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RESEARCH

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Morphological characterization and yield of pepper (*Piper nigrum* L.) types grown in Morogoro District, Tanzania

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Abstract

Background: Pepper (*Piper nigrum* L.) is among key spice crops grown in Morogoro district of Tanzania. Most of the pepper types grown in the district are only known by their local names as Babu kubwa, Babu ndogo, Babu kati and Ismailia. This may limit information on germplasm collection or genetic resource for plant improvement and trade in markets with variety specifications. The aim of this study was to generate preliminary information of the pepper types based on their morphological characteristics for easy comparison with other known pepper varieties in the spices industry.

Methods: The evaluation of pepper morphological characters was conducted following a randomized complete block design with three replications and four treatments (pepper types). Observations were recorded with respect to 28 characters (9 qualitative and 19 quantitative) which entail vegetative (8) and reproductive (20) traits. The quantitative data for vegetative, inflorescence and berry characters were subjected to analysis of variance. Mean separation test was conducted using Turkey's Honest Significance Test at ($\alpha = 0.05$). Correlation and regression analyses were performed to explore the relationship between yield and yield attributes of pepper.

Results: Babu kubwa and Babu ndogo pepper types were characterized by erect and horizontal branching habit, whereas the others showed hanging habit. Babu kubwa had longer spikes (12.4 cm), leaves blade (17.9 cm), leaf petiole (2.8 cm), wider leaves (12.9 cm) and larger berries (5.8 mm) than all other pepper types. Babu kubwa and Babu kati had cordate and acute leaf bases, respectively while other types had round leaf base shapes. The highest number of flowers was recorded on Babu kubwa (93.5) and Ismailia (90.7) with spikes weighing 7.6 g and 7.5 g, respectively compared to other types. Babu ndogo and Ismailia had compact spikes, while other types had medium loose spikes. Babu kati had the highest number of spikes kg^{-1} (282.6) due its lower spike weight compared to other types. The highest weight of 100 fresh spikes (704.3 g) and 1000 fresh berries (164.2 g) was recorded on Ismailia. Spike length was significantly positively correlated to yield ($r = 0.23$, $R^2 = 0.08$, $p < 0.001$). However, yield had a significant negative correlation with the number of spikes kg^{-1} ($r = -0.85$, $R^2 = 0.017$, $p = 0.001$) and fresh weight of 1000 berries ($r = -0.91$, $R^2 = 0.003$, $p = 0.04$).

Conclusions: The pepper types grown in Morogoro district differed significantly based on most of the evaluated traits. This information can be used to formulate methods and strategies for conservation and in turn genetic improvement of the crop. Despite that the pepper types literary matched with characters of some well-known commercial varieties, confirmation of genetic relatedness is yet needed. Further studies need to be conducted in

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consecutive years and involve assessment of internal quality attributes. Other studies should encompass wider range of pepper types from other producing areas in Tanzania in order to establish their morphological distinctness, genetic diversity and interrelationships in relation to the globally known commercial varieties.

Keywords: Pepper, Germplasm, Descriptors, Morphology, Yield, Morogoro district

Background

Pepper (*Piper nigrum* L.) belongs to the family Piperaceae and is one of the most valuable spices consumed throughout the world. Pepper is widely known for its peculiar flavour and pungency due to the presence of alkaloid piperine in its fruits (Parthasarthy and Zachariah 2008; Gorgani et al. 2017). Pepper with the prefix; black, green and white is used to describe appearance of the product, however the crop plant is popularly referred as "Black pepper" in order to distinguish from pepper of *Capsicum* spp. (i.e., chilli) (Damanhouri and Ahmad 2014). The total commercial production of pepper in the world has been increasing at an estimated range of 510,184–690,467 Metric tons (MT) annually (FAOSTAT 2019). Vietnam with 102,570–151,761 MT year^{-1} stands out as the predominant producer and exporter of pepper, whereby in the year 2018, Vietnam produced 262 658 MT, contributing over 30% of the world production (FAOSTAT 2019). The estimated range of pepper production in Africa is 22,051–25,975 MT year^{-1} with Tanzania accounting for 395–435 MT year^{-1} (FAOSTAT 2019). Pepper is cultivated for its fruits (berries) and serves as a cash crop with diverse domestic and industrial uses. It is used as an ingredient for imparting agreeable flavour and as a preservative in food and drinks (Luxita et al. 2018), production of essential oil and in the pharmaceutical and perfumery industries (Parthasarthy and Zachariah 2008; Gorgani et al. 2017).

Pepper is a woody perennial climbing plant with numerous cultivars varying in yield, branching pattern, size, stem structure and orientation of the various parts (Hussain et al. 2017b). The plants exhibit a dimorphic branching pattern consisting of orthotropic and plagiotropic branches. Orthotropic branches have short, thick internodes with several adventitious roots at the nodes helping the plant to climb over the supports. Plagiotropic branches have no aerial roots but produce a spike from the terminal bud as they grow. Further growth of the branches is continued by axillary buds. As the axillary buds develop, they expose the developing spike and become opposite to the leaves (Parthasarathy et al. 2007; Krishnamurthy et al. 2010).

In presence of adequate soil moisture, runner shoots with aerial root initials at the nodes are produced from the base. These shoots trail on the ground but climb up when in contact with vertical supports. The inflorescence is a catkin (spike) produced at the nodes opposite to the leaves. Its flower is sessile, bracteate, achlamydeous and uni/bisexual. Cultivated pepper has more percentage of bisexual flowers compared to wild species. Berry set highly depends upon the prevailing weather conditions of the growth season. Continued droughts, heavy or irregular rains can reduce pollination, affects the crop physiology, and also leads to failure of berry set (Ravindran et al. 2000; Srinivasan et al. 2012; Krishnamurthy et al. 2016).

