Evaluation of yield and other agronomic traits in pepper (*Capsicum chinense* Jacq.) under open-field conditions in the humid tropics

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Sixty-eight pepper (*Capsicum chinense* Jacq.) accessions were evaluated for yield (measured as total number of fruits per plant and total fruit weight per plant) and 15 other traits under open-field conditions in two trials, one conducted in the dry (Trial-1) and the other in wet season (Trial-2) of 2014. Each trial was set in a randomized complete block design with three replications (20 plants per replicate) at The University of the West Indies Field Station, Mount Hope, Trinidad and Tobago. There were significant differences ($p < 0.01$ to 0.001) among the accessions for all traits except plant height, plant canopy width in Trial-1, and early vigour in Trial-2. Total number of fruits per plants was weakly correlated ($r = 0.37$ in Trial-1, $r = 0.45$ in Trial-2; $p < 0.01$ to 0.001) with total fruit weight per plant, but was strongly associated with number of fruits per plant in the first and second 5 pickings ($r = 0.78$ to 0.97, $p < 0.001$) and moderately negatively correlated ($r = -0.33$ to -0.56, $p < 0.01$ to 0.001) with fruit width and average fruit weight. Total fruit weight per plant was positively associated with fruit weight per plant in the first and second 5 pickings ($r = 0.66$ to 0.89, $p < 0.001$), and negatively correlated ($r = -0.41$ to -0.69, $p < 0.001$) with days to 50% flowering and fruiting. A comparison of linear regression lines showed that the relative ranking of the accessions over seasons did not change for days to 50% flowering and fruiting, fruit weight per plant in the second 5 pickings, total fruit weight per plant and fruit width. The implications of these results are discussed.

Keywords: *Capsicum chinense* Jacq., early flowering and fruiting, stability of traits, total fruit weight

Pepper (*Capsicum chinense* Jacq.), a member of the plant family, Solanaceae (Bosland et al. 1996; Eshbaugh 1993), is a short-lived herbaceous perennial (Basu and De 2003) which is indigenous to the Caribbean, Central and South America (Bosland and Votava 2000; Elibox et al. 2015; Heiser 1976; Shoemarker and Teskey 1955). Although *C. annuum* is the pepper that is largely consumed worldwide, *C. chinense* is the most important pepper in the Caribbean. There exists enormous phenotypic (Bharath et al. 2013) and genotypic (Moses and Umaharan 2012) diversity in *C. chinense* with accessions clustering into three separate phylogenetic groups (Upper Amazon, Lower Amazon and Greater Antilles of the Caribbean). Pepper is an important source of vitamins A, B complex, E (Lee and Kader 2000), C (Eshbaugh 1976) and minerals (DeWitt and Bosland 1996). It is consumed mostly as a fresh vegetable or a spice to enhance the taste of foods, but is sometimes processed into sauces (Sinha and Petersen 2011), pharmaceuticals (Stewart et al. 2005), cosmetics, and sprays used in the defence industry (Bosland and Votava 2000).

In the Caribbean, pepper is primarily grown as an annual crop under open-field conditions and is subjected to several harvests, at the mature green stage (Elibox et al. 2015, 2017; Sinha and Petersen 2011), during the growing season. It is viewed as a cash crop of great importance in the diversification of the agricultural sector from the traditional plantation crops such as banana, sugarcane and cocoa. A major problem with *C. chinense* cultivation in the Caribbean is that its average yield (10,000 to 20,000 kg/ha per crop) is low (Moses and Umaharan 2012) compared to at least 60,000 kg/ha in *C. annuum* (Aminifard et al. 2012; Lozano-Fernández et al. 2018).

Currently, there is very little available scientific information on yield measured as total number of fruits per plant and total fruit weight per plant for pepper or the association of yield with other traits of economic importance. Such information is important towards developing a breeding programme for improving yield and fruit traits. Hence the aim of this study was to evaluate 68 pureline *C. chinense* accessions for yield and other agronomic traits under open-field conditions in the hot humid tropics.

Materials and methods

Selection of pepper accessions, germination and care of seedlings

Sixty-eight pureline accessions of *C. chinense* representing the three phylogenetic groups of Moses and Umaharan (2012) were selected for this study from The University of the West Indies pepper germplasm collection. Selection was based on fruit traits (shape, size, colour of fully-developed, immature fruit) of market importance and on resistance to pest and diseases. The nursery practices to generate healthy seedlings were according to Elibox et al. (2015).

Cultural conditions in the field

Experimentation was carried out in two trials; one was planted during the dry season (Trial-1) and the other in the wet season of 2014 (Trial-2) at The University Field Station, Mount Hope, Trinidad and Tobago. The soil type at the Field Station is the well-drained river estate loam (Brown and Bally 1967; Elibox et al. 2015) and the mean temperature, rainfall, and relative humidity are 31.5^{o}C, 1231 mm, and 72.8%, respectively.

