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Full Length Research Paper

Potential in a collection of adapted and exotic tropical maize inbred lines as resistance source for stem borers

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Lepidopteran borers are the most devastating field pests of maize in West and Central Africa. In view of the rapidly changing climate which favours an upsurge of more destructive biotypes of insect pests, diverse sources of resistance from different genetic backgrounds need to be harnessed for crop improvement purposes. Forty tropical maize inbreds comprising adapted and exotic lines from International Institute of Tropical Agriculture (IITA) and International Maize and Wheat Improvement Centre (CIMMYT) maize breeding programs were evaluated for resistance to two species of stem borers- *Sesamia calamistis* and *Eldana saccharina* at Ibadan and Ikenne, Nigeria, under artificial infested and non-infested conditions in 2015 and 2016 cropping seasons. The experiment was laid out in a randomized complete block design in three replicates. Data were collected on agronomic traits and stem borer damage parameters. On average, the CML lines had relatively higher grain yield despite the high level of stem tunneling, stalk breakage and cob damage, with the exception of CML 67 (0.19 ton/ha) and CML 71 (0.06 tons/ha). BD 74-395 had the highest yield (1.45 t/ha) among the BDs, despite its high stalk breakage and cob damage. Among IITA lines, KU1414SR/SR, 1368 and 9030STR were the highest yielding with grain yields of 1.71, 1.39 and 1.19 t/ha, respectively. Moderate to high heritability was observed among the stem borer damage parameters. Negative genetic gain was observed in stem tunneling. Mean square of lines was significant for all the traits studied. The top-performing inbreds were similarly grouped using the rank summation index and principal component analysis. The exotic lines had good adaptability and showed potential as sources of stem borer resistance, and could therefore be explored in breeding programs for resistance to Eldana and Sesamia.

Key words: *Eldana saccharina*, maize inbreds, resistance, *Sesamia calamistis*, tropics.

INTRODUCTION

Maize is the most widely cultivated staple food crop in sub-Saharan Africa (SSA), providing up to 70% of the daily calorie intake for over 300 million people (FAO, 2007). In West and Central Africa (WCA), maize has evolved from subsistence to a cash crop (Fajemisin, 2014). Nigeria is the largest producer of maize in SSA with current estimates for green and grain maize production at 0.74 and 10.8 million tonnes respectively

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(FAO, 2017). Numerous biotic and abiotic stresses limit maize yields in SSA (Semagn et al., 2015) depriving resource poor farmers of 10-100% of potential yield.

Stem borers are among the most damaging insect pests of maize causing yield losses of 20-100% in susceptible germplasms (Bosque-Perez and Mareck, 1990; Schulthess and Ajala, 1999; Oloyede-Kamiyo, 2013). In Africa, the four most destructive species are the African stalk borer (*Busseola fusca,)* the pink stem borer (*Sesamia calamistis),* the sugar cane borer (*Eldana saccharina),* and the spotted stem borer *(Chilo partellus)*. The first three are African, and are present in most countries of SSA (Bosque Perez and Marek, 1991), while *C. partellus* originated in Asia and was accidentally introduced to East Africa (Tams, 1932). Stem borer resistant genotypes showing specific and cross resistances to the prevalent borer species have been developed for WCA, and East and Southern Africa (ESA) (Ajala et al., 2008; Murenga et al., 2015).

Sourcing of novel alleles in introduced or exotic germplasm has been identified as an effective breeding strategy for diversifying the genetic base of adapted materials and for raising the odds of developing superior hybrids (Dhliwayo et al., 2009; White et al., 2011; Adebayo et al., 2013). Recurrent selection procedure has been used extensively in concentrating genes of resistance into the maize genepool. Exchange of tropical maize germplasm in collaborative research efforts in Africa with International Institute of Tropical Agriculture (IITA) and International Maize and Wheat Improvement Centre (CIMMYT), and partners has fast-tracked varietal development and release in recipient countries through partial and total inclusion of introduced germplasms. Many newer tropical hybrids contain at least some exotic germplasm, often as a part of a hybrid pedigree (Goodman, 1999). Tropical maize has been reported to combine wide geographic range, opportunities for genetic germplasm improvements, and higher potential biomass yields attributed to perennial grasses (White et al., 2011).

Following combining ability studies involving inbreds from IITA and CIMMYT, some CIMMYT lines were identified to have potentials for improving IITA's early maturing and intermediate maturing germplasms for drought and low nitrogen tolerance (Adebayo et al., 2013; Ifie et al., 2015; Badu Apraku et al., 2016). However, limited studies have been conducted to examine the potentials of adapted and exotic non-borer maize inbred lines for their direct use in hybrid combinations aimed at stem borer resistance efforts. The effects of the rapidly changing climate which favours proliferation and evolution of new strains of insect pests call for rapid development of better forming varieties with horizontal resistance to cope with changing times. This study was carried out to (i) explore potentials in a collection of IITA and CIMMYT maize inbreds for stem borer resistance, and (ii) assess the performance of the exotic inbreds in the forest ecology of WCA.

MATERIALS AND METHODS

Germplasm

Forty maize inbred lines comprising of both adapted and exotic materials were used for this study. The maize lines were of different maturity groups and possess different levels of resistance to various field stresses. Sixteen of the lines were introduced from CIMMYT Mexico and Kenya, while others are lowland adapted lines from IITA, Nigeria. The attributes and stress adaptation of the lines is shown in Table 1.

Experimental protocol

The 40 maize inbred lines were evaluated in 2015 and 2016 cropping seasons (Table 1). Evaluations were carried out under artificial stem borer infested and non-infested conditions at Ibadan (Lat.7° 22'N, Long. 03° 58'E) in the derived savanna and Ikenne (Lat. 6° 54'N, Long.03° 42'E) in the humid forest zone of Nigeria. A Randomized Complete Block Design (RCBD) with three replications was used. In Ibadan, a plot was a single row of 7 m length. Half plot technique was employed by dividing each row into two halves of 3 m each, separated by 1 m in the middle. Spacing was 0.75 m between rows and 0.25 m within row. Two seeds were planted per hole but thinned to one plant per hill at three weeks after planting (WAP) just before infestation. A maximum of 13 plants per plot was obtained resulting in a plant density of 53,333 plants/ha. Each plant in the first half was artificially infested with egg masses of *S. calamistis* and *E. saccharina,* containing 30-40 eggs at black head stage, while the other half was left uninfested (control). *Sesamia* was introduced 3WAP, while plants were infested with *Eldana* at flowering. Evaluations in Ikenne were planted in 5 m single row plots and non-infested. All agronomic practices were carried out as appropriate at both locations.

Data collection

Number of days to 50% silking was determined as the number of days from planting to the day when half of the plants in a plot produced silk. Leaf feeding damage was rated on the infested plots at 3 weeks after infestation (WAI) on a scale of 1-9 based on visual rating, with 1 representing 0-5% defoliation of the leaf area of the plants in a plot, and 9 for 80-100% defoliation of the entire leaf area. Plant aspect was rated per plot after anthesis on a scale of 1 - 9, with 1- representing vigorous and appealing plants without lodging, leaf defoliation, nor disease symptoms and carrying their first ear at the middle of the plant, while 9 represents lodged, diseased and defoliated plants with their first ear closer to the soil surface or to the tassel. Plant height was measured in centimeters (cm) as average of five competitive plants as distance from the ground level to the collar of the upper most leaf after flowering. Stalk breakage was counted at maturity as number of broken stalks above the first ear per plot and expressed as percentage of plant stand. Cob damage was recorded at harvest as the number of damaged cobs due to stem borer infestation and expressed as percentage of number of ears at harvest. Stem tunneling was assessed on five competitive plants per plot after harvesting by splitting each plant stalk longitudinally and measuring the length tunneled by the insect larvae. The length was then expressed as percentage of the plant height.

After taking cob weights, small quantities of shelled grains were taken per plot to determine grain moisture content using Dickey-John moisture meter, Mini GAC® 2500, United States. Grain yield (t/ha) adjusted to 15% moisture content, was calculated from ear field weight (FWT) per plot, assuming 80% shelling percentage. Percentage yield reduction was estimated from grain yield on

Table 1. Source, kernel colour and attributes of the maize inbred lines used for the evaluation.

Lines	Source	Kernel colour	Attributes
CML 67	CIMMYT Mexico	Yellow	Resistant to SWCB/FAW
CML 70	CIMMYT Mexico	Yellow	Resistant to SWCB/FAW
CML 139	CIMMYT Mexico	Yellow	Resistant to SWCB/FAW
CML 334	CIMMYT Mexico	White	Resistant to SWCB/FAW
CML 331	CIMMYT Mexico	Yellow	Resistant to SWCB/FAW
CML 345	CIMMYT Mexico	White	Resistant to SCB/FAW
CML 71	CIMMYT Mexico	Yellow	Resistant to SWCB/FAW
CML 338	CIMMYT Mexico	Yellow	Resistant to SWCB/FAW
CML 346	CIMMYT Mexico	White	Resistant to SCB/FAW
BD74-219	CIMMYT Kenya	Yellow	Elite yellow
BD74-59	CIMMYT Kenya	White	Low nitrogen tolerant
BD74-221	CIMMYT Kenya	Yellow	Elite yellow
BD74-164	CIMMYT Kenya	Yellow	Drought tolerant
BD74-162	CIMMYT Kenya	Yellow	Drought tolerant
BD74-217	CIMMYT Kenya	Yellow	Elite yellow
BD74-161	CIMMYT Kenya	Yellow	Drought tolerant
BD74-395	CIMMYT Kenya	White	Low nitrogen tolerant
TZEI 2	IITA Nigeria	White	Early maturing
TZEI 158	IITA Nigeria	Yellow	Early maturing
TZEI 9	IITA Nigeria	White	Early maturing
TZEI 18	IITA Nigeria	White	Early maturing
TZEI 46	IITA Nigeria	White	Early maturing
TZEI 89	IITA Nigeria	White	Early maturing
TZEI 5	IITA Nigeria	White	Early maturing
TZEI 1	IITA Nigeria	White	Early maturing
TZEI 60	IITA Nigeria	White	Early maturing
TZEEI 29	IITA Nigeria	White	Extra-early maturing
TZEEI 21	IITA Nigeria	White	Extra-early maturing
TZEEI 13	IITA Nigeria	White	Extra-early maturing
TZEEI 14	IITA Nigeria	White	Extra-early maturing
TZEEI 55	IITA Nigeria	White	Extra-early maturing
TZEEI 15	IITA Nigeria	White	Extra-early maturing
5012	IITA Nigeria	White	Drought tolerant and streak resistant
4001	IITA Nigeria	Yellow	Striga resistant , low nitrogen tolerant
9071	IITA Nigeria	White	Striga resistant, drought tolerant and streak resistant
1368	IITA Nigeria	White	Streak resistant, striga resistant and drought tolerant
5057	IITA Nigeria	White	Drought tolerant and streak resistant
9450	IITA Nigeria	Yellow	Striga resistant, streak resistant, drought and low nitrogen tolerant
9030STR	IITA Nigeria	White	Striga resistant, drought tolerant and streak resistant
KU1414SR/SR	IITA Nigeria	Yellow	Drought tolerant and streak resistant