Pepper types grown in the Morogoro district of Tanzania are widely known by local names such as Babu kubwa (Komoro), Babu ndogo (Kikong'oro), Babu kati (Ya zamani), and Ismailia (Bwana shamba) (Shango et al. 2020). The pepper types are believed to have originated from other places and introduced by either Missionary or Arab traders through route of domestication some years ago. However, very little is known about their morphological characterization, yield in comparison to the globally known commercial cultivars, information on pedigree of pepper types grown in the district are missing and confirmation of genetic relatedness is yet needed. The pepper types have been arbitrarily given names by farmers in Swahili and Luguru tribe vernacular based on components like the striking morphological features and source of planting materials (Shango et al. 2020). Similar naming of pepper types/cultivars by farmers has also been reported in other producing areas around the world including India (Mathew et al. 2005, 2006).

Observation and recording of morphological characters/descriptors has been a typical approach for identification and description of various pepper germplasms (Hussain et al. 2017b; Bermawie et al. 2019; Prayoga et al. 2020). Other methods include pedigree, agronomic performance, biochemical and molecular/DNA-based data (Mohammadi and Prasanna 2003; Raghavan et al. 2010; Deka et al. 2016). Phenotypic descriptors of a plant species that determine similarity and diversity between and within crop accessions are the bases for Morphological assessment. Phenotypic descriptors are plant traits which can be analyzed during different developmental stages of the crop and may appropriate used in distinguishing crop accessions (Meilawati et al. 2020; Prayoga et al. 2020). Local, native and wild pepper can be source of genetic diversity through germplasm collection, hence understanding their morphological characteristics can assist in the analysis of genetic diversity and can provide valuable information on germplasm resources for crop improvement (Mathew et al. 2006; Prayoga et al. 2020). The aim of this study was to generate preliminary information on morphological characteristics of pepper types grown in Morogoro district, Tanzania compared to globally well-known commercial varieties.

Materials and methods

Description of the study site

The study was conducted in Tandai village (Kinole ward) in Mkuyuni division the Eastern part of Morogoro district during the 2019/2020 cropping season. The village is located at 6°54´ S, 37°45´ E and altitude of 779 m above sea level along the Uluguru Mountains. The area experiences a bimodal rainfall pattern with short rains between late-October to the end of January, and long rains between February and May while a dry season is between June and mid-October (Meteoblue 2019). The area receive monthly precipitation ranging from 16 to 606 mm, where mean total rainfall range between 1000 and 3000 mm annually and mean monthly minimum and maximum air temperature range from 17 to 20 °C and 27 to 31 °C, respectively (Meteoblue 2019). The soils of the Eastern part of Morogoro district are mostly sandy clay loams in the topsoils and clays in subsoils (Msanya et al. 2001). The village was selected for the study based on its importance in pepper production. Pepper is an introduced crop to this area and suitably grown due to the ecological requirements of relatively high rainfall, humidity and warm temperature. Moreover, a multipurpose market exists in Kinole ward particularly at Tandai village where buyers collect, dry and store produce including spices (Maerere and Van Noort 2014).

Soil sampling and analysis

The method by Zu et al. (2014) was used, whereby three composite soil samples were collected in each study site. Each of the three composite samples was made up of five sub-samples collected on an S-shape sampling configuration at a plough depth of 0–20 cm in each farm. The composite soil samples were reduced by the quartering procedure to obtain a representative sample weighing 0.5 kg and then passed through a 2 mm aperture sieve before laboratory analysis. The soil samples were analyzed for physical and chemical properties in the Soil and Geological Science Laboratory at Sokoine University of Agriculture (SUA), Morogoro. Soil particle size distribution was determined using the hydrometer method (Gee and Bauder 1986). Soil pH was determined potentiometrically in water (H_2O) solution after 24 h in soil suspension (soil/liquid = 1/2.5 w/v) (Mclean 1982). Exchangeable bases were extracted with neutral ammonium acetate solution. Exchangeable bases calcium (Ca) and magnesium (Mg) were determined by atomic absorption spectrophotometer, while potassium (K) and sodium (Na) were determined by flame photometry (Thomas 1982). Soil available phosphorus (P) was determined by Bray II method (Bray and Kurtz 1945) and soil organic carbon determined by Walkley–Black method (Nelson and Sommers 1992). Total nitrogen (N) was determined by the Kjeldahl digestion method (Bremner 1996). Plant extractable copper (Cu), zinc (Zn), manganese (Mn), and iron (Fe) were extracted by the DTPA and measured by atomic absorption spectrometer (Lindsay and Norvell 1978).

Experimental design

The evaluation of pepper morphological characters was conducted following a randomized complete block design (RCBD) with three replications (farmers' gardens) and four treatments which included pepper types; Babu kubwa, Babu ndogo, Babu kati and Ismailia. Since the preference and number of plants for a particular pepper type vary among farmers (Shango et al. 2020), the selected farms were those containing all pepper types. The farms that fit this criteria had unequal number ranging between 5 and 15 plants for each pepper type based on respective farmer's preference, for uniformity therefore a total of five pepper plants per treatment were picked for the evaluation. The plants were of more than four years old and trained on living supports Physic/Purging nut (*Jatropha curcas*) at none specific spacing as the common traditional cropping system (Shango et al. 2020). Pepper production in the study area followed smallholders' agricultural practices which included training of pepper plants on supports and weeding. Soil management practices including manure application, irrigation and drainage are not commonly practiced, thus farmers mainly rely on seasonal rainfall for moisture for the pepper plants (Maerere and Van Noort 2014; Shango et al. 2020). Observations were recorded with respect to 28 characters (9 qualitative and 19 quantitative) which entail vegetative (8) and reproductive (20) traits following descriptors of pepper (IPGRI 1995) and guidelines of Distinctiveness, Uniformity and Stability (DUS) test on pepper crop (PPV and FRA 2009). Institutional website and literature/publications were referred to make relevant comparisons between pepper types grown in Morogoro district and other globally known varieties (the full list of commercial varieties and respective characteristics can be referred to in Additional file 1).