The experimental field was disc ploughed, limed (dolomitic lime, Fersan, Dominican Republic) at a rate of 1000 kg/ha and then rotovated prior to planting. Hardened ten-week old seedlings were transplanted onto cambered beds (10 m x 130 m) in a randomized complete block design with three replications. The beds were covered with black, ground cover mulch (Reifenhäuser Reicofil, Troisdorf, Germany) to prevent weed growth. Each replicate consisted of 20 plants arranged in a 5 x 4 layout with intra- and inter-row spacing of 0.9 m. Twelve replications of accession K-100, a popular, high-yielding accession, were used as a control. Following planting, 3 g of a granular compound fertilizer 12N:24P:12K (Caribbean Chemicals, San Juan, Trinidad) were placed 5 cm away from the base of each plant, following which all plants were adequately watered using a drip irrigation system. Soon thereafter, Regent SC 200 (ai 20% fipronil; BASF Corporation NC, USA), a broad spectrum insecticide was applied at the rate of 5 ml/l of water and three days later, Fastac (ai 5% alpha-cypermethrin, BASF Corporation NC, USA) was applied at the rate of 5 ml/l of water to control mole crickets and black cutworms (*Agrotis ipsilon*). Two weeks after planting, a compound fertilizer, calcium ammonium nitrate (53% N) (Hydro Agri, Sluiskil, the Netherlands) was applied at the rate of 3g/plant. Weekly spraying with a cocktail mixture comprising either fungicide, Trump 80WP (ai 80% mancozeb; BASF Schweiz AG, Switzerland) at 8 g/l of water or Bellis 38WG (ai 12.8% pyraclostrobin, 25.2% boscalid; BASF Corporation NC, USA) at 1 g/l, with either insecticide, Fastac at 5 ml/l of water or Caprid 20 SL (ai 20% acetamiprid; Wangs Limited, Guangong China) at 2.5 ml/l of water, and a miticide Newmectin (ai 1.8% abamectin, Marketing ARM Panama, Republic of Panama) at the rate of 2.5 ml/l of water was carried out to control pests and diseases. Also, a monthly dose of the soluble fertilizer 7N:11P:27K plus microelements (Master-Plant-Prod Inc., Ontario, Canada) was applied through fertigation at the rate of 25 g/l of water to meet the additional nutritional needs of the plants.

Data collection

Seventeen traits were measured in Trial-1 (Table 1) and sixteen in Trial-2 (Table 3) from six guarded plants within each replicate per accession. Yield was determined as the total number of fruits and total fruit weight per accession harvested over 10 and 15 weekly pickings, respectively, in Trial-1 and Trial-2. Yield was partitioned into early yield over the first five pickings and late yield over the second five pickings in Trial-1 and early yield (first 5 pickings), late yield (second five pickings) and very late yield (last five pickings) in Trial-2. At each weekly picking, the number of fruits per replicate per accession was counted and then weighed (g) using the electronic balance (PGW 753e; Adam Equipment Inc, CT, USA). Days to 50% flowering and days to 50% fruiting were determined as the number of days from transplanting until 50% of the plants had at least one open flower and one mature ripe fruit per replicate (IPGRI et al. 1995), respectively. Early vigour was recorded before harvest when 50% of plants per replicate bore mature ripe fruits and was scored as follows: 1- short and narrow ≤ 2 primary branches; 2- tall and narrow ≤ 2 primary branches; 3- short and wide < 4 primary branches; 4- tall and wide ≤ 5 primary branches; and 5- tall and wide > 5 primary branches. The growth traits *viz.* plant height and plant canopy width were measured using a measuring tape (Stanley, Connecticut, USA) at the end of the harvest period. Plant height (cm) was measured as the distance from the base of the plant at the soil level, to the top of the canopy. Plant canopy width (cm) was measured at the widest point of the canopy. The number of primary branches, secondary branches and productive nodes were each counted and recorded at the end of the harvest period. The fruit parameters *viz.* average fruit length, fruit width and fruit weight, were taken from 10 ripe fruits from the second picking for each replicate per accession as described by IPGRI et al. (1995). Fruit length (mm) and width (mm) were measured using a pair of electronic calipers (Stanley, Connecticut, USA), and average fruit weight (g) was calculated as the mean weight of the 10 fruits per replicate.

Statistical analysis

Analysis of variance (NCSS 2007) was conducted to determine the significance of differences among accessions for all traits measured, separately for each trial. Treatment comparisons were made against the control. Where accession differences were significant for a trait, a standard error and least significant difference relative to the control accession, a within accession coefficient of variation (CV_{within}), a between accession coefficient of variation (standard deviation between the mean of the accessions divided by the general mean) and an index of discrimination (ID = $CV_{between}$ / CV_{within}) were calculated. Pearson's product moment correlation (NCSS 2007) was carried out to determine the strength of associations between traits in Trial-1 and Trial-2.