SCB- Southern corn borer; SWCB- South western corn borer; FAW- Fall armyworm; SR- Streak resistance.

infested and non-infested plots and adjusted by the extent of stem tunneling to obtain level of tolerance of the maize inbreds according to Ajala (1992).

Data analyses

Percent data were transformed using arcsine before analysis. Means and ranges were estimated. Means of the maize lines were separated using the least significant difference (LSD). Analysis of variance (ANOVA) was performed using Proc Mixed of SAS, version 9.1. Combined ANOVA was conducted separately for data collected under infested and non-infested conditions from which estimates of variance components were generated. Broad-sense heritability was estimated from the variance components on entry-mean basis. The location-year combinations were considered as environment in the ANOVA. The effects of environments, replication, and environment by lines interaction were considered random, while effect of maize lines was considered fixed.

Expected gains from selection (Gs) and standard error of heritability were computed according to Hallauer and Miranda (1988). Expected gains (Gs) was estimated as:

$Gs = k\, \sigma^2 g / \sigma p$

Where k = standardized selection differential at 20% selection intensity (k=1.399), $\sigma^2 g$ = genotypic variance, and σp denotes square root of phenotypic variance. Gains were expressed as percentage of means for easier comparison.

Rank Summation Index (RSI) of Mulumba and Mock (1978) was used to rank the maize lines using plant aspect, stalk breakage, grain yield, cob damage and tolerance as selection criteria. This was used to select the top maize lines based on 20% selection intensity. Principal component analysis was also conducted to determine contribution of traits to the variation observed using data from the infested plots. The traits contributing most to the variation were used to perform cluster analysis on the inbreds. Similarity was measured based on Euclidean distance.

RESULTS

Mean performance of the maize inbreds is shown in Table 2. The CMLs had relatively good grain yield except CML 67 (0.19 tons ha^{-1}) and CML 71 (0.06 tons ha^{-1}), despite the high level of stem tunneling, stalk breakage and cob damage. CML334 had the highest yield (4.46 tons ha^{-1}) followed by CML 331 (2.42 tons ha^{-1}). Among the BDs, BD 74-395 was the highest yielding (1.45 tons ha^{-1}) despite the high stalk breakage and cob damage recorded. Among the IITA lines, KU1414SR/SR, 1368 and 9030STR had significantly high mean grain yield of 1.71, 1.39 and 1.19 tons ha^{-1} respectively. Among these lines, 1368 had the lowest stem tunneling and stalk breakage with moderate leaf feeding damage (Table 2).

Means of stalk breakage and cob damage were high among the maize lines (Table 3). Range was high for all the traits studied. Moderate to high heritability was observed for the damage parameters ranging from 30.51% for tolerance to 68.9% for cob damage except for stem tunneling (Table 3). Heritability was however low for grain yield under stem borer infestation (10%). Genetic gains were generally low for the damage parameters. Only stem tunneling had negative genetic gain. Heritability was generally low among the agronomic traits measured with increased genetic gains. Days to 50% silking (27.25%) had the highest broad-sense heritability value.

Combined analysis of variance revealed significant mean squares for the maize lines, and line × environment interaction for all the traits under infested and non-infested conditions (Table 4). Mean square of environment was significant for grain yield both under infested and non-infested conditions. Mean square for environment was significant for all the damage parameters except for stalk breakage. The top 20% maize lines selected by RSI are shown in Table 5. Line 1368 was selected as the best followed by 9450 and 4001. CML 334, a stem borer resistance source ranked fifth on the list. Out of the eight selected lines, five were selected from IITA lines, while two were selected from the BD lines. Only CML334 was selected among the CML lines.

From the result of principal component analysis, PCA 1, 2 and 3 accounted for 90% of the variation (Table 6) with days to 50% silking, plant height, yield loss, tolerance, cob damage and stalk breakage being responsible for this variation. Based on these traits, a dendrogram was developed (Figure 1). At 30% similarity distance, six distinct groups were identified. It is worth noting that the best 8 entries (on 20% selection intensity) were grouped into the best three clusters (G2, G3, G4) based on data from infested plots (Figure 1). Inbred CML 334, the only CML among the best 8 inbreds, stood alone in a group (G3) with the highest grain yield despite its high percentage cob damage and stalk breakage. Inbred 1368, 4001, BD 74-219, BD74- 395 and KU1414SR/SR also formed one of the best groups (G4) with good grain yield and tolerance level and low stalk breakage. Inbred 9450 and TZEI 2 clustered in G2 (Figure 1).

DISCUSSION

Mean performance of the lines, the wide ranges and the moderate to high heritability of most of the stem borer damage parameters showed a high level of variability among the maize lines for stem borer resistance and that the traits are under genetic control. The wide range is expected because the lines are from diverse background, maturity group as well as diverse stress adaptations. The high heritability for the damage parameters indicated that rapid progress would be achieved in selection. Ajala (1992) also reported moderate heritability for resistance to the spotted stem borer, *Chilo partellus.* The low heritability for plant aspect, plant height and grain yield under infestation indicated that expression of the traits is greatly influenced by the environment and direct selection for the characters may be ineffective. The low heritability for grain yield under infested condition was also reported by Oloyede-Kamiyo (2013) in DMR ESR-Y maize population under stem borer infestation.

The CMLs having high grain yield despite the high level of damage showed that they are tolerant to stem borer infestation. The CML lines were actually developed at CIMMYT for resistance to different species of stem borers. BD74-395 with high grain yield despite the high stalk and cob damage showed that it is a stem borer resistance source. Inbred 1368 is also a promising source of stem borer resistance. It is used as a general check at IITA for various field stresses. Hence, inbred CML 334 and BD74-395 are good exotic stem borer resistance lines which could be adopted in stem borer breeding programs in the tropics. White et al. (2011) reported that hybrids derived from local × exotic germplasm (temperate adapted × tropical parents) successfully combined the high biomass potential of

Table 2. Mean performance of the 40 maize inbreds evaluated under artificial stem borer infestation in Ibadan in 2015 and 2016.

Inbreds	Days to 50% silking	Plant height (cm)	Plant aspect (1-9)	Stem tunneling (%)	Leaf feeding damage (1-9)	Stalk breakage (%)	Cob damage (%)	Grain yield (tons/ha)	*Tolerance
1368	63.33	144.00	3.67	8.00	3.00	0.00	36.67	1.39	-1.37
4001	60.33	132.67	3.67	13.67	3.00	0.00	21.67	0.68	0.81
5012	57.67	155.00	4.33	11.00	3.33	30.00	75.40	0.65	4.18
5057	69.67	112.67	5.00	5.67	4.33	9.70	66.67	0.48	-20.00
9030STR	62.67	106.17	4.67	8.95	3.17	15.06	52.22	1.19	-5.26
9450	63.00	116.67	3.00	4.33	3.67	9.09	0.00	0.81	-13.86
BD74-161	61.00	89.33	5.33	6.00	3.00	72.22	83.33	0.27	-9.52
BD74-162	63.17	102.67	4.33	7.17	2.83	0.00	85.71	0.75	-25.31
BD74-164	58.33	144.33	4.33	11.33	2.40	15.38	54.17	0.94	-8.28
BD74-217	64.00	96.67	4.33	7.33	3.00	34.07	56.35	0.50	-8.14
BD74-219	58.00	148.00	2.67	12.67	2.00	10.26	37.50	1.30	1.51
BD74-221	66.50	94.83	4.00	8.78	3.00	9.26	64.29	0.88	-9.02
BD74-395	60.67	138.83	4.00	5.35	3.50	19.44	57.80	1.45	-12.80
BD74-59	71.33	100.67	5.33	12.00	4.67	33.33	25.00	0.41	-
CML 139	59.33	127.33	5.00	2.67	2.67	5.56	0.00	0.44	0.00
CML 331	63. 00	124.00	4.17	14.45	3.00	6.48	85.00	2.42	-1.71
CML 334	65.00	124.83	4.50	5.12	3.50	28.24	47.44	4.46	-66.65
CML 338	59.67	165.67	3.17	14.18	3.17	15.81	57.14	1.86	0.82
CML 345	60.67	107.83	4.50	16.82	3.50	7.41	83.33	0.84	-5.46
CML 346	60.67	115.00	5.00	15.00	4.67	14.69	25.00	0.45	1.33
CML 67	64.67	76.33	4.33	0.00	4.33	36.36	33.33	0.19	.-
CML 70	65.67	107.00	4.33	10.90	2.67	5.56	75.40	0.68	2.39
CML 71	71.33	76.33	5.33	5.33	3.33	6.67	155.56	0.06	10.00
KU1414SR/SR	67.33	127.17	3.83	10.35	2.50	10.37	56.67	1.71	-1.00
TZEEI 13	57.83	111.00	4.50	12.57	3.33	33.84	66.94	0.78	7.30
TZEEI 14	55.17	98.17	4.67	3.62	3.50	10.28	50.40	0.78	-0.48
TZEEI 15	60.00	90.50	5.50	5.00	2.83	0.00	40.00	0.22	6.00
TZEEI 21	55.00	121.17	5.00	8.35	2.83	21.69	86.67	0.66	5.75
TZEEI 29	56.67	117.33	6.00	11.13	3.17	43.91	80.16	0.75	-0.78
TZEEI 55	57.50	101.50	5.50	1.00	4.25	32.37	78.57	0.21	-18.75
TZEI 1	59.67	126.67	4.00	10.72	3.50	16.92	66.87	1.10	-1.76
TZEI 158	56.17	94.67	5.83	0.00	3.33	4.23	83.33	0.36	.-
TZEI 18	58.00	113.50	4.33	6.60	3.83	34.89	81.11	0.91	1.45
TZEI 2	58.17	103.50	4.00	12.10	3.50	11.03	55.56	1.18	-8.43
TZEI 46	59.00	113.33	5.17	7.07	3.83	40.28	87.96	0.69	-107.40
TZEI 5	60.33	110.17	5.00	10.88	3.00	37.15	68.52	0.73	-1.13
TZEI 60	62.17	144.00	4.83	13.75	3.17	21.17	48.33	0.46	-1.47
TZEI 89	56.33	120.33	5.17	11.48	3.83	42.58	61.67	0.71	7.21
TZEI 9	54.67	86.50	5.50	0.00	3.50	30.70	61.91	0.96	.-
Mean	60.74	115.05	4.58	8.72	3.28	19.85	63.79	1.01	-7.94
S.E	0.34	1.69	0.08	0.54	0.08	1.61	3.1	0.11	3.18
LSD (0.05)	6.25	30.61	1.41	0.23	0.97	0.45	0.49	1.52	65.13