Data collection

Vegetative characters

Lateral branching pattern was recorded through visual assessment of the appearance of plagiotropic branches including; Erect, Horizontal or Hanging type (Table 1). Leaf length was measured from the base of midrib to the tip while leaf width was measured at the widest leaf part and leaf petiole length was measured from the base to the insertion with the leaf lamina. Data were recorded on 10 randomly picked matured leaves considered to be 4th leaf with spike of plagiotropic branches from each plant. Leaf length (cm) was rated as short (< 10); medium (10–16); long (> 16), while leaf width (cm) was recorded as narrow (< 7); medium (7–10); broad (> 10) and leaf petiole length (cm) as short (< 2); Medium (2–3); Long (> 3) (Table 1).

Leaf lamina and base shape were assessed through visual observation of 10 randomly picked matured leaves considered to be 4th leaf with spike of plagiotropic branches from each plant. The leaf lamina shape was recorded as ovate (with the widest axis below midpoint and symmetrically curved egg-shaped margins); ovate-lanceolate (much longer than the width, widening above the base and tapering to the apex); ovate-elliptic (ovate in shape but with widest axis at the midpoint); cordate (heart-shaped, with a sinus and rounded lobes at the base and ovate in general outline). Leaf base shapes were; round (margins forming a smooth arc); cordate (rounded lobes, sinus depth of 1/8 to 1/4 distances towards midrib point of the blade) or acute (straight to convex margin forming a terminal angle of 45° to 90°) (Table 1).

Leaf margin and type of veining was assessed from 10 randomly picked matured leaves of plagiotropic branches at 2 m height from the base of pepper plants. Leaf margins were either even (leaves without indentations or incisions on margins) or wavy (slightly folded or with insertion), while types of veining were characterized as acrodromous (with two or more primary or strongly developed secondary veins arch upward from

Table 1 Qualitative and quantitative character states for pepper

S/N	Qualitative characters	States	S/N	Quantitative characters	States	Range
1	Lateral branching pattern	Erect	1	Leaf length (cm)	Short	< 10
		Horizontal			Medium	10–16
		Hanging			Long	> 16
2	Leaf lamina shape	Ovate	2	Leaf width (cm)	Narrow	< 7
		Ovate-lanceolate			Medium	7–10
		Ovate-elliptic			Broad	> 10
		Cordate	3	Petiole length (cm)	Short	< 2
3	Leaf base shape	Round			Medium	2–3
		Cordate			Long	> 3
		Acute	4	Spike length (cm)	Short	< 10
4	Leaf margin	Even			Medium	10–15
		Wavy			Long	> 15
5	Type of leaf veining	Acrodromous	5	Berry size (mm)	Small	< 3.0
		Campilodromous			Medium	3.0–4.26
		Eucamptodromous			Bold/Large	> 4.26
6	Spike orientation	Erect	6	No. of berries/spike	Few	< 25
		Prostate/Pendant			Medium	25–50
7	Spike shape	Filiform			Many	> 50
		Cylindrical	7	No. of flowers/spike		
		Globular	8	No. of spikes/100 leaves		
		Conical	9	No. of spikes at 1 m height from the ground		
8	Spike setting	Loose	10	No. of spikes at 2 m height from the ground		
		Medium loose	11	Number of spikes/kg		
		Compact	12	Fresh weight of spikes/plant (kg)		
9	Berry shape	Round	13	Fresh weight of berries/plant (kg)		
		Oval/Ovate	14	Individual weight of fresh spike (g)		
		Oblong	15	Percentage berry set or full size berries (%)		
			16	Intermediate-size berries (%)		
			17	Undeveloped berries (%)		
			18	Fresh weight of 100 spikes		
			19	Fresh weight of 1000 berries		

either the base or above it), campilodromous (with a series of more or less equal primary veins originating from a common point at the base, arch upward, and reunite toward the apex) or eucamptodromous (secondary veins do not reach the margin and do not form a series of prominent arches) (Table 1).

Inflorescence and berry characters

The spike orientation and shape were recorded based on visual assessment of inflorescences of the entire plant. Spike orientations were characterized as either erect or prostate/pendant (Table 1). Spike shapes were characterized as; filiform, cylindrical, globular and conical (Table 1). Spike length (cm) was assessed as short (< 10); medium (10–15); long (> 15) (Table 1). Spike length was measured from the base of the first pedicel to the tip of the spike, on 10 randomly picked spikes/inflorescences. Spike setting was characterized based on visual assessment of the extent of compactness of the berries. Spike setting was characterized as either loose, medium loose or compact depending on berries filling (Table 1).

The number of berries per spike (berries spike^{-1}) was recorded from 10 randomly picked spikes on each of the five evaluated plants. The number of berries per spike was characterized as few (< 25); medium (25–50); or many (> 50) (Table 1). Berry shape was recorded through visual observation of the shape of berries as round, oval/ovate and oblong shape (Table 1). Berry size was measured using a veneer caliper to an average diameter based on 25 randomly picked matured berries. The size of fresh berries (diameter in mm) was rated as small (< 3.0); medium (3.0–4.26); bold/large (> 4.26) (Table 1). A total of 50 randomly picked matured spikes were weighed to obtain the average weight (g) of an individual fresh spike. A total of five randomly picked plants were harvested in order to assess the fresh weight (kg) of spikes and berries plant^{-1}.

Data analysis

The quantitative data for vegetative, inflorescence and berry characters were subjected to the analysis of variance (ANOVA) using Genstat 16th edition software (VSN International). Mean separation test was conducted using Turkey's Honest Significance Test at ($\alpha = 0.05$). The correlation and regression analyses were performed to explore the relationship between yield (fresh weight of fruits per plant) and yield attributes of pepper mainly; spike length, number of spikes/kg, fresh weight of 1000 fruits and number of well-developed (full size) fruits.