With respect to each trait for which there were significant differences among the accessions in both Trial-1 and Trial-2, a comparison of linear regression lines (COLR, CARDI 1974) was performed to determine whether accession x trial interactions were of the crossover type. Spearman's rank correlations (NCSS 2007) were also used to assess the strength of association between each individual trait over the two trials. Accessions with superior yields were identified.

Results

Trial-1

Differences between pepper accessions with respect to all traits evaluated in Trial-1 were significant ($p < 0.001$) except for plant height and plant canopy width (Table 1). Only 8.8% and 10.3% of the accessions showed significantly ($p < 0.05$) earlier times to 50%

flowering (39.7 to 40.6 days) and fruiting (52.7 to 59.3 days), respectively, relative to the control (accession K-100) which took 49.0 days to 50% flowering and 69.5 days to 50% fruiting. With regard to early yields (first 5 pickings), six (256.7 to 787.7) and seven (1.47 to 1.93 kg) accessions, had significantly ($p < 0.05$) larger number of fruits per plant and fruit weight per plant, respectively, than the control which averaged 138.0 fruits per plant at a weight of 1.00 kg. For late yields (the second 5 pickings), four accessions had significantly higher number of fruits per plant (358.0 to 1177.3) than the control which had 212.7 fruits. No accession showed significantly higher fruit weight per plant than the control (1.00 kg) in the second 5 picking.

For overall yield in Trial-1, the control had 350 fruits per plant at a weight of 2.00 kg. Thirty-two accessions (47.1%) had similar total number of fruits per plant as the control, but only seventeen (25.0%) of them (TT-42, CAB-219, CAC-225, TT-398, K-35, TT-400, C-60, UAB-86, LAG-192, TT-321, UAE-257, TT-179, FYG-334, UAP-240, TT-53, CAB-110, VEN-234) had similar total fruit weight per plant as the control. Importantly, five accessions viz. UAP-242, LAM-304, LAM-303, LAM-267 and UAB-256 (551.7 to 1965.0) and two accessions viz. UAB-256 and K-40 (2.50 to 2.70 kg), had significantly ($p < 0.05$) higher total number of fruits per plant and total fruit weight per plant, respectively, than the control.

With regard to fruit characteristics, 60.3% and 27.9% of the accessions had significantly ($p < 0.05$) larger fruit width (37.0 to 55.2 mm) and heavier fruits (18.0 to 29.7 g), respectively, than the control which had a mean value of 30.8 mm for fruit width and 14.0 g for average fruit weight. Fruit length had the largest index of discrimination (ID = 3.3) followed by number of fruits per plant in the first and second 5 pickings, fruit width, average fruit weight and total number of fruits per plant (ID: 2.3 to 2.7) (Table 1).

Table 1: Range, significance level, mean, standard error of the mean, least significant difference, coefficient of variation within and between accessions and index of discrimination for 17 yield and yield associated traits obtained for 68 pureline accessions of pepper (*Capsicum chinense* Jacq.) evaluated under field conditions in Trial-1

Traits	**Range**	**Sig. (P <)**	**Mean**	**SEM**	**LSD**	**CVw**	**Cvbet.**	**ID**
Days to 50% flowering	39.7 - 65.3	0.001	50.5	2.95	8.28	0.09	0.14	1.6
Days to 50% fruiting	52.7 - 88.0	0.001	69.5	3.63	10.18	0.08	0.13	1.6
Early vigour	1.3 - 4.7	0.001	3.0	0.39	1.09	0.20	0.27	1.3
Number of fruits per plant in 1st 5 pickings	28.0 - 787.7	0.001	130.2	27.00	75.75	0.32	0.85	2.6
Fruit weight per plant (kg) in 1st 5 pickings	0.17 - 1.93	0.001	1.0	0.16	0.45	0.25	0.39	1.5
Number of fruits per plant in 2nd 5 pickings	25.0 -1117.3	0.001	129.2	42.80	120.07	0.51	1.17	2.3
Fruit weight per plant (kg) in 2nd 5 pickings	0.20 - 1.27	0.001	0.6	0.14	0.38	0.35	0.38	1.1
Total number of fruits per plant	62.0 - 1965.0	0.001	259.3	61.03	171.21	0.36	0.97	2.7
Total fruit weight per plant (kg)	0.4 - 2.7	0.001	1.6	0.18	0.50	0.17	0.31	1.8
Plant height (cm)	48.0 - 87.0	NS	65.3	9.01	-	0.21	0.13	0.6
Plant canopy width (cm)	63.3 - 102.0	NS	84.9	11.00	-	0.20	0.10	0.5
Number of primary branches	4.3 - 10.3	0.001	7.1	0.53	1.49	0.12	0.18	1.6
Number of secondary branches	9.0 - 21.3	0.001	15.2	1.39	3.90	0.14	0.18	1.3
Number of productive nodes	38.3- 115.7	0.001	71.7	6.43	18.04	0.14	0.21	1.5
Fruit length (mm)	22.1- 88.9	0.001	49.9	2.62	7.35	0.08	0.27	3.3
Fruit Width (mm)	17.6 - 55.2	0.001	37.4	2.18	6.12	0.09	0.22	2.4
Average fruit weight (g)	4.0 - 29.7	0.001	15.1	1.41	3.96	0.14	0.35	2.4