*The lower the value, the better the tolerance. The negative values are equated to zero.

tropical maize with the genetic improvements from the past century of corn breeding for high grain yields in temperate environments.

The low genetic response for the traits studied indicates slow progress from selection. However, the estimated negative gains for stem tunneling indicated that stem tunneling will reduce with selection. The significant means squares of lines for days to flowering, plant height and

Table 3. Mean± S.E, range and estimate of genetic variability of characters of the maize inbreds under artificial stem borer infestation in Ibadan in 2015 and 2016.

Traits	Mean ± S.E	CV (%)	Range	H^2 (%) ± S.E	Expected gain	Gain as% of mean
Days to 50% silking	60.74±0.34	6.36	53.0 -75.0	27.25± 0.45	0.94	1.54
Plant height (cm)	115.05±1.69	16.29	63.0-172	3.02± 14.28	0.52	0.85
Plant aspect (1 – 9)	4.58±0.08	19.22	2.0-8.0	8.12± 0.03	0.06	0.10
Stem tunneling (%)	8.72±0.54	54.97	0- 36.3	-5.75± 0.001	-0.01	-0.01
Leaf feeding damage (1 – 9)	3.28±0.08	18.08	0-5.0	49.54± 0.01	0.29	0.48
Stalk breakage (%)	19.85±1.61	69.59	0-100.0	42.90± 0.003	0.13	0.21
Cob damage (%)	63.79±3.10	31.65	0-100.0	68.86± 0.002	0.20	0.32
Grain yield (t/ha)	1.01±0.11	25.36	0- 11.86	10.00± 0.06	0.11	0.18
Tolerance	-7.94±3.18	-326.1	-350- 24.99	30.51± 24.03	7.79	12.82

CV: Coefficient of variation; S.E: Standard error; H^2: Broad-sense heritability.

Table 4. Mean squares from combined analysis of variance of characters of the 40 maize inbreds evaluated under artificial stem borer infestation at Ibadan and under non-infested condition at Ibadan and Ikenne in 2015 and 2016.

Source	df	Days to 50% silking	Plant height (cm)	Plant aspect (1-9)	Grain yield (tons/ha)	Leaf feeding damage (1-9)	Stem tunneling (%)	Stalk breakage (%)	Cob damage (%)	Tolerance
Infested condition										
Env	1	214.65**	214.40	0.51	124.93**	61.88**	0.10*	0.17	17.52**	284.21
Rep (Env)	4	49.86	1198.11	12.10	0.27	0.75	0.07	0.10	0.03	710.92
Inbreds	39	36.23**	905.44*	1.74**	4.07**	1.06**	0.04**	0.26**	0.25**	1993.8**
Env x Entry	32	26.36*	878.26**	1.60**	3.69**	0.53**	0.04**	0.15**	0.08	1385.3**
Error	126	14.94	358.58	0.76	0.89	0.36	0.02	0.08	0.09	638.93
Non-infested condition										
Env	3	33.40	28930.02**	76.74**	25.68**	-	-	-	-	-
Rep (Env)	8	29.96	1847.40	4.79	0.77	-	-	-	-	-
Inbreds	38	36.54**	1283.69**	2.40**	0.97**	-	-	-	-	-
Env x Entry	85	30.92**	1174.53**	2.08**	1.24**	-	-	-	-	-
Error	236	14.00	410.99	0.69	0.29	-	-	-	-	-

*, **: Significant at P = 0.05 and 0.01 respectively.

Table 5. Means of the top performing inbreds (20% selection intensity) from the evaluation of the 40 maize inbreds under stem borer infested condition at Ibadan in 2015 and 2016.

Selected inbreds	Gain yield (tons/ha)	Plant aspect (1-9)	Cob damage (%)	Stalk breakage (%)	*Tolerance	RSI
1368	1.4	4	36.7	0	-1.3	36
9450	0.8	3	0.0	9.1	-13.0	48
4001	0.7	4	21.7	0.0	0.8	58
BD74-219	1.3	3	37.5	10.3	1.5	58
CML 334	4.5	4	47.4	28.2	-66.7	58
TZEI 2	1.2	4	55.6	11.0	-8.4	61
BD 74-395	1.5	4	57.8	19.4	-12.8	62
KU1414SR/SR	1.7	4	56.7	10.4	-1.0	63

*The lower the value, the better the tolerance. Negative values are equated to zero.

grain yield was also reported by Mary (2016) for tropicalized temperate maize lines under well watered and water-stress conditions. The significant mean squares of lines for all the traits studied suggested that the traits

Table 6. Percentage variation from the principal component (PC) analysis.

PC	Eigenvalue	% variance
1	5327.46	67.719
2	996.59	12.668
3	868.87	11.045
4	243.42	3.094
5	128.38	1.632
6	121.38	1.543
7	68.56	0.871
8	51.06	0.649
9	32.71	0.416
10	16.25	0.207
11	8.80	0.112
12	1.81	0.023
13	0.85	0.011
14	0.29	0.004
15	0.23	0.003
16	0.19	0.002
17	0.11	0.001

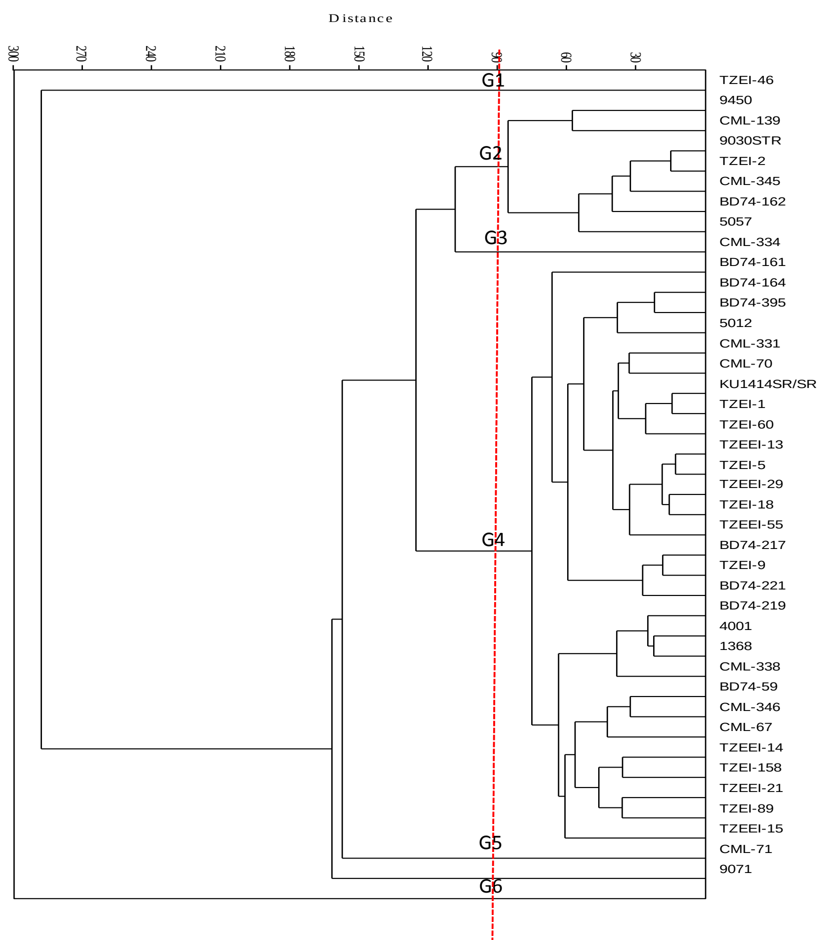

Figure 1. Dendrogram of the 40 maize inbred lines based on Euclidean similarity distance.

are under genetic control and improvement can be made. The significant line by environment interaction for the traits suggests that the lines responded differently in the test environments.