Results

Status of soil nutrients in pepper gardens

The study sites had sandy clay soils with optimum pH values ranging between moderately acidic (pH 5.95) to slightly acidic (pH 6.09–6.25) (Table 2). Soils of the study sites had deficiency of P (10.2–11.45 ppm), K (0.2–0.85 ppm), Ca (0.59–0.8 ppm), Mg (0.95–1.5 ppm), optimum levels for OC (2.3–2.78%), Zn (2.96–4.43 ppm) and Cu (1.56–3.52 ppm) as well as high levels of Mn (56.29–62.39 ppm) content required for pepper production. Exceptions were for Fe which was between optimum to high, ranging from 37.1 ppm to 81.19 ppm and N which was between low to medium/optimum level, ranging from 0.17% to 0.22% (the diagnosis and recommendation integrated system norms of soil nutrient status for pepper can be referred to in Additional file 2).

Vegetative characters

Erect and horizontal lateral branch habit was observed in Babu kubwa and Babu ndogo, whereas Ismailia and Babu kati showed hanging branch habit. The canopy for each pepper type is illustrated (Fig. 1). Round leaf base shape was observed in Ismailia and Babu ndogo, while cordate and acute leaf base shapes were observed on Babu kubwa and Babu kati, respectively (Fig. 2).

Pepper types "Babu kubwa", "Babu ndogo", "Babu kati" and "Ismailia" were observed to have cordate, ovate, ovate-lanceolate and ovate-elliptic leaf lamina shapes,

Table 2 Chemical and physical properties of soil (0–20 cm depth) in study sites

Soil property	Optimum value	Farm 1	Farm 2	Farm 3
Chemical properties				
pH	4.75–6.25	5.95^{MA}	6.09^{SLA}	6.25^{SLA}
OC	2.0–7.5%	2.78^{OP}	2.45^{OP}	2.33^{OP}
Tot. N	0.2–0.5%	0.19^{L}	0.17^{L}	0.22^{OP}
Bray P	12–96 ppm	10.20^{L}	11.45^{L}	11.28^{L}
Exch. K^{+}	91–286 ppm	0.22^{D}	0.85^{D}	0.81^{D}
Exch. Ca^{2+}	61–139 ppm	0.59^{D}	0.80^{D}	0.60^{D}
Exch. Mg^{2+}	40–194 ppm	0.95^{L}	1.50^{L}	1.10^{L}
DTPA Fe	12–65 ppm	81.19^{H}	38.20^{OP}	37.10^{OP}
DTPA Mn	5–35 ppm	62.39^{H}	57.26^{H}	56.29^{H}
DTPA Zn	2.1–7.0 ppm	4.43^{OP}	3.32^{OP}	2.96^{OP}
DTPA Cu	0.51–7.7 ppm	1.56^{OP}	2.81^{OP}	3.52^{OP}
Physical properties				
Soil particle size density (P.S.D)	%Clay	39.2	37.2	39.22
	%Silt	10.82	9.82	9.82
	%Sand	49.96	52.96	50.96
	Texture class	Sandy clay	Sandy clay	Sandy clay

L, low; H, high; D, deficient and OP, optimum Srinivasan et al. (2007). MA, moderately acidic and SLA, slightly acidic (Landon 1991)

Fig. 1 Pepper types trained on low statute living support Physic/Purging nut (*Jatropha curcas*)

respectively (Fig. 3). Even leaf margin and campilodromous leaf venation were observed in all pepper types grown in Morogoro district (Fig. 3).

Significant difference was revealed between pepper types in terms of leaf length ($F=167.9$, $df=3$, $p<0.001$), width ($F=275.2$, $df=3$, $p<0.001$) and petiole length ($F=123.1$, $df=3$, $p<0.001$). Babu kubwa had significantly longer (17.9 cm) and broader (12.9 cm) leaves with longer petioles (2.8 cm) than all other pepper types grown in Morogoro district (Table 3).

Fig. 2 Pepper types distinguished based on the size of leaves and spikes

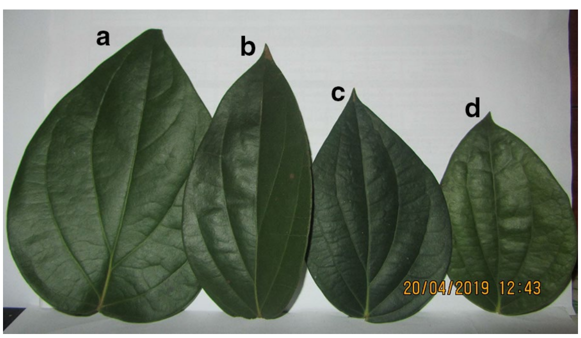

Fig. 3 Leaf lamina shape. **a** Cordate. **b** Ovate-lanceolate. **c** Ovate-elliptic. **d** Ovate

Inflorescence and berry characters

All pepper types grown in Morogoro district had filiform spike shape, prostate/pendant spike orientation and round berry shape. The pepper types grown in Morogoro district differed significantly ($F=49.7$, $df=3$, $p<0.001$) with respect to berry size. Despite all the four pepper types had berries which their size fall into the category of large (>4.26 mm), "Babu kubwa" had the largest (5.8 mm) berries than all the others, while "Babu ndogo" had smallest (4.8 mm) berries out of all pepper types (Table 3).

Babu kubwa, Babu kati and Ismailia spike length was categorized as medium, while "Babu ndogo" spike length was categorized as short. Spike length differed

