-Ngua in Korogwe district, Tanga; Scotch Bonnet Habanero (SBH) obtained from Ubungo, Dar es Salaam; Big Red Cayenne (BRC) obtained from Kigamboni, Dar es Salaam; African Bird's Eye (ABE1)was collected from Kigamboni, Dar es Salaam; African Bird's Eye (ABE 2) from Kwesine - Lushoto, Tanga; Long Red Cayenne (LRC) obtained from Kwesine – Lushoto, Tanga; Orange Bird's Eye hot pepper (OBE) obtained from Mbelei – Lushoto, Tanga and Chiltepin chili peppers (CCP) obtained from Ubungo, Dar es Salaam (Plate 1). The seeds extracted from the hot pepper fruits collected from farmers were sown in plastic containers containing a mixture of soil, compost manure and sand soil in the ratio of 3:2:1. The seedlings were transplanted to the field when they had 5 to 7 leaves. At the field, they were uniformly supplied with water and nutrients and other agronomic practices. Weeding was done manually whenever required in order to control weed growth.

Experimental design
The design used in this study was Completely Randomized Design (CRD) with three replications. Two hot pepper plants from the middle row and one plant at the side row of each plot were selected as sample plants. The plants at the side edges of each plot were not selected in order to minimize edge effects (Tesfaw et al., 2013). From each variety, nine sample plants were used to collect samples. The fresh and ripe hot pepper fruits randomly picked from the sample plants were taken to the laboratory and were cleaned pure water in order to remove any dirt. Then, fruit extracts were prepared and used to measure vitamin C, beta-carotene, lycopene, total phenolic and flavonoid contents, and antioxidant capacity.

Data collection
From the sample plants selected for data collection, growth and yield performance information were collected by using the following parameters: plant height, plant diameter, number of branches per plant, days to 50% flowering, fruit setting days, first harvest and shoot and root dry weights for growth. Where number of fruits per plant, single fruit weight, seeds number per fruit, seeds weight per fruit and total yield per hectare were used collect data for yield and yield-related traits.

Bioactive compounds determination

Vitamin C
Determination of vitamin C content in the hot pepper fruit extracts carried out by using a method described by Adebisi et al. (2014) and Desai et al. (2019) with modification; where extraction was done by using hot distilled water, and ascorbic acid was used as the standard. Before the analysis, 2 ml of each sample extract solution, 2 ml of standard solution and 2 ml of blank solution (distilled water) were measured by using a measuring cylinder and placed into separate 25 ml capacity flasks. Then, 2 ml of sulphuric acid (10% v/v) was added and followed by 5 ml of ammonium molybdate (10% w/v). The mixtures were vortex mixed and allowed to stand for 50 minutes at room temperature for color development. Each mixture was further diluted with distilled water to obtain 25 ml final volume. The absorbances of samples and standard solutions were measured at 450 nm against the blank by using a spectrophotometer. Standard absorbances were plotted to obtain a calibration curve and equation. The calibration equation was then used to calculate concentration of vitamin C in each sample extract solution. The results were reported in mg/100grams of the sample.

Beta-carotene and Lycopene
Beta-carotene and lycopene contents were determined in the hot pepper fruit extracts by using a method described by Barros et al (2007).

Total phenolic content (TPC)
Total phenolic contents (TPC) in hot pepper fruit extracts were determined by using Folin-Ciocalteu colorimetric method which base on oxidation-reduction reaction described by Phuyal et al. (2020).

Total flavonoid content (TFC)
The TFC were estimated by using aluminum chloride colorimetric assay described by Rahman et al. (2015).

Antioxidant capacity
TheDPPH free radical scavenging activity assay described by Rahman et al. (2015) and Phuyal et al. (2020)

Statistical analysis
All analyses were performed in triplicated. The results were analyzed by a One-wayAnalysis of Variance (ANOVA) and a comparison of means was made by Tukey's test with the help of SAS (Statistical Analysis Software of 1999) version 8.0. The means were accepted as significantly different at a 95% confidence interval ($p \leq 0.05$).

Conclusions

Among the nine hot pepper varieties evaluated, the Big Red Cayenne outperformed the others in terms of plant height, plant width, days to 50% flowering, days to first harvest, shoot and root dry weight, fruit size, single fruit weight, and total yield per hectare. However, varieties with smaller and lighter fruits recorded a higher number of fruits per plant. Overall, the Big Red Cayenne variety excelled in all these traits, followed by the Orange Habanero, Red Habanero, and Scotch Bonnet Habanero. These varieties appear to be suitable for sustainable and profitable cultivation in the studied area. Additionally, the study revealed differences in the content of bioactive compounds and antioxidant activity among the nine selected hot pepper varieties cultivated in Tanzania. Vitamin C content was determined in fresh ripe hot pepper fruit extracts. Beta-carotene and lycopene were measured in dried ripe fruit extracts, while total phenolic content (TPC) and total flavonoid content (TFC) were assessed in thick and viscous ripe fruit extracts. Big Red Cayenne had the highest concentrations of TPC, TFC, and lycopene, and also showed high amounts of vitamin C. The Orange Bird's Eye variety exhibited the highest concentrations of vitamin C (ascorbic acid) and beta-carotene, as well as a high amount of TFC. The Orange Habanero presented high amounts of TFC and TPC. Varieties with the highest content of bioactive compounds also showed the greatest antioxidant activity, in the order of BRC > CCP > OBE > OH. The significant amounts of TPC and TFC in the fruit extracts contributed to the high antioxidant activity of the samples. Further evaluation is necessary to gather more information on the performance of these selected hot pepper varieties in different locations and seasons.

Data availability statements
The data that support the findings of this study are available from the corresponding author, Nnungu, Stephen. Issa, upon reasonable request.

Authors' contributions
SIN Participated in origination of idea on productivity and phytochemical analysis of hot pepper grown in Tanzania, designing, editing of the manuscript and submission of the manuscript. APM conducted a field work and laboratory analysis of hot pepper varieties, Organization of manuscript, interpretation of relevant literature and revised the manuscript critically for important intellectual content. All authors proofread the work before submission.

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