The RSI ranking selected lines with different genetic backgrounds from CIMMYT and IITA as the top 20%. BD74-395 is a low nitrogen tolerant line, while BD74-219 is an elite yellow inbred line and both are from CIMMYT, Kenya. CML 334 is a borer resistant line (resistant to southwestern corn borer and fall armyworm) from CIMMYT Mexico, while the others (1368, 9450, 4001, TZEI 2, KU1414SR/SR) are elite tropical lines tolerant to different field stresses from IITA, Nigeria currently used in hybrid production. This suggests good adaptation of the exotic lines in the low land ecology of WCA and also an indication that the lines have direct utility for breeding for resistance to *S. calamistis* and *E. saccharina.* Goodman (1999) reported that tropical germplasm has traditionally been used in the U.S. as a source of disease- and insect-resistance. Hallauer and Carena (2013), in a study involving four populations with 25% tropical germplasm and four populations with 100% exotic germplasm reported that the yield of the 25% tropical germplasm was significantly greater (average yield of 7.72 tons/ha) than that of the exotic (average yield of 6.47 tons/ha). They were therefore reported to have potential as alternative sources of germplasm for temperate environments.

The result of the cluster analysis complemented that of the RSI. Some of the lines selected as the best by RSI also cluster together in the dendogram. Ajala et al. (1995) stated that the possible limitation of RSI is its inability to indicate significant differences between ranks to enable classification of varieties into homogenous groups. Result of the present study suggested that the perceived limitation is not a hindrance to the use of RSI for selection purposes. In summary, there is existence of useful genes for adaptability and resistance to stem borers in the exotic maize inbreds which could be exploited for breeding purposes in WCA. Planned crosses involving IITA and CIMMYT inbreds could produce outstanding hybrids for commercialization in SSA.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Agro-morphological characterization of some taro (*Colocasia esculenta* (L.) Schott.) germplasms in Ghana

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Taro (*Colocasia esculenta* (L) Schott.) is one of the underutilized crops in Ghana which has great potential in terms of food and nutritional value. Eighteen (18) accessions collected from Samoa (8), Malaysia (2), Indonesia (2) and Ghana (6) were studied under field conditions to collect data on their agro-morphological characteristics and yield potential for the development of the crop. The study was conducted at Nobewam in the Ejisu-Juaben Municipality in Ashanti Region. Randomized complete block design (RCBD) was used with three replications. Data were collected for 16 qualitative and 13 quantitative traits. Variations were observed in the vegetative and yield components. Plant height of the accessions ranged from 66.1 to 110.4 cm; corm length ranged from 12.5 to 18.5 cm; the maturity period ranged from 7 to 9 months and the corm weight ranged from 0.26 to 0.79 kg. Significant differences (p<0.05) were observed, indicating higher degree of variability in the accessions. Significant (p<0.001) and positive correlations were observed between corm length and corm diameter; economic (corm) yield and biological (stover) yield, corm diameter, corm length and corm weight. Leaf length correlated positively with corm diameter and corm weight. The principal component analysis (PCA) showed that the first component (PC1) accounted for 53.98% of the morphological traits. Nine accessions: CE/MAL/32, BL/SM/158, BL/SM/10, BL/SM/116, CE/IND/16, BL/SM/132, BL/SM/16, CE/MAL/14 and SAO/006 possess desirable characters such as earliness and yield which could be exploited for varietal development of taro in Ghana.

Key words: Agro-morphological traits, characterization, *Colocasia esculenta*, principal component analysis.

INTRODUCTION

Taro, Colocasia esculenta (L) Schott is a member of the monocotyledonous family, Araceae and sub-family, Aroideae (Lebot, 2009; Van Wyk, 2005). Taro is the most widely cultivated species in the Colocasia genus (Vinning, 2003) and it is the fourth most consumed tuber crop in the world (Revill et al., 2005).

Taro is important for food security since many tropical areas often experience unfavorable environmental

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conditions (Singh et al., 2012). The crop is widely cultivated in Africa, especially in Ghana (Darkwa and Darkwa, 2013) where it represents the third most important root crop after yam and cassava (Nwanekezi et al., 2010) and in more than 65 countries worldwide (USDA, 2001). Globally, about 12 million tons of taro are produced from 2 million hectares of land with an average of 6 tons per hectare (FAOSTAT, 2010).

The corm of taro is an excellent source of carbohydrate and its digestibility is estimated to be 98% (Deo et al., 2009). Due to its ease of assimilation, it is suitable for persons with digestive problems. Taro is useful to people allergic to cereals and can be consumed by children who are sensitive to milk and as such its flour is used in infant food formulae (Opara, 2001). The leaves of taro have higher levels of protein, potassium, calcium, phosphorous, iron, vitamin A, thiamine, niacin, riboflavin and dietary fibre (Xu et al., 2001; Yared, 2007).

Taro has enormous health benefits which include building strong immune system, lowering blood pressure, reducing weight gain and fatigue, preventing cell damage, building strong bone and also supports thyroid function (Misram and Sriram, 2002).

In Ghana, taro has been cultivated mainly in extensively dense populated high rainfall areas of the country (Ofori, 2003). Taro is cultivated mainly in developing countries using low input production systems. It is generally considered as an easy crop to grow provided there is adequate rainfall (Matthews, 2010). It has been used as a potential crop in Ghana since the 1983 famine and used as gap filling seasonal food crop when other crops are not available (Chaïr et al., 2016). In spite of taro's value as food source and other enormous benefits and uses, it is still considered as an 'orphan' crop in Ghana.

The taro industry in West Africa provides very useful source of livelihood; however, the crop is getting extinct especially in Ghana due to several biophysical and socio-economic factors (Darkwa and Darkwa, 2013). Considering the socio-economic importance of taro in the Pacific countries and in West Africa, a concerted effort that will be beneficial to both regions especially in Ghana should be sought. This would go a long way to improve the role of taro in providing staple food and income for taro socio-economic groups in Ghana. For any effective work to be done on taro, it is important to know its characteristics (both qualitative and quantitative) in local and exotic accessions found in Ghana. The characteristics of these accessions will serve as the basis for selection of accessions that are high yielding, nutritious and tolerant to the taro leaf blight disease in Ghana. This will help identify their characteristics and their qualities for further improvement and will be very important in both germplasm conservation and the root and tuber improvement program of the country.

The objective of the study was therefore, to determine the qualitative and quantitative characteristics of taro germplasm using agro-morphological traits.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at Nobewam in the Ejisu-Juaben Municipal. The site is situated at latitude 06° 41'N and longitude 01° 23'W with an altitude of 228.7 m above sea level. The area has a bimodal rainfall pattern and receives mean annual rainfall of 2000 mm with maximum and minimum temperatures of 32.1 and 21.8°C, respectively (Meteorological Department, Ejisu Ashanti, 2014). The soil of the area has a pH of 5.3 to 6.5 (MOFA Ejisu-Juaben District, 2012). The environmental conditions are conducive for the production of *Colocasia esculenta* (L.) Schott.

Accessions evaluated

Eighteen *C. esculenta* (L.) Schott accessions were used in the study. The accessions used consisted of 12 exotic accessions from South-East Asia and 6 locals obtained from the Crops Research Institute (CRI) in Fumesua, Kumasi, Ghana.

The exotic ones were obtained from Malaysia, Indonesia, Samoa, while the local ones were obtained from different parts of Ghana which included Ejisu in the Ashanti Region, Magrivi and Gambia No. 2 in the Brong Ahafo Region, Ankokrom in the Central Region, Akrofo-Agove in the Volta Region and Bunso in the Eastern Region.

Experimental design

The experiment was laid out in a randomized complete block design (RCBD) using 20 m × 12 m plots with three replications. A single row plot, with each row 10 m long was used. Ten plants were spaced 1 m between rows and 1 m between plants. The planting materials were raised from tissue culture materials at Crop Research Institute and planted in November, 2014.

Data collection

Descriptors of taro (*C. esculenta* (L.) Scott.) developed by International Plant Genetic Resource Institute (IPGRI)/International Institute for Tropical Agriculture (IITA) (1999) were used for data collection.

Among the descriptors developed by IPGRI/IITA (1999) to characterize taro cultivars, 16 qualitative and 13 quantitative traits were measured. Both foliar and subterranean data were considered. Foliar traits were measured at five months after planting, while, subterranean traits were evaluated at harvest (at nine months). Quantitative traits were recorded on individual plant basis using sample average of five plants selected at random from the row. While for the qualitative traits, only the first replications of the experiment were considered, whereas for quantitative characters, the entire replications were considered.

A total of 29 plant characteristics, split into vegetative and corm characteristics were used to characterize the accessions as described by IPGR/IITA (1999). Qualitative traits were stolon and sucker formation, shape of lamina, orientation of lamina, leaf lamina margin, lamina colour, variegation of lamina, sinus, colour of leaf petiole, variation on petiole, flowering, maturity, leaf lamina margin colour, leaf vein pattern, corm shape and corm flesh colour. The quantitative traits measured were corm weight, corm length, corm diameter, plant height, number of leaves, leaf length, leaf width, number of stolons, number of suckers, economic yield, biological yield, dry matter and harvest index.

Table 1. Frequency distribution of leaf characteristics of the taro accessions

Qualitative trait	Description Adopted	No. of accessions	Frequency (%)
Shape of lamina	Flat	18	100
Orientation of lamina	Tip pointing downwards	7	38.9
	Semi-horizontal	11	61.1
Leaf lamina margin	Undulated narrow waves	18	100
Lamina colour	Green	9	50
	Light green	3	16.7
	Dark green	3	16.7
	Yellow green	3	16.7
Variegation of lamina	Absent	14	77.8
	Present	4	22.2
Leaf lamina margin colour	Purple	13	72.2
	Green	5	27.8
Leaf vein pattern	Y-pattern	18	100
Sinus	Wide	18	100

Table 2. Frequency distribution of petiole characteristics of the taro accessions.