Table 3 Pepper types and their respective leaf and inflorescence characters

Pepper types	Leaf length (cm)	Leaf Width (cm)	Petiole length (cm)	Spike length (cm)	No. of flowers spike^{-1}	% of Berry spike^{-1}			Berry size (mm)
						Full size (Berry set)	Intermediate-size	Undeveloped berries	
Babu kubwa	17.92 ± 0.12a[a]	12.96 ± 0.09a	2.82 ± 0.05a	12.4 ± 0.12a	93.5 ± 2.03a	51.3 ± 4.44ab	34.0 ± 0.20a	12.7 ± 0.34b	5.8 ± 0.05a
Babu ndogo	13.97 ± 0.22c	8.88 ± 0.07b	2.15 ± 0.02b	5.9 ± 0.22c	55.4 ± 1.40b	65.0 ± 3.79ab	26.3 ± 0.28b	6.7 ± 0.45c	4.8 ± 0.04d
Babu kati	13.54 ± 0.16c	8.94 ± 0.25b	2.03 ± 0.02bc	10.6 ± 0.11b	90.7 ± 2.89a	46.7 ± 10.51b	15.3 ± 0.38c	36.0 ± 0.73a	5.1 ± 0.08c
Ismailia	14.73 ± 0.08b	8.65 ± 0.07b	1.95 ± 0.04c	10.6 ± 0.14b	67.6 ± 0.78b	86.0 ± 6.19a	10.7 ± 0.33d	1.3 ± 0.06d	5.3 ± 0.06b
Mean	15	9.9	2.2	9.9	76.8	62.2	21.6	14.2	5.2
CV%	3.9	4.9	6.2	4.7	5.0	19.3	38.0	55.3	4.6
d.f	3	3	3	3	3	3	3	3	3
F value	167.9	275.2	123.1	167.2	16.4	6.3	13.8	5.4	49.7
P value	< 0.001	< 0.001	< 0.001	< 0.001	0.003	0.026	0.046	0.007	< 0.001

[a] Means (± SE) bearing the same letter(s) within the column are not significantly ($p>0.05$) different according to Turkey's Honest Significance Test. CV, coefficient of variation and d.f, degrees of freedom

significantly ($F = 167.2$, $df = 3$, $p < 0.001$) among pepper types grown in Morogoro district. Babu kubwa had significantly longer (12.4 cm) spikes than all other pepper types grown in Morogoro district (Table 3). Pepper types "Babu kati" and "Ismailia" had significantly longer spikes (10.6 cm) than "Babu ndogo" (5.9 cm).

Number of flowers spike^{-1} differed significantly ($F = 16.4$, $df = 3$, $p = 0.003$) among pepper types grown in Morogoro district (Table 3). Babu kubwa had a significantly higher number of flowers spike^{-1} (93.5) than all other pepper types, while "Babu kati" and "Ismailia" had the highest number of flowers spike^{-1} (90.7, 67.6) than "Babu ndogo" (55.4).

Pepper types grown in Morogoro differed significantly with respect to percentage of berries spike^{-1} which include: full size ($F = 6.3$, $df = 3$, $p = 0.026$), intermediate size ($F = 13.8$, $df = 3$, $p = 0.046$) and undeveloped berries ($F = 5.4$, $df = 3$, $p = 0.007$) (Table 3). Pepper types "Ismailia" and "Babu ndogo" had compact spike setting (Fig. 4a, b) depicted by presence of high percentage of full-size berries (86%, 65%), while medium loose spike setting was observed in "Babu kubwa" and "Babu kati" (Fig. 4c, d) which had high percentage of intermediate size (34%, 15.3%) and undeveloped berries (12.7%, 36%) (Table 3). The number of well-developed berries spike^{-1} differed significantly ($F = 25.9$, df $= 3$, $p < 0.001$) among pepper types (Fig. 5). The highest number of well-developed berries spike^{-1} were recorded on "Ismailia" (58 berries spike^{-1}) followed by "Babu kubwa" (48.1), "Babu kati" (40.2) and "Babu ndogo" (35.9).

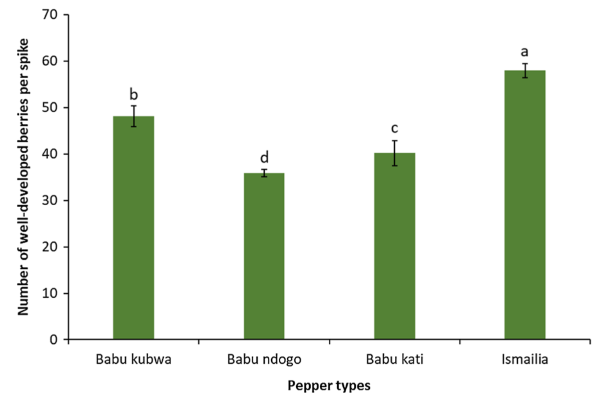

Fig. 5 Variation in the number of well-developed berries/spike among pepper types grown in Morogoro district

Yield and yield components

The pepper types grown in Morogoro district differed significantly with respect to the number of spikes per 100 leaves ($F = 6.3$, $df = 3$, $p = 0.028$), number of spikes at 1 m ($F = 6.8$, $df = 3$, $p = 0.023$) and 2 m ($F = 141$, $df = 3$, $p < 0.001$) height from the ground (Table 4). Babu kati had significantly higher number of spikes per 100 leaves (76.5) and at 1 m height (141.3) from the ground, while "Ismailia" had significantly higher number of spikes (254.4) at 2 m height from the ground than all other types grown in Morogoro district.

A significant difference ($F = 67.7$, $df = 3$, $p < 0.001$) was revealed between the pepper types in terms of number of spike/kg (Table 4). Pepper type "Babu kati" had higher number of spike/kg (282.6) than all other pepper types while, "Ismailia" had the lowest number of spike/kg (139.4). Individual weight of fresh spike differed significantly ($F = 27.97$, $df = 3$, $p < 0.001$) among pepper types. The highest weight of individual spike was recorded on both "Babu kubwa" (7.58 g) and "Ismailia" (7.52 g). Significant difference was recorded among pepper types in terms of fresh weight of 100 spikes ($F = 252.7$, $df = 3$,

Fig. 4 Berry set variation among pepper cultivars grown in the study area. **a** Babu kati. **b** Babu kubwa. **c** Ismailia. **d** Babu ndogo