Sig. = significance level, SEM= Standard error means, LSD= Least Significance Difference relative to the control; CVw= Coefficient of variation within; Cvbet.= Coefficient of variation between; ID= Index of Discrimination

Total number of fruits per plant showed strong positive correlations (r = 0.95 to 0.97, $p < 0.001$) with number of fruits per plant in the first and second 5 pickings, a moderate positive correlation (r = 0.50, $p < 0.001$) with fruit weight per plant in the second 5 pickings, and moderate negative correlations (r = -0.54 to -0.56, $p < 0.001$) with fruit width and average fruit weight (Table 2). The correlation between total number of fruits per plant and total fruit weight per plant, although significant, ($p < 0.01$) was weak (r = 0.37). Total fruit weight per plant, however, showed strong positive correlations (r = 0.66 to 0.89, $p < 0.001$) with fruit weight per plant in the first and second 5 pickings, a moderate positive correlation (r = 0.44, $p < 0.001$) with number of fruits per plant in the first 5 pickings, and strong negative correlations (r = -0.62 to -0.69, $p < 0.001$) with days to 50% flowering and fruiting. Days to 50% flowering also showed a strong positive correlation with days to 50% fruiting (r = 0.89, $p < 0.001$) and moderate to strong negative correlations with number of fruits in the first 5 pickings and fruit weight per plant in the first 5 pickings (r = -0.46 to -0.70, $p < 0.001$). Days to 50% fruiting also showed moderate to strong negative correlations with number of fruits in the first five pickings and fruit weight per plant in the first 5 pickings (r = -0.44 to -0.81, $p < 0.001$). Number of fruits per plant in the first 5 pickings also showed a strong positive correlation with number of fruits in the second 5 pickings (r = 0.86, $p < 0.001$). Number of fruits per plant in the second 5 pickings also showed a moderate correlation with fruit weight per plant in the second 5 pickings (r = 0.56, $p < 0.001$).

Trial-2

In Trial-2, differences between the pepper accessions with respect to all traits evaluated were significant ($p < 0.01$ to 0.001) except for early vigour (Table 3). Only one accession (LAM-267) had a significantly ($p < 0.05$) earlier time to 50% flowering (38.5 days) and fruiting (50.0 days) relative to the control, which took 50 days to 50% flowering and 75 days to 50% fruiting. For early yield (first 5 pickings), 10 (56.0 to 134.0) and 8 accessions (0.50 to 1.60 kg), respectively, produced significantly ($p < 0.05$) higher number of fruits per plant and fruit weight per plant, respectively, relative to the control which had 21.0 fruits per plant at a weight of 0.13 kg. For late yield (second 5 pickings) three accessions viz. UAE-90, UAP-242 and UAB-256 (130.7 to 298.7) and five accessions viz. K-40, CAB-219, UAE-257, LAM-301 and TT-41 produced significantly higher number of fruits per plant and fruit weight per plant, respectively, than the control which averaged 50.7 fruits per plant at a weight of 0.37 kg. For very late yield (third 5 pickings), only two accessions viz. LAM-267 (242) and UAB-256 (399) and one accession viz. LAM-301 (1.40 kg) produced significantly higher ($p < 0.05$) number of fruits per plant and fruit weight per plant relative to the control which had 133 fruits at a weight of 0.83 kg.

Table 2: Pearson correlations among 14 traits (minus early vigour, plant height and plant canopy width) evaluated for 68 accessions of *Capsicum chinense* Jacq. in Trial 1