Qualitative trait	Description adopted	No. of accessions	Frequency (%)
Colour of leaf petiole	Green	4	22.2
	Light green	4	22.2
	Yellow green	3	16.7
	Dark green	2	11.1
	Light purple	1	5.6
	Dark purple	2	11.1
	Blackish	2	11.1
Variegation on petiole	Absent	15	83.3
	Present	3	16.7

Statistical data analysis

Data for quantitative characters were subjected to analysis of variance (ANOVA) using Genstat Release 12.1. Least significant difference (LSD) was used to separate the means at 5% probability level ($P<0.05$). Pearson correlation, principal component and clustering of genotypes were carried out to assess the diversity between genotypes for the traits measured.

RESULTS

Frequency distribution of major qualitative traits

Vegetative characters

Tables 1 to 4 show variation in qualitative traits. A wide range of variations were observed among the 18 taro accessions that were studied with regards to agro-morphological characters that were assessed. Variation was shown in major phenotypic characters in foliar and subterranean plant parts. However, no variation was seen in some characters such as shape of lamina, leaf lamina margin, leaf vein pattern and sinus as they appeared similar for all accessions.

Leaf characteristics

Out of the eight phenotypic classes of this character, four showed variation among the accessions while four were

Table 3. Frequency distribution of corm characteristics of 18 the taro accessions.

Qualitative trait	Description adopted	No. of accessions	Frequency (%)
Corm shape	Elliptical	9	50.0
	Dump-bell	1	5.6
	Cylindrical	3	16.7
	Conical	5	27.8
Corm flesh colour	Pink	3	16.7
	Purple	1	5.6
	White	5	27.8
	Brown	1	5.6
	Light yellow	6	33.3
Corm eating quality	Yellowish	2	11.1
	Poor	0	0.0
	Ok	6	33.3
	Good	12	66.7

Table 4. Frequency distribution of other qualitative characteristics of the 18 taro accessions

Qualitative trait	Description adopted	No. of accessions	Frequency (%)
Sucker formation	Absent	3	16.7
	Present	15	83.3
Stolon formation	Absent	7	38.9
	Present	11	61.1
Flower formation	Flowering	9	50
	Rarely flowering	2	11.1
	Absent	7	38.9
Maturity	Early	3	16.7
	Medium	9	50
	Late	6	33.3

similar. The cultivars studied showed that 61.1% (representing 11 accessions) had semi-horizontal leaf orientation and 38.9% that represents seven accessions had the tip of the leaf pointing downwards (Table 1 and Figure 1). Four predominant leaf lamina colours were observed among the accessions. These were 50 (green), 16.7 (light green), 16.7 (yellow green) and 16.7% (dark green).

With respect to leaf lamina margin colour, the accessions fell into two categories as purple (72.2%) and green (28.8%). A little over 22% of the accessions exhibited variegation of the lamina with the rest of the accessions (77.8%) showing no variegation of the lamina.

In this study, all the taro accessions had Y-shaped leaf vein pattern, undulated leaf lamina margin, flat lamina shape and wide (>45°) sinus.

Petiole characteristics

Table 2 and Figure 2 show variation among the taro accessions based on petiole characteristics.In this study, seven distinct petiole colours were exhibited by the accessions. Over 22% of the accessions exhibited green and light green colours each, 16.7% of the accessions exhibited yellow green petiole colour. Dark green, light purple and blackish petiole colours which represents 11.1% each for dark green, light purple and blackish clours respectively was seen for some of the accessions. Light purple colour was exhibited by only accession

Figure 1. Photograph showing leaf vein pattern and variability in petiole colour of the accessions of taro

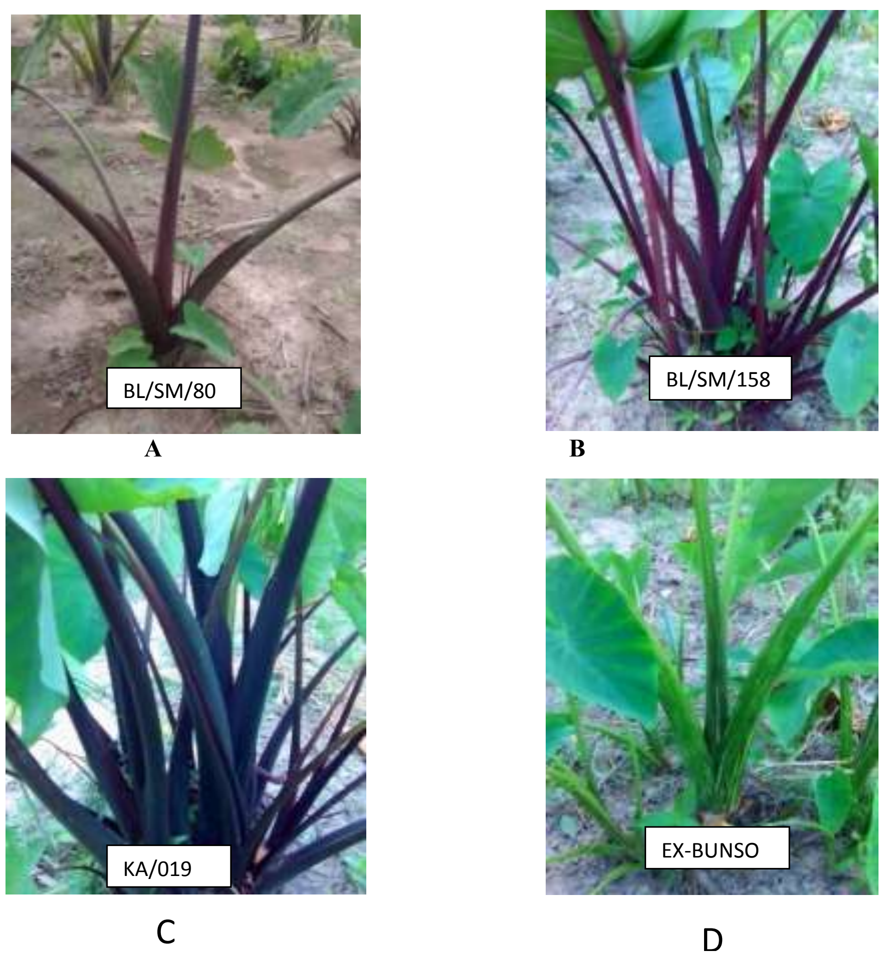


Figure 2. Variation in Petiole Colour of the Accessions

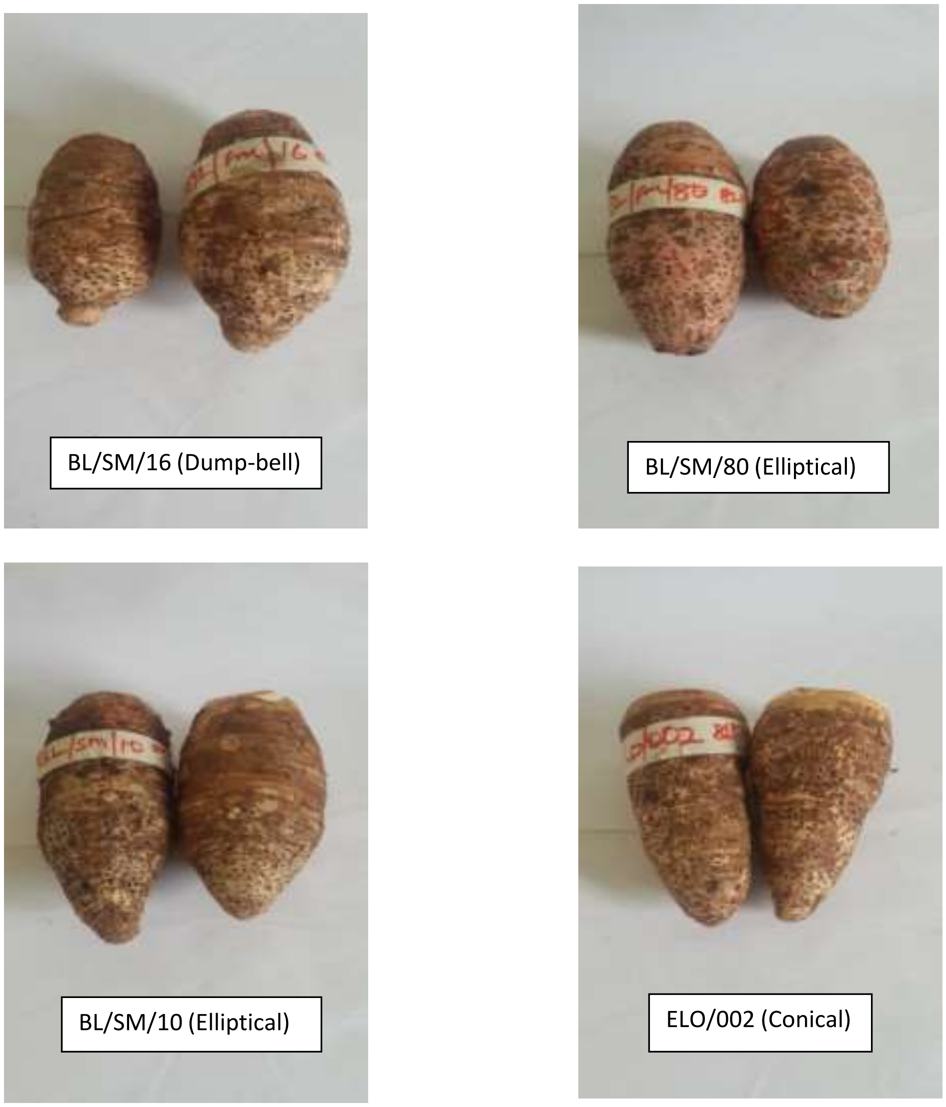


Figure 3. Variation in Corm Shape of the Accessions

(5.6%).

Variegation on the petiole were present in three accessions (16.7%) while the rest of the accessions (83.3%) did not show any variegation on the petiole.