Table 4 Yield and yield components of pepper types grown in Morogoro district

Pepper types	No. of spikes/100 leaves	No. of spikes at different height from the ground		Individual wt. of fresh spike (g)	Fresh wt. of spike plant^{-1} (kg)	Fresh wt. of berries (kg/plant)	No. of spikes/kg	Fresh wt. of 100 spikes (g)	Fresh wt. of 1000 berries (g)
		1 m	2 m						
Babu kubwa	65.0 ± 4.2c[a]	86.6 ± 6.8bc	105.5 ± 9.9d	7.6 ± 0.12a	3.1 ± 0.25a	2.8 ± 0.25a	230.8 ± 2.04b	502.8 ± 9.9b	146.9 ± 1.15b
Babu ndogo	37.7 ± 4.03d	73.6 ± 7.02c	127.5 ± 18.7c	5.4 ± 0.09b	2.0 ± 0.17a	1.9 ± 0.16a	214.8 ± 5.85b	223.8 ± 21.8c	132.0 ± 1.95c
Babu kati	76.5 ± 3.3a	141.3 ± 9.8a	183.7 ± 18.9b	6.1 ± 0.29b	3.0 ± 0.61a	2.5 ± 0.6a	282.6 ± 13.38a	238.2 ± 16.5c	123.6 ± 2.12d
Ismailia	71.2 ± 4.2b	121.0 ± 10.7ab	254.4 ± 15.9a	7.5 ± 0.27a	2.3 ± 0.2a	2.2 ± 0.19a	139.4 ± 1.01c	704.3 ± 2.6a	164.2 ± 1.32a
Mean	62.6	105.6	167.8	6.6	2.6	2.3	216.9	417.3	141.7
CV%	5.1	2.4	1.3	12.1	52.4	57.6	12.9	13.5	4.7
d.f	3	3	3	3	3	3	3	3	3
F value	6.3	6.8	141.01	27.97	2.3	1.2	67.7	252.7	109.8
P value	0.028	0.023	< 0.001	< 0.001	0.084	0.310	< 0.001	< 0.001	< 0.001

[a] Means (± SE) bearing the same letter(s) within the column are not significantly ($p > 0.05$) different according to Turkey's Honest Significance Test. CV, coefficient of variation and d.f, degrees of freedom

$p < 0.001$) and fresh weight of 100 spikes and 1000 berries ($F = 109.8$, $df = 3$, $p < 0.001$). Ismailia had significantly higher fresh weight (704.3 g) of 100 spikes and fresh weight of 1000 berries (164.2 g) than all other pepper types. Both "Babu kati" and "Babu ndogo" had the lowest fresh weight (238.2 g and 223.8 g, respectively) of 100 spikes while, "Babu kati" had the lowest fresh weight (123.6 g) of 1000 berries.

Relationship between yield and yield components

The results (Fig. 6a) revealed that, spike length was significantly positively correlated to yield ($r = 0.23$, $R^2 = 0.08$, $p < 0.001$). However, yield had a significant negative correlation with the number of spikes kg^{-1} ($r = -0.85$, $R^2 = 0.017$, $p = 0.001$) (Fig. 6b) and fresh weight of 1000 berries ($r = -0.91$, $R^2 = 0.003$, $p = 0.04$) (Fig. 6c). The relationship between yield and number of well-developed berries/spike was not significant ($r = -0.23$, $R^2 = 0.02$, $p = 0.1$) (Fig. 6d).

Discussion

Relevant comparisons between pepper types grown in Morogoro district and other globally known commercial varieties with respect to vegetative and inflorescence characters has been revealed in this study. The leaf margin and venation were literary similar to improved variety "Panniyur-1" (an F1 of Uthirankotta-female parent and Cheriyakaniyakadan-male parent) of India (Mathew et al. 2006). "Panniyur-1" was described as having hanging lateral branch habit (Hussain et al. 2016, 2017a) similar to "Ismailia" and "Babu kati" as well as cordate leaf base and cordate leaf lamina shapes similar to "Babu kubwa". The round shaped leaves character of pepper type "Ismailia" and "Babu ndogo" evaluated in this study have also been reported in the improved Indian varieties released by Indian institute of spice research-IISR (Sasikumar et al. 2004; ICAR-IISR 2020). The varieties include "IISR Thevam" (a clone from landrace Thevamundi) and "IISR Girimunda" (an F1 of Narayakodi and Neelamundi). Variety "IISR Malabar Excel" (an F1 of Cholamundi and Panniyur-1) has acute shaped leaves seemingly relative to "Babu kati". Sasikumar et al. (2004); ICAR-IISR (2020) also reported the ovate-elliptic leaf lamina shape on varieties "IISR Thevam" and "IISR Girimunda".

The ideal characteristics of pepper indicate that, leaf length range from 10 to 12 cm, leaf width range from 7 to 8 cm and petiole length between 1.2 and 1.5 cm at the top and 1.8–2.0 cm at the bottom of the canopy (Krishnamurthy et al. 2010). The leaves characteristics of pepper types evaluated in this study seem to resemble other cultivars grown in India. Two pepper landraces "Ampirian" and "Vattamundi" with petiole length of 1.9 cm, and landrace "Panchami" (Mathew et al. 2006) with leaves of 14.5 cm long and 8.5 cm wide, similar to pepper type "Ismailia". Improved variety IISR Shakthi (an open pollinated progeny of Perambramundi) with leaves of 13.4 cm long (Sasikumar et al. 2004; ICAR-IISR 2020) closely resembled pepper type "Babu ndogo". Landrace "Kallubalankotta" with leaves of 17.3 cm long (Mathew et al. 2006) and improved varieties "IISR Malabar Excel" with leaves of 17 cm long (Sasikumar et al. 2004; ICAR-IISR 2020) and "Panniyur-1" with leaves of 13.3 cm wide (Hussain et al. 2017a) closely matched with pepper type "Babu kubwa". The observed morphological variations were likely to be attributed to genetic and growing environmental effects (Hussain et al. 2017a).