	DTFR	NFP 1st 5p	FWP 1st 5p	NFP 2nd 5p	FWP 2nd 5p	TNFP	TFWP	FL	FW	Fr wt	NPB	NSB	NPN
DTFL	0.89	-0.46	-0.70	-0.21	-0.19	-0.33	-0.62	0.16	0.05	0.00	-0.23	-0.29	-0.08
DTFR		-0.44	-0.81	-0.14	-0.15	-0.28	-0.69	0.07	-0.06	-0.11	-0.15	-0.22	-0.03
NFP 1st 5p			0.34	0.86	0.37	0.95	0.44	-0.34	-0.51	-0.53	0.45	0.46	-0.05
FWP 1st 5p				0.04	0.24	0.18	0.89	0.09	0.25	0.36	0.12	0.21	0.05
NFP 2nd 5p					0.56	0.97	0.30	-0.32	-0.53	-0.55	0.40	0.35	-0.10
FWP 2nd 5p						0.50	0.66	0.05	-0.23	-0.14	0.34	0.32	0.02
TNFP							0.37	-0.34	-0.54	-0.56	0.43	0.41	-0.09
TFWP								0.07	0.10	0.22	0.27	0.33	0.08
FL									-0.14	0.24	-0.21	-0.20	-0.19
FW										0.86	-0.22	-0.23	0.24
Fr wt											-0.26	-0.24	0.18
NPB												0.95	0.41
NSB													0.42
NPN													

The correlation is significant at $p < 0.05$, $p < 0.01$, $p < 0.001$ for 66 d.f. when r = 0.24, 0.31 and 0.39, respectively. DTFL: days to 50% flowering, DTFR: days to 50% fruiting, NFP 1st 5p: number of fruits per plant first 5 pickings, FWP 1st 5p: fruit weight (kg) per plant first 5 pickings, NFP 2nd 5p: number of fruits per plant second 5 pickings, FWP 2nd 5p: fruit weight (kg) per plant second 5 pickings, TNFP: total number of fruits per plant, TFWP: total fruit weight (kg) per plant, FL: fruit length (mm), FW: fruit width (mm), Fr wt: average fruit weight (g), NPB: number of primary branches, NSB: number of secondary branches, NPN: number of productive nodes.

Table 3: Range, significance level, mean, standard error of the mean, least significant difference, coefficient of variation within and between accessions and index of discrimination for 16 yield and yield associated traits obtained for 68 pureline accessions of pepper (*Capsicum chinense* Jacq.) evaluated under field conditions in Trial-2

Traits	**Range**	**Sig. (P <)**	**Mean**	**SEM**	**LSD**	**CVw**	**Cvbet.**	**ID**
Days to 50% flowering	38.5 - 78.0	0.01	57.5	4.07	11.42	0.11	0.14	1.3
Days to 50% fruiting	50.0 - 101.7	0.001	81.0	5.40	15.15	0.10	0.1	1.0
Early vigour	2.3 - 4.0	NS	3.2	0.36	-	0.17	0.14	0.8
Number of fruits per plant in 1st 5 pickings	2.3 - 134.0	0.001	29.2	12.30	34.51	0.65	0.95	1.5
Fruit weight per plant (kg) in 1st 5 pickings	0.00 - 1.60	0.001	0.24	0.131	0.368	0.85	1.06	1.3
Number of fruits per plant in 2nd 5 pickings	3.0 - 298.7	0.001	47.5	19.82	55.60	0.65	0.86	1.3
Fruit weight per plant (kg) in 2nd 5 pickings	0.00- 0.90	0.001	0.34	0.112	0.314	0.51	0.57	1.3
Number of fruits per plant in 3rd 5 pickings	16.3-398.3	0.001	83.5	25.61	71.85	0.47	0.66	1.4
Fruit weight per plant (kg) in 3rd 5 pickings	0.15- 1.40	0.01	0.59	0.193	0.541	0.51	0.44	0.9
Total number of fruit per plant	25.0 - 806.7	0.001	160.1	52.71	147.87	0.51	0.7	1.4
Total fruit weight per plant (kg)	0.15 - 2.80	0.001	1.2	0.29	0.81	0.37	0.5	1.3
Plant height (cm)	36.5 - 73.7	0.01	54.1	6.46	18.12	0.18	0.16	0.9
Plant canopy width (cm)	58.3 - 96.0	0.001	76.7	5.38	15.09	0.11	0.11	1.0
Fruit length (mm)	17.7 - 88.3	0.001	43.7	2.98	8.36	0.11	0.25	2.4
Fruit width (mm)	13.8 - 48.1	0.001	31.9	1.99	5.58	0.10	0.22	2.3
Average fruit weight (g)	2.5 - 22.8	0.001	10.1	1.18	3.31	0.18	0.38	2.1

Sig.= significance level, SEM= Standard error means, LSD= Least significance difference relative to the control; CVw = Coefficient of variation within; Cvbet.= Coefficient of variation between; ID= Index of Discrimination.

For overall yield in Trial-2, the control accession averaged 204.7 fruits per plant at a weight of 1.33 kg. Importantly, three accessions viz. UAE-90, UAP-242 and UAB-256 (399.7 to 806.7) and four accessions viz. TT-41, UAE-257, UAP-328 and LAM-301 (2.37 to 2.80 kg) produced significantly ($p < 0.05$) higher total number of fruits and fruit weight per plant, respectively, than the control. Six accessions (CAC-225, UAP-240, TT-41, UAE-257, UAP-328, LAM-301) produced > 2.00 kg of fruits per plant and all except UAP-328, produced > 200 total fruits per plant.