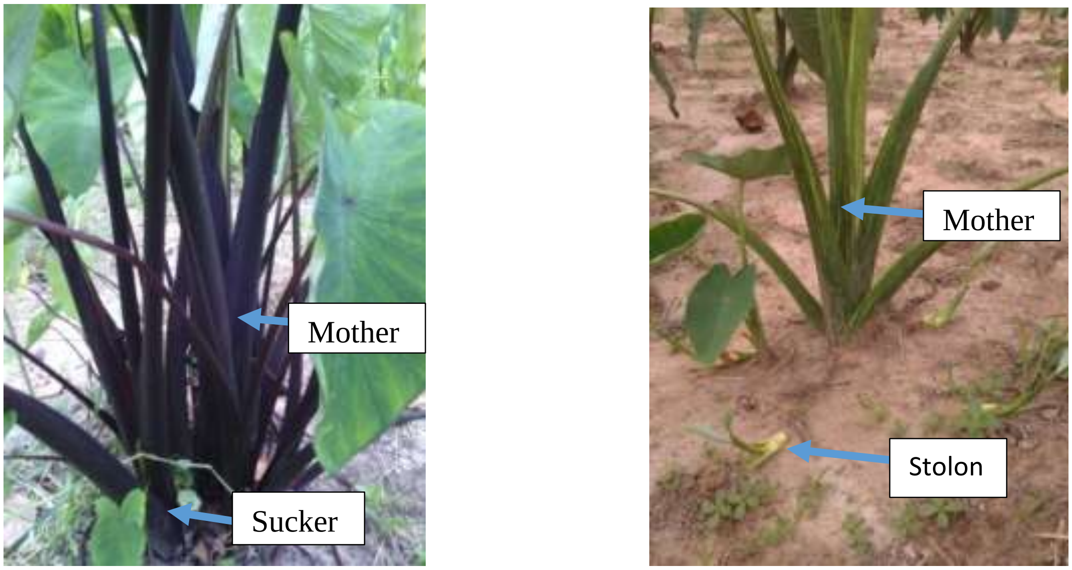
Corm characteristics

Table 3 and Figure 3 show the variation in corm characteristics of the accessions. Corm flesh colour of the accessions ranged from pinkish white (16.7%), purple (5.6%), white (27.8%), brown (5.6%), light yellow (33.3%) and yellowish (11.1%). The corm shape of *C. esculenta* varied from elliptical (50%), dump-bell (5.6), cylindrical (16.7%) to conical (27.8%).

The maturity of the accessions were classified as early (16.7%), medium (50%) and late (33.3%). Assessement based on corm eating quality was put into three groups as poor (Corm Quality Score (CQS) =1-<1.50), ok (1.50-<2.25) and good (2.25-<3.00). Twelve out of the 18 accessions (66.7%) were classified as good, 6 accessions (33.3%) were on the other hand ok with none of the accessions having a poor eating quality of the corm.

Stolon/sucker formation and flowering

Table 4 and Figure 4 show variation in stolon and sucker formation and Figure 5 shows variation in flower formation among the accessions. Sixty-one percent of the accessions had stolons, while 38.1% had no stolon. For sucker formation, 16.7% of the accessions did not show any formation of suckers while 83.3% had suckers. Forthy-four percent of the accessions exhibited the



(a) Mother plant and sucker (b) Mother plant and stolons

Figure 4. Variability in suckering and stolon formation of the accessions of taro

(a) Introduced accession with flowers (b) Local accession without flowers

Figure 5. Flowering ability of local and introduced accessions of taro (The arrow shows the flower).

formation of both stolons and suckers. Flowering was observed in 61.1% of the accessions and 38.9% did not flower.

Variation in quantitative traits

The analysis of variance for quantitative traits showed significant difference ($p<0.05$) among the 18 taro accessions for all the characters examined (Table 5). Among the accessions, plant height ranged from 66.09 to 110.40 cm. Plant height was highest in accession CE/MAL/32 (110.40 cm) with accession BL/SM/115 recording lowest plant height (66.09 cm). Leaf length ranged from 29.3 to 46.9cm. Accession BL/SM/116 recorded the highest leaf length (46.9 cm) and accession BL/SM/115 however showed the lowest leaf length (29.3 cm). Leaf width ranged from 20.1 to 34.4 cm with

Table 5. Variation in quantitative traits of the 18 taro accessions

Accession	PH (cm)	LL (cm)	LW (cm)	NLP	NStP	NSuP	CL (cm)	CD (cm)	CW (kg)	EY (kg)	BY (kg)	HI (%)	DM (%)
CE/MAL/32	110.4	44.8	34.4	5.6	6.2	3.1	17.8	31	0.79	0.20	0.22	90.9	32.7
BL/SM/10	101.6	39.8	26.5	5.6	3.9	0.0	18.5	27.6	0.77	0.19	0.27	70.4	27.7
BL/SM/16	90.6	43.1	28	5	3.7	1.6	14.9	26.4	0.47	0.13	0.16	81.3	28.0
BL/SM/116	99.1	46.9	32.4	5.1	4.3	2.0	17.3	28.7	0.68	0.21	0.22	95.5	35.3
BL/SM/80	84.8	34.5	23.7	4.8	0.0	5.0	16.3	24.7	0.52	0.19	0.20	95.0	35.3
CE/IND/12	79.1	37.4	26.1	4.8	0.0	2.3	15.4	26.8	0.56	0.18	0.21	85.7	32.0
BL/SM/115	66.1	29.3	20.1	4.4	0.0	3.2	12.5	20.5	0.28	0.11	0.12	91.7	32.0
BL/SM/151	91.9	42.6	29.6	5.3	3.4	1.6	12.7	22.2	0.36	0.13	0.18	72.2	30.0
CE/MAL/14	84.2	34.4	25.1	4.8	5.0	2.0	13.9	22.6	0.34	0.11	0.12	91.7	36.3
SAO/006	76.2	33.6	25.3	4.2	0.0	6.3	16.9	25.0	0.50	0.088	0.09	97.8	17.7
CE/IND/16	103.9	41.4	29.8	6	6.8	0.0	16.7	25.6	0.55	0.16	0.21	76.2	27.3
BL/SM/132	82.7	32.8	22	4.4	0.0	3.7	12.5	21.0	0.26	0.1	0.12	83.3	40.3
BL/SM/158	82.5	33.9	24.5	4.7	0.0	5.3	13.6	24.7	0.39	0.12	0.13	92.3	32.7
EX-BUNSO	104.5	42.4	28.5	4.9	8.7	0.0	14.4	25.1	0.42	0.13	0.14	92.9	35.3
SAO/020	89.3	41.5	29.2	4.9	3.0	0.7	13.2	23.1	0.39	0.17	0.25	68.0	28.0
ELO/002	68	32.9	22.1	4.7	1.4	0.4	15.5	23.8	0.44	0.19	0.29	65.5	26.0
KA/019	89.5	36	24.7	4.6	0.0	4.1	13.3	22.8	0.37	0.17	0.19	89.5	32.0
KA/035	98.8	45.2	30.1	4.9	4.0	0.9	15.3	22.9	0.41	0.14	0.18	77.8	25.7
LSD (<0.05)	21.95	9.99	6.63	0.72	1.93	1.58	2.72	4.2	0.21	0.06	0.08	0.26	0.09

PH: Plant height, LL: Leaf length, LW: Leaf width, NLP: number of leaves/plant, NStP: number of stolons/plant, NSuP: number of sucker/plant, CL: corm length, CD: corm diameter, CW: corm weight, EY: economic yield, BY: biological yield, HI: harvest index, DM: dry matter.

accession CE/MAL/32 recording the highest leaf width (34.4 cm) and accession BL/SM/115 had the lowest leaf width (20.1 cm). The range for number of leaves per plant was between 4.2 and 6.0. Accession CE/IND/16 had the highest number of leaves per plant (6.0) and accession SAO/006 had the lowest number of leaves per plant (4.2). Number of stolons ranged from 0 to 8.7 and the highest number of stolons per plant among the accessions was seen in accession EX-BUNSO (8.7). Seven of the accessions did not show the presence of stolons and these were KA/019, BL/SM/158, BL/SM/132, SAO/006, BL/SM/115, CE/IND/12 and BL/SM/80. Among the accessions studied, number of suckers per plant ranged from 0 to 6.3. Accession SAO/006 recorded the highest number of suckers per plant (6.3), while accessions BL/SM/10, CE/IND/16 and EX-BUNSO had no suckers. From the studies conducted, the corm diameter of the accessions ranged from 20.5 to 31.0 cm. Accession CE/MAL/32 had the highest corm diameter (31.0 cm) and the lowest corm diameter was recorded for accession BL/SM/115 (20.5 cm). The corm length was between 12.5 and 18.5 cm among the accessions. The highest corm length was seen in accession BL/SM/10 (18.5) and accessions BL/SM/132 and BL/SM/115 however, recorded the lowest corm length (12.5 cm). Corm weight of the accessions ranged between 0.26 to 0.79 kg. Accession CE/MAL/32 had the highest corm weight (0.79 kg) among the accessions studied and accession BL/SM/132 however, recorded the lowest corm weight (0.26 kg). For economic yield, the range was between 0.09 and 0.21 kg, and accession BL/SM/16 recorded the best economic yield (0.21 kg) with accession SAO/006 recording the worst economic yield (0.09 kg) among the accessions studied. The biological yield of the accessions ranged from 0.09 to 0.29 kg. With this, accession ELO/002 recorded the best biological yield (0.29 kg) and the worst biological yield was recorded for accession SAO/006 (0.09 kg). Table 5 shows that, harvest index among the accession ranged from 65.5 to 97.8% with accession SAO/006 recording the highest of 97.8% and accession ELO/002 recorded the least harvest index of 65.5%. For dry matter among the accessions, the range was between 17.7 to 40.3%. Accession BL/SM/132 had the best dry matter of 40.3% and accession SAO/006 recorded the least dry matter of 17.7%.