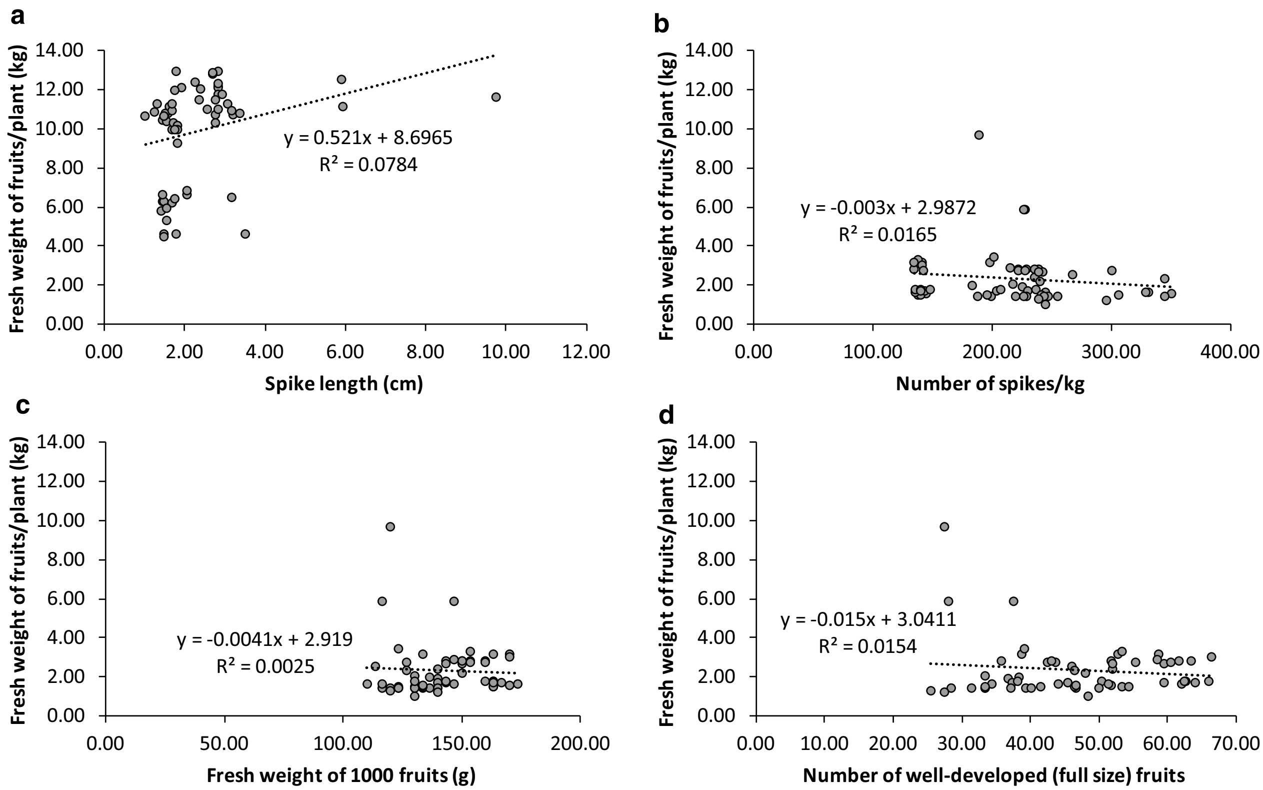

Fig. 6 Relationship between yield and yield components of pepper types grown in Morogoro district

Spike shape, spike orientation and berry shape characteristics of pepper types “Babu kubwa”, “Babu ndogo”, “Babu kati” and “Ismailia” evaluated in this study literary resemble improved varieties “Panniyur-6, Panniyur-7” (Sasikumar et al. 2004) and “Panniyur-1” (Hussain et al. 2017a). These varieties also have filiform spike shape, prostate/pendant spike orientation and round berry shape similar to the pepper types grown in Morogoro district. The spike length of “Babu ndogo was closely related to landrace “Areepadappan” with spike length of 5.5 cm, while two landraces “Kallubalankotta” and “Orumaniyan” with spike length of 10.4 cm and 10.7 cm, respectively (Mathew et al. 2006) were similar to “Babu kati” and “Ismailia”. Nevertheless, the information on pedigree of pepper types grown in Morogoro district are missing and confirmation of genetic relatedness is yet needed.

The number of flowers in pepper varies from 50 to 150, however, the number of hermaphrodite flowers affects the percentage of berry set. The higher the percentage of hermaphrodite flowers, the higher the percentage of berries (Krishnamurthy et al. 2010). The “Ismailia” and “Babu ndogo” pepper types likely have higher percentage of hermaphrodite flowers resulting to spikes full of well-developed berries. Landrace “Kallubalankotta” and “Karimunda” of India were reported having 36 berries spike^{-1} (Mathew et al. 2006; Bhagavantagoudra et al. 2008) which matched with pepper type “Babu ndogo”, while variety “IISR Thevam” was reported having 57 berries spike^{-1} (Sasikumar et al. 2004; ICAR-IISR 2020) comparative to those of pepper type “Ismailia”.

Improved variety “Panniyur-1” was described as having higher number of spikes at 1 m (147.4) and at 2 m height (211.2) from the ground (Maheswarappa et al. 2012; Hussain et al. 2017b) presumably similar to “Babu kati” and “Ismailia” in this study. The development of productive laterals and sustenance of relatively large number of spikes in variety “Panniyur-1” was associated to the relative high leaf area in the upper part of the canopy and higher photosynthetic rate during spike development (Hussain et al. 2017b). The spike setting characteristics of pepper types “Babu kubwa” and “Babu kati” resembled variety “Panniyur-1” with medium loose spike setting (Hussain et al. 2017a). The improved varieties “Panniyur-6” (clonal selection of landrace “Karimunda”) and “Panniyur-7” (an open pollinated progeny of landrace “Kalluvally”) of India were described as having compact spike setting (Arya et al. 2003) which was similar to “Ismailia” and “Babu ndogo” in this study.