The control averaged 25.1 mm for fruit width and 8.2 g for average fruit weight in Trial-2. The results showed that 63.2% (30.8 to 48.1 mm) and 29.4% (11.6 to 22.8 g) of the accessions had significantly ($p < 0.05$) wider and heavier fruits, respectively, than the control. Fruit length, fruit width and average fruit weight had the largest indices of discrimination (ID ~ 2.0).

In Trial-2, total number of fruits per plant showed strong positive correlations (0.78 to 0.94, $p < 0.001$) with number of fruits per plant in the first, second and third 5 pickings and moderate correlations (0.40 to 0.45, $p < 0.001$) with fruit weight in the third 5 pickings and total fruit weight per plant (Table 4). Total fruit weight per plant also showed strong positive correlations ($r = 0.79$ to 0.84, $p < 0.001$) with fruit weight per plant in the first, second and third 5 pickings, a moderate positive correlation ($r = 0.59$, $p < 0.001$) with number of fruits per plant in the first 5 pickings, and moderate negative correlations ($r = -0.41$ to -0.54, $p < 0.001$) with days to 50% flowering and fruiting. Days to 50% flowering showed a strong positive correlation with days to 50% fruiting ($r = 0.89$, $p < 0.001$) and moderate negative correlations ($r = -0.41$ to -0.48, $p < 0.001$) with number of fruits per plant in the first 5 pickings, and fruit weight per plant in the first, second and third 5 pickings. Number of fruits per plant in the first 5 pickings also showed moderate to strong positive correlations with fruit weight per plant in the first 5 pickings, number of fruits and fruit weight per plant in the second 5 pickings, and number of fruits per plant in the third 5 pickings ($r = 0.40$ to 0.71, $p < 0.001$). Fruit weight per plant in the first 5 pickings also showed moderate positive correlations with fruit weight per plant in the second and third 5 pickings ($r = 0.44$ to 0.47, $p < 0.001$). Number of fruits per plant in the second 5 pickings also showed moderate to strong positive correlations with fruit weight per plant in the second 5 pickings and number of fruits per plant in the third 5 pickings ($r = 0.50$ to 0.81, $p < 0.001$). Fruit weight per plant in the second 5 pickings also showed a strong positive correlation with fruit weight per plant in the third 5 pickings ($r = 0.60$, $p < 0.001$). Number of fruits per plant in the third 5 pickings also showed a moderate positive correlation ($r = 0.46$, $p < 0.001$) with fruit weight per plant in the third 5 pickings.

Stability of traits evaluated over trials

When the mean accession values for individual traits were correlated over trials (Table 5), Spearman's rank correlations were strong for number of fruits per plant in the second 5 pickings, total number of fruits per plant, fruit length, fruit width and average fruit weight ($r = 0.81$ to 0.92, $p < 0.001$). Comparison of linear regression lines showed that accession performances over trials can be described by parallel lines for days to 50% flowering and fruiting, fruit weight per plant in the second 5 pickings, total fruit weight per plant and fruit width, suggesting no accession x trial interactions of the crossover type (Table 5).

Seven accessions (GAC-291, LAB-187, TT-82, CAC-225, CAB-219, UAE-257, UAP-240) showed consistent total fruit per plant over trials. Two accessions (UAB-242, UAB-256) consistently showed larger total number of fruits per plant than the control over trials. Although accession UAB-256 performed better than the control in Trial-1, it (1.43kg) was not significantly different from the control in Trial-2 for total fruit weight per plant. Three accessions (CAC-225, UAP-240, UAE-257) showed consistently high total number of fruits per plant (> 200.0) and total fruit weight per plant (2.00 kg) over trials.

Table 4: Pearson correlations among the 15 traits (minus early vigour) evaluated in 68 pure line accessions of *Capsicum chinense* Jacq. in Trial 2

	DTFR	NFP 1st 5p	FWP 1st 5p	NFP 2nd 5p	FWP 2nd 5p	NFP3rd 5p	FWP 3rd 5p	TNFP	TFWP	PH	PCW	FL	FW	Fr wt
DTFL	0.89	-0.48	-0.46	-0.25	-0.41	-0.33	-0.45	-0.37	-0.54	0.01	-0.20	-0.10	0.18	0.00
DTFR		-0.38	-0.32	-0.27	-0.31	-0.38	-0.37	-0.38	-0.41	0.00	-0.17	-0.08	0.25	0.08
NFP 1st 5p			0.71	0.67	0.40	0.58	0.32	0.78	0.59	-0.14	0.12	-0.14	-0.20	-0.06
FWP 1st 5p				0.18	0.47	0.12	0.44	0.30	0.79	-0.10	0.24	0.02	0.28	0.50
NFP 2nd 5p					0.50	0.81	0.26	0.94	0.37	-0.01	0.10	-0.14	-0.34	-0.27
FWP 2nd 5p						0.23	0.60	0.39	0.82	0.37	0.45	0.22	0.28	0.44
NFP3rd 5p							0.46	0.94	0.34	-0.10	0.14	-0.21	-0.49	-0.42
FWP 3rd 5p								0.40	0.84	0.27	0.59	0.16	0.14	0.28
TNFP									0.45	-0.09	0.13	-0.19	-0.42	-0.33
TFWP										0.21	0.53	0.17	0.28	0.49
PH											0.60	0.25	0.25	0.28
PCW												0.15	0.34	0.41
FL													-0.08	0.23
FW														0.87