Diversity among the accessions

Figure 6 shows a dendrogram for the existing diversity and similarity among the taro accessions based on agro-morphological traits At similarity index of 0.94 (94.0%), five major clusters were identified and the number of accessions belonging to each cluster varied from 1 to 12. Cluster I consisted of two accessions (CE/MAL/32 and BL/SM/116). Cluster II was also made up of two accessions (BL/SM/10 and CE/IND/16). Cluster III had the highest number of accessions including KA/035,

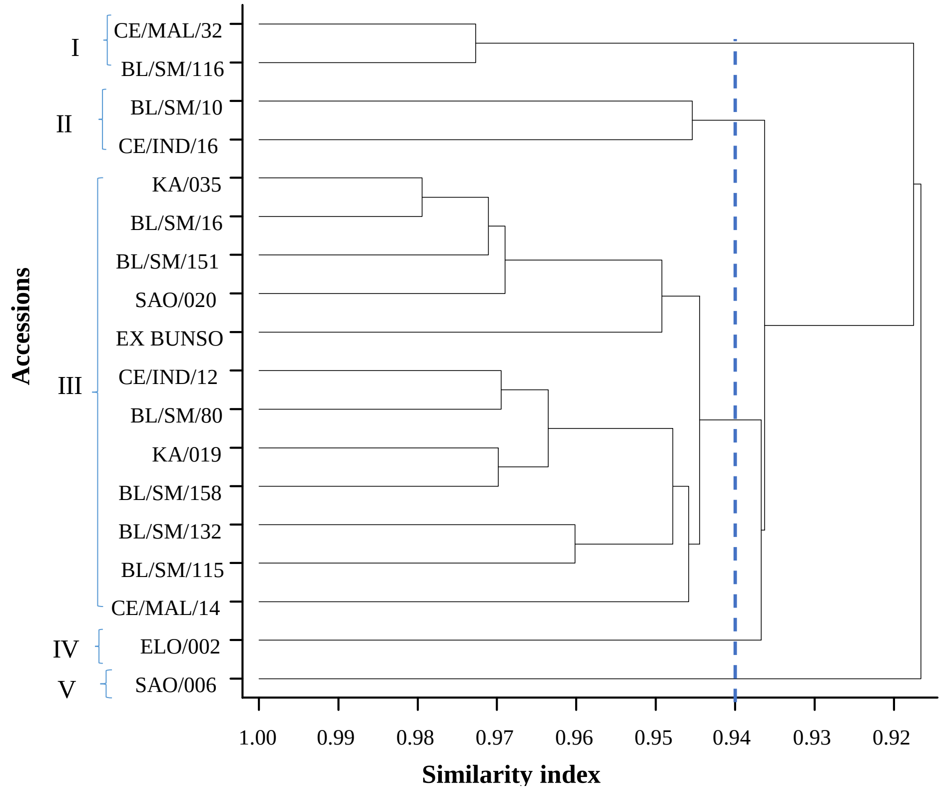


Figure 6. Cluster analysis of 18 accessions of taro using morphological characters

Table 6. Principal component analysis of the morphological traits of the taro accessions.

Character	PC1	PC2	PC3
BY	0.00191	0.00276	-0.00134
CD	0.09790	-0.09745	-0.11907
CL	0.05346	-0.04685	-0.15807
CW	0.00561	-0.00369	-0.00840
DM	0.01577	-0.06010	0.94245
EY	0.00120	0.00048	-0.00029
HI	-0.35871	-0.92099	-0.04659
LL	0.32065	-0.06970	-0.1819
LW	0.21951	-0.10108	-0.16424
NLP	0.02596	0.00292	-0.00563
NStP	0.15214	-0.03985	0.00373
NSuP	-0.08532	-0.09117	0.00728
PH	0.82249	-0.33388	0.10111
Variation (%)	53.98	33.61	7.54

BL/SM/16, BL/SM/151, SAO/020, EX-BUNSO, CE/IND/12, BL/SM/80, KA/019, BL/SM/158, BL/SM/132, BL/SM/115 and CE/MAL/14. Clusters IV and V consisted of only one accession each: ELO/002 and SAO/006 respectively. At similarity index of 1.00 (100%), all the accessions were totally distinct from each other.

Principal component analysis

The first five principal components (PCs) cumulatively accounted for over 98% of variation (Table 6). The first component (PC1) alone explained 53.98% of total variation and was mainly associated with characters such as plant height, leaf length and leaf width. The second principal component (PC2) explained 33.61% of variation.

Association among traits

Table 7 shows the character associations among the 18 taro accessions studied. The results show strong significant ($p<0.001$) and positive correlation between biological yield and corm weight (0.55*), economic yield (0.88***) and number of leaves per plant (0.55*). There was significant ($p<0.001$) but negative correlation between biological yield and harvest index (-0.70***) as well as number of suckers per plant (0.55*). Corm diameter showed significant ($p<0.001$) and positive correlation with corm length (0.83***), corm weight (0.94***), economic yield (0.62**), leaf length (0.57**), leaf width (0.66**), number of leaves per plant (0.56**)

Table 7. Correlation matrix among morphological characters of the taro accessions.

Characters	BY	CD	CL	CW	DM	EY	HI	LL	LW	NLP	NStP	NSuP	PH
BY	1												
CD	0.42	1											
CL	0.45	0.83***	1										
CW	0.55*	0.94***	0.92***	1									
DM	-0.15	-0.09	-0.34	-0.18	1								
EY	0.88***	0.62**	0.57**	0.70***	0.07	1							
HI	-0.70***	0.13	0.08	0.01	0.08	-0.35	1						
LL	0.38	0.57**	0.38	0.51*	-0.07	0.43	-0.25	1					
LW	0.32	0.66**	0.45	0.59**	-0.1	0.41	-0.09	0.94***	1				
NLP	0.55*	0.56**	0.51*	0.63**	-0.04	0.52*	-0.43	0.66**	0.69***	1			
NStP	0.18	0.4	0.31	0.35	0.06	0.17	-0.2	0.70***	0.71***	0.69***	1		
NSuP	-0.55*	-0.1	-0.12	-0.16	0.05	-0.32	0.75***	0.52*	-0.36	-0.59**	-0.69**	1	
PH	0.27	0.57**	0.45	0.56**	0.11	0.37	-0.15	0.84***	0.84***	0.76***	0.79***	-0.42	1

*=Significant at P<0.05, **=Significant at P<0.01, ***=Significant at P<0.001, CD=corm diameter, CL=corm length, BY=biological yield, CW=corm weight, DM=dry matter, EY=economic yield, HI=Harvest Index, LL=leaf length, NLP=number of plant, NStP=number of stolons/plant, NSuP=number of suckers/plant, PH=plant height.

and plant height (0.57**). The results also showed that corm length had strong significant (p<0.001) and positive correlation with corm weight (0.92***) and significant (p<0.01) and positive correlation with economic yield (0.57**) as well as number leaves per plant (0.51**). Corm weight correlated significantly (p<0.01) and positively with economic yield (0.70***), leaf width (0.59**), number of leaves per plant (0.63**), plant height (0.56**) and leaf length (0.51*). Economic yield correlated significantly (p<0.05) and positively with number of leaves per plant (0.52*). The correlation between harvest index and number of suckers per plant was also significant (p<0.001) and positive (0.75***). Leaf length showed significant (p<0.001) and positive correlation with leaf width (0.94***) and plant height (0.84***). Leaf length again was significant (p<0.01) and positive with number of leaves per plant (0.66**). There was also significant (p<0.001) and positive correlation between leaf width and number of leaves per plant (0.69***), number of stolons per plant (0.71***) and plant height (0.84***). Number of leaves per plant also showed significant (p<0.001) and positive correlation with number of stolons per plant (0.69***) and plant height (0.76***); however, it showed significant (p<0.01) and negative correlation with number of suckers per plant (-0.59**). Number of stolons per plant correlated significantly (p<0.001) and positively with plant height (0.79***) and significantly (p<0.01) but negative with number of suckers per plant (-0.69**).

DISCUSSION

Variation in qualitative traits

There was a wide range of variability in most of the qualitative traits studied except for shape of lamina, leaf lamina margin, leaf vein pattern and sinus. The green petiole colour of some of the accessions suggests that they might have made contribution to the production of assimilates which were channeled to the economic part of the plant which resulted in some accessions (CE/MAL/32, BL/SM/10 and BL/SM/116) with green petioles having the greatest corm weight, while those with non-green petiole colour particularly BL/SM/132 had low corm weight. The presence of many stolons and suckers probably had little or no effect on the accession's ability to produce reasonable corm weight as some of the accessions such as SAO/006 and CE/MAL 32 had greater number of suckers and stolons, respectively, and still recorded a significant corm weight (0.5 and 0.79 kg, respectively). This suggests that stolons and suckers are independent structures from the 'mother corm' in assimilate production and thus do not affect the mother corm.

The diversity in eating quality among the accessions collaborates with the findings of Opoku-Agyemang et al. (2004). It was seen that most of the accessions that were classified as good had high dry matter content. This also supports the findings of Markwei et al. (2000) in an ethno-botanical study on cocoyam and taro. It was observed that eating quality is one of the major characters that local farmers use to distinguish between cocoyam varieties, especially when all other visible characters fail to distinguish them. The variation in the vegetative and corm characteristics are in agreement with the works of Yared (2007) and Tewodros (2013) who identified variations in qualitative characters in taro.