Similar findings have been reported on variety "Ciinten" from Indonesia which is characterized with compact spikes and was associated to higher percentage of hermaphrodite flowers (Bermawie et al. 2019). High percentage (98%) of productive bisexual flowers and berry setting percentage (91.5%) was also attributed to the very compactly arranged berries (133 berries spike^{-1}) on improved variety "Panniyur-7" (Arya et al. 2003). Failure of berry set (improper filling of the spikes) or undeveloped ovules on pepper varieties has been associated with insufficient pollination, unfertilized flowers or imperfect fertilization, loss of stigma receptivity before pollination either singly or a combination of these factors (Satheeshan 2000; Parthasarathy et al. 2007). This may suggest that cultivar "Ismailia" and "Babu ndogo" which had low spike shedding indicated by the higher percentage of full-size berries (berry set per spike), likely received sufficient pollination and high rate of fertilization of flowers compared to cultivar "Babu kubwa" and "Babu kati".

Pepper type "Ismailia" has several characters that fulfil that with high berry set (minimum 80%) like in variety Panniyur-1, Panniyur-3 (an F1 of landrace Uthirankotta and Cheriyakaniyakadan), IISR Thevam, IISR Girimunda, Panchami (a clone from landrace Aimpiriyan) and over 50 fruits per spike like in Panniyur-1, Pournami (a clone from landrace Ottaplackal), Panchami, IISR Malabar Excel, IISR Girimunda, IISR Shakthi (Krishnamurthy et al. 2010; Tripathi et al. 2018; ICAR-IISR 2020). In comparing the number of spikes and spike weight, Ismailia is likely more efficient in harvest cost, since to get the same spike weight per kg only requires either a half or one third the number of other pepper types' spikes. Besides that, weight of 1000 fresh berries from Ismailia was higher than those from other pepper types. In Indonesia, Bermawie et al. (2019) similarly reported that variety "Ciinten" was more efficient in harvest cost, as only 417 spikes/plant or half the number of Petaling-1 (836 spikes/plant) was required to get the same spike weight (2.5 kg/plant). Moreover, findings by Preethy et al. (2018) partly opposed the present findings on the relationship between yield and yield components. Their study showed that yield of fresh pepper berries significantly negatively correlated with number of well-developed berries/spike, 100 berry weight and volume. Hence, selection programme based on these characters may likely not lead to the high yielding pepper variety compared to a selection based on of dry weight of pepper berries as dry weight of berries showed a negative significant genotypic correlation with number of berries/spike, 100 berry weight and 100 berry volume (Preethy et al. 2018; Prayoga et al. 2020). On the contrary, number of berries/spike has been reported as the most important morphological character that has direct and positive effect on pepper yield (Bermawie et al. 2019).

The variation in vegetative, inflorescence and yield characters among pepper types grown in Morogoro district may be attributed to several factors like differences in genetic makeup, edaphic factors and influence of environmental condition. Soils of study sites in Tandai village had deficiency of nutrients such as N, P, K, Ca and Mg. Moreover a long dry season was experienced in the Morogoro district during the year 2019. Increased competition for nutrients coupled with low soil moisture content and low availability of photosynthates were also reported to affect berry development in pepper (Krishnamurthy et al. 2010; Paduit et al. 2018). Other findings (Kandiannan et al. 2007; Bermawie et al. 2019) also showed that yield in pepper is influenced by many factors including soil fertility, cultural practices and age of the crop. Genotypic characters, exposure to environment, distribution of rainfall, incidence of diseases and spike shedding (when developing pepper flowers or berries are aborted from the spike) influence the growth and performance of pepper varieties (Bhagavantagoudra et al. 2008; Preethy et al. 2018). Krishnamurthy et al. (2011) also reported decreasing trend in pepper productivity due to lower rainfall and higher temperature concurrently. Continued droughts, heavy or irregular rains that can reduce pollination, affect crop physiology, and also lead to either intensive shedding of berries or failure of berry set (Krishnamurthy et al. 2016). Moreover, environmental factors (temperature, light intensity, micro humidity and rainfall intensity) during flowering, berry set and development plays a vital role in pepper productivity. Plenty of water and high amount nutrients are demanded by pepper plants (Ann 2012). Rainfall ranging between 2000 to 3000 mm year^{-1} with an average of 2300 mm year^{-1} without dry months during the reproductive stage is required for optimum growth of pepper plants. Its growth however, is hampered when the monthly rainfall is less than 90 mm month^{-1} (Yudiyanto et al. 2014).

Conclusions

This study has revealed considerable differences among pepper types grown in Morogoro district based on the evaluated vegetative and inflorescence characters. The genetic differences are particularly of great importance in crop improvement studies. The morphological characteristics assessed in pepper plants could be used to formulate methods and strategies for conservation and will help breeders utilize the desired qualities identified from populations so as to be used for breeding programs in future. Despite that, the pepper types literary matched with characters of some well-known commercial varieties, confirmation of genetic relatedness is yet needed. Further studies need to be conducted in consecutive years and involve the quality attributes of pepper produce. Other studies should involve wider range of pepper types grown in the major producing areas in Tanzania in order to establish morphological distinctness, measure the genetic diversity and interrelationships with respect to those of well-known commercial varieties. These could be exploited to identify pepper types highly adaptive to extreme environmental conditions and biotic stress.

Supplementary Information

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Additional file 1: Table S1. Vegetative characters of commercial pepper varieties used for comparison with pepper types evaluated in the study. **Table S2.** Inflorescence characters of commercial pepper varieties used for comparison with pepper types evaluated in the study. **Table S3.** Yield and yield components of commercial pepper varieties used for comparison with pepper types evaluated in the study.

Additional file 2: Table S1. Diagnosis and recommendation integrated system norms (DRIS Norms) for soil nutrient status for pepper (*Piper nigrum* L.).

Abbreviations

ANOVA: Analysis of variance; DUS: Distinctness, uniformity and stability; IISR: Indian institute of spice research; masl: Meters above sea level; MT: Metric tons; RCBD: Randomized complete block design; SUA: Sokoine University of agriculture.

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Authors' contributions

AJS performed the conception or design of the work, data collection, data analysis, interpretation, and was a major contributor in writing the manuscript (drafting the article). ROM and APM performed a critical revision of the article, providing critical comments concerning the discussion of results, conclusions, and recommendations. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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