The correlation is significant at $p < 0.05$, $P < 0.01$, $p < 0.001$ for 66 d.f. when r = 0.24, 0.31 and 0.39, respectively.
DTFL: days to 50% flowering, DTFR: days to 50% fruiting, NFP 1st 5p: number of fruits per plant first 5 pickings, FWP 1st 5p: fruit weight (kg) per plant first 5 pickings, NFP 2nd 5p: number of fruits per plant second 5 pickings, FWP 2nd 5p: fruit weight (kg) per plant second 5 pickings, NFP 3rd 5p: number of fruits per plant third 5 pickings, FWP 3rd 5p: fruit weight (kg) per plant third 5 pickings TNFP: total number of fruits per plant, TFWP: total fruit weight (kg) per plant, PH: plant height (cm), PCW: plant canopy width (cm), FL (mm): fruit length (mm), FW: fruit width (mm), Fr wt: average fruit weight (g).

Table 5: Spearman's rank correlations and comparison of linear regression lines for the 12 traits (which showed significant within trial accessions differences) evaluated for 68 pureline accessions of pepper (*Capsicum chinense* Jacq.) over Trial-1 and Trial-2

Parameter	**Spearman's Correlations**	**COLR**
Days to 50% flowering	0.35	Parallel
Days to 50% fruiting	0.18	Parallel
Early vigour	0.08	Not single, parallel
Number of fruits per plant 1st 5 pickings	0.43	Not single, parallel
Fruit weight (kg) per plant 1st 5 pickings	0.27	Not single, parallel
Number of fruits per plant 2nd 5 pickings	0.81	Not single, parallel
Fruit weight (kg) per plant 2nd 5 pickings	0.34	Parallel
Total number of fruits per plant	0.81	Not single, parallel
Total fruit weight (kg) per plant	0.32	Parallel
Fruit length (mm)	0.88	Not single, parallel
Fruit width (mm)	0.92	Parallel
Fruit weight (g)	0.86	Not single, parallel

Spearman's correlation is significant at $p < 0.05$, $p < 0.01$, $p < 0.001$ for N = 68 when r = 0.24, 0.31, 0.39.

Discussion

This study was the first to characterize yield and agronomic traits of importance in *C. chinense*. Evaluation of the 68 accessions showed that there is considerable variability for yield and other important traits which supports earlier findings that showed a high degree of variability at the phenotypic (Bharath et al. 2013; Elibox et al. 2015, 2017) and molecular (Moses and Umaharan 2012; Moses et al. 2014) levels among *C. chinense* cultivated in Latin America and the Caribbean. This was evidenced by the large ranges for all parameters, the highly significant differences among the accessions for most traits within trials based on ANOVA, and the large index of discrimination for fruit length, fruit width and average fruit weight in Trial-1 and Trial-2. Large genetic variability is necessary for systematic improvement of pepper for yield and other related traits.

A comparison of the mean performance of the accessions indicated better performance in Trial-1 than in Trial-2 as evidenced by greater number of accessions showing earlier times to flowering and fruiting; and larger number of fruits and fruit weight per plant in the first and second 5 pickings, total number of fruits and total fruit weight per plant, fruit length, fruit width and average fruit weight, relative to the control. Furthermore, the control accession K-100 also had a faster time to flowering and fruiting, and higher mean values for traits in Trial-1 as compared to Trial-2. Because temperatures at the experimental site are very consistent throughout the year, the results suggest that the pepper accessions were sensitive to the higher rainfall (Adams et al. 2007) in the wet season (246.4 mm- October) versus the dry season (105.4 mm- February). Heavy rainfall causes waterlogging of soils (Adams et al. 2007), and results in decreased pollination and greater fruit damage (Delelegne et al. 2014), which together can result in low yields of pepper. Furthermore, day length and photoperiod (Nkansah et al. 2017) are generally shorter in the wet season relative to the dry season. Longer photoperiod resulted in increased fruit yields in *C. annuum* (Dorais et al. 1996) and this may hold true for *C. chinense* as well. The results further revealed that higher yields in *C. chinense* accessions in this study, were a function of early times to flowering and fruit maturity, and higher early yields. The study of Delelegne et al. (2014) also reported that early flowering and fruit maturity, and high total yield, all contribute to high yielding capacities in *Capsicum* species.

This study shows that although the correlations between the two main measurements of yield in pepper (total number of fruits and total fruit weight per plant) were significant ($p < 0.01$), they were generally weak within trials ($r = 0.37$ in Trial-1, $r = 0.45$ in Trial-2). Commercially, both traits are important since pepper is sold by numbers in the domestic fresh vegetable markets, and by weight for the fresh export markets (Elibox et al. 2015) and for processing (Sinha and Petersen 2011). Their weak association could be explained by the large variation in fruit traits, particularly fruit size and average fruit weight, shown in this study and that of Bharath et al. (2013). However, their lack of strong association augurs well for selective breeding to create high yielding pepper varieties with large fruit sizes and heavy fruit weights to meet the various market requirements.

The strengths of correlation coefficients between yield and other agronomic traits are important and could form additional criteria for selection in breeding programmes for improvement of yield and fruit parameters (Todorova et al. 2003), since strong correlations between desirable traits make breeding easier. This study, for the first time, showed that total number of fruits per plant was strongly and positively correlated with number of fruits per plant in the first and second 5 pickings but moderately correlated with smaller fruit width and lower average fruit weight, while total fruit weight per plant was moderately correlated with early flowering and fruiting, but strongly and positively correlated with fruit weight per plant from the first and second five pickings, within trials and over trials. The smaller values of the correlation coefficients among traits in Trial-2 may be due to the fact that the pepper plants generally had longer times to 50% flowering and fruiting and had longer harvesting periods, thereby resulting in variable and inconsistent yields.

The stability of yield and other important traits are also important criteria in the selection process for any crop improvement programme. Comparison of linear regression lines showed that while some of the evaluated traits were sensitive to environmental changes over trials, the relative rank of the accessions did not change for five traits viz. days to 50% flowering and fruiting, fruit weight per plant in the second five pickings, total fruit weight per plant and fruit width, as evidenced by parallel lines based on comparison of linear regression lines of mean accession values over trials. Furthermore, Spearman's rank correlation showed strong associations over trials for six traits viz. number of fruits per plant in the first and second 5 pickings, total number of fruits per plant, fruit length, fruit width and average fruit weight. These aforementioned traits showed minimal accession x trial interactions over Trial-1 and Trial-2. Stability analyses are important in helping plant breeders to identify and select the most stable, high performing genotypes under a given set of environmental conditions (Jandong et al. 2011). This study revealed 7 pepper accessions (10.3% of accessions evaluated) that had consistent number of fruits and fruit weight per plant over trials. These accessions could form the basis of a breeding programme for predictable yields in pepper.

Currently, the average yield of *C. chinense* in the Caribbean is 10,000 to 20000 kg/ha per crop (Moses and Umaharan 2012). Based on the planting density of 12,345.7 plants per hectare and two crops per year used in this study, the control can produce 41,111.2 kg/ha which is similar to the upper average limit of Moses and Umaharan (2012). However, this study identified 19 and 6 accessions in Trial-1 and Trial-2, respectively, that combine both large total fruit number (> 200) and high fruit weight per plant (> 2.00 kg). These accessions can result in at least a 1.2-fold increase in total fruit weight per hectare per year relative to the control. Furthermore, using accession K-40 (dry season) and LAM-301, UAP-328 (wet season), 67,901.4 kg of fruits can be obtained per hectare per year, which is a 1.7-fold increase relative to the control and within the range for *C. annuum*. Therefore, in the short term, these accessions can be released to farmers to boost local pepper productivity, while breeding should be pursued to further increase yields.

In conclusion, this open-field study performed over two seasons found that there is considerable diversity in *C. chinense* for yield, based on total number of fruits per plant and total fruit weight per plant. Significant accession differences ($p < 0.01$ to 0.001) were observed for all the traits except for plant height and plant canopy width in Trial-1 and early vigour in Trial-2. The performance of high yielding accessions was mainly attributed to early flowering, early fruit maturity and early yields. Yield measured as total number of fruits per plant was weakly associated with total fruit weight per plant but was associated with number of fruits from the first and second 5 pickings, smaller fruit width and lower average fruit weight; while total fruit weight per plant was associated with early flowering and fruiting, and fruit weight per plant in the first and second 5 pickings. The relative ranking of the accessions over seasons did not change for five traits viz. days to 50% flowering and fruiting, fruit weight in the second five pickings, total fruit weight per plant, and fruit width based on comparison of regression lines. Three pepper accessions were high yielding, combining both large total fruit number (> 200) and high fruit weight per plant (> 2.00 kg) over trials.

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