Variability in quantitative traits

The analysis of variance of quantitative traits showed significant difference among the accessions for all the characters examined. Plant height among the accessions indicates that, the accessions were all tall as plants with heights greater than 50 cm are considered as tall plants (IPGRI/IITA, 1999) (Table 5). Accession CE/MAL/32 was highest in terms of corm weight and this could be attributed to the significant values for the growth parameters (plant height, leaf length, leaf width and number of leaves per plant). The low biological yield and high harvest indices for accessions SAO/006 and BL/SM/115 indicates that these accessions are early mature types and may have lost most of the vegetative parts at the time of harvesting. The studies show that there is a great potential of the accessions in future breeding programs of taro through selection for the improvement of the crop in Ghana. The significant difference in the traits among the accessions also gives enough room to select superior ones. Also, other workers including Asfaw (2006), Tewodros (2013) and Yared (2007) have reported a wide range of variation among taro (*C. esculenta*) species in Ethiopia. Furthermore, Muluneh (2006) and Tewodros (2008), reported similar results in yam and Amsalu (2003) in cassava.

Diversity among the accessions

The cluster analysis indicates the extent of diversity that is practical for use to breeders (Sultana et al., 2006). The range in similarity index for both morphological and biochemical traits among the accessions are large enough to suggest sufficient variability among the accessions. The dendrogram summarizing the existence of diversity and similarities among the accessions based on quantitative agro-morphological characters revealed that the accessions were clustered mainly by origin and by plant height (tall or dwarf plant). Accessions BL/SM/132 and BL/SM/115, which were clustered, are from Samoa and accessions SAO/006 and ELO/002 which were also clustered and very distinct are landraces. Accessions CE/IND12, BL/SM/80, KA/019 and BL/SM/158 were clustered and are tall plant (plant height >50 cm).

Principal component analysis (PCA)

PCA was used to obtain a simplified view of the relationship between variables, and the PCA loading are presented in Table 6 for morphological traits. The first principal component (PC1 = 53.98%) contributed more to the total variation in morphological traits and plant height, leaf length and leaf width had a high contributions towards the variability among the accessions. This suggests that for any improvement in the yield of taro, attention should be on plant height, and traits that correlated positively and significantly such as leaf length, leaf width and number of leaves per plant as they contributed to the plant height and yield. This means that higher plant height could restrict high harvest index and number of suckers per plant. This study is in line with earlier reports on taro germplasm by Tewodros (2013) in Ethiopia on the contribution of PC1 to variation in taro on morphological traits.

Association among the traits

The results show significant ($p<0.001$) correlation among some of the accessions. Traits with significant ($p<0.001$) and positive correlation suggest that these traits could be improved together. The significant ($p<0.001$) but negative correlation between some of the traits signifies that an increase in one trait could result in a decrease in the other. The strong significant ($P<0.001$) and positive correlation of the growth parameters and yield parameters agrees with the findings of Rubaihayo et al. (2001) and Pandey et al. (2005) in cassava and potato, respectively. Therefore, selection based on these traits will be efficient to maximize the fresh corn yield as well as future improvement program of taro.

Conclusion

From this study, it can be concluded that agro-morphological characterization was useful in identifying variations among the accessions. The positive correlation between yield components and leaf length, leaf width, number of leaf per plant and plant height indicates that the yield of taro can be improved by concentrating on these characters. The study also indicates that there is a wide range of variation in different traits of *C. esculenta* in the country (Ghana). Nine accessions: CE/MAL/32, BL/SM/158, BL/SM/10, BL/SM/116, CE/IND/16, BL/SM/132, BL/SM/16, CE/MAL/14 and SAO/006 possess desirable characters such as earliness and yield which could be exploited for varietal development of taro in Ghana. Therefore, there is need to consider effort in conservation and research into taro.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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Varietal screening for resistance against field and storage crop pests: An implication for Ethiopian crop variety development

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Food security in developing countries like Ethiopia has been a challenge for many years due to pre and post-harvest losses of agricultural products which are caused by different biotic and abiotic factors. Grain losses from pest infestation prior to harvest and during storage are a serious problem, particularly in developing countries like Ethiopia. More than 70% insect pests have been identified; they attack stored grains among which beetles and moths are the most important. The overall quantitative and qualitative damages caused by these insect pests are estimated at 30 to 40% annually. To minimize these damages, development of less susceptible germplasms, cultivars and varieties which are an eco-friendly and economically feasible management options has been encouraged by many scholars since the development of modern breeding technologies. Thus, resistant varieties can have a tremendous impact on sustainable crop production to ensure future food security. This paper provides a comprehensive literature review of varietal screening research for field and storage pests associated with the major food and export crops with particular emphasis on Ethiopia.

Key words: Insect, screening, biotic stress, breeding, grain pests.

INTRODUCTION

Events of biotic stresses such as, potato blight Ireland, maize leaf blight in USA, coffee in Brazil and Bengal famine were mentioned as historical significance cases in the world (Hussain, 2015; Singh et al., 2017). These events had devastated food production which resulted in a number of human population's deaths and migration to avoid famine. These stresses continue to cause an important risk to agricultural production and productivity even though different research and development activities have been implemented to investigate the host-plant interaction and availing effective methods to control it (Lucas, 2011). In this case both insects and disease are among the important biotic factors that cause significant losses in yield and quality which lead to many types of damages. In many agro-ecological zones, the crop production and productivity has been also threatened due

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to the appearance of new races and biotypes of pathogen and insect (Sanghera et al., 2011). Significant yield losses from plant diseases such as wilt, phyllody, powdery mildew, blight and leaf spots in addition to insect pest such as capsule borer, and sucking pests like mites and thrips have been reported (Abd-El-Ghany et al., 1974; Jyothi et al., 2011). Metabolic stresses on crop plants as well as physical damage to commodities due to insects, diseases, nematodes, larger animals such as rodents, weeds, etc. are factors reducing crop productivity and grain quality. However, the world food supply can increase through; increasing the crop acreages, fertilization, and irrigation and improving the use of improved varieties, cultivation methods and improved crop protection strategies which may also cause different genetic and environmental impacts on plant product (Yazici and Bilir, 2017).

Ethiopia has a wide variety of favorable climates and soil types where different crops can be grown for domestic consumption as well as for export. The major crops produced in Ethiopia constitute cereals, grain legumes, and oilseeds. These crops are produced mostly during the main growing season which extends from June to October. Some crops are also planted during the short rains (March to May). Though crop production in Ethiopia contributes a major share to the agricultural sector, it has suffered for years from several factors, including the use of traditional farm implements, subsistence farming system, limited use of modern farm inputs, drought and pre- and post-harvest pests and other unlimited challenges that bring the food security scenario of the country into question and remains a critical issue for many households.

To alleviate the biotic stress on crop plants, various genomics research and completion of the genome sequence of different crops has been implemented which enables a precise mapping of different genes through linkage to DNA markers. Genes linked to markers could be resistant to or tolerant to different stress including blast, bacterial blight, virus diseases, brown planthopper (*Nilaparvata lugens*), drought, submergence, salinity, and temperature (Jena and Mackill 2008; Ashraf and Foolad 2013).

Hence, the linked genes which are called quantitative trait loci (QTLs) that govern different traits could be identified, as a result, indirect selection techniques can be implemented to ameliorate the breeding efficiency via marker-assisted selection (MAS) (Ashraf and Foolad, 2013). Thus, both conventional and MAS breeding techniques could be combined for testing the presence or absence of these genes in the breeding populations. The development of molecular markers and MAS technology helps to conduct many studies to identify genes or QTLs affecting pest tolerances in many plant species (Simcox et al., 1993; Adhikari et al., 2003; Singh et al., 2004; Soundararajan et al., 2004; Chu et al., 2010; Foolad et al., 2012; Shi et al., 2014; Liu et al., 2016; Sorkheh et al., 2016) (Table 1). The study general objective is to review the plant genetic diversity for yield and pest resistance, while the specific objectives are:

(1) Review the varietal screening research approaches against major field and storage pests.
(2) Provide an overview of breeding methods for biotic stress and source of pest resistance.
(3) Assess existing pest management options in Ethiopia.

Crop genetic diversity

Ethiopia is a major of genetic diversity for a number of cultivated crops and their wild relatives (Tanto and Demissie, 2000; Worede et al., 2000), and this diversity can play a major role in enhancing and improving the productivity of the crops through maintaining and enhancing the durability of the crop to diseases, pests, drought, and other stresses. Sorghum, barley, teff, chickpeas, and coffee, which are largely represented in the country by landraces and wild types, are uniquely adapted to local environments (CSA, 2014/2015; Tanto and Demissie, 2000). Hence, maintaining the crop, species and genetic diversity in farmers' field is very important to sustain agricultural production, improve nutrition, and help the ecosystem which is essential for the livelihood of communities, particularly for resource-poor farmers practicing agriculture under low-input conditions on the marginal lands (Worede et al., 2000).

Overview of plant disease and insect pets

Plant disease

More than 800 million people lack adequate food as a result of plant diseases (FAO, 2012; Christou and Twyman, 2004). Field surveys conducted in wheat growing areas of Ethiopia have shown that diseases are the major constrains to wheat production (CSA 2014/15), among these, leaf, stem and stripe rust are the most important with stem rust (*Puccinia graminis tritici*) considered the most destructive due to emergence of race Ug99 (Singh et al., 2011). In 1988, stem rust race Ug99 was first observed in Uganda. According to Singh et al., (2011), seven races of Ug99 ancestry are known and spread to different wheat-growing countries in the eastern African highlands, Zimbabwe, South Africa, Sudan, Yemen, and Iran. The wheat varieties growing in these countries are reported as very susceptible (90%), and then the Ug99 group of races was considered as a major threat to wheat production and food security (Singh et al., 2011).

Plant Insect pests

Nearly 60 insect species are known to feed on crop

Table 1. Identified molecular markers, gene locus and chromosomal locations for pest tolerance in different plant species.

Crop plants	Molecular markers	QTL/genes Locus	Chromosomal location	Pests	Traits governed	References
Rice (*Oryza sativa* L.)	SSR	Est9–RZ337B; RG157–RZ318; RG146–RG345; RG213–Est2; Pgi2–pRD10B; RG773–Est2	7; 2; 1; 6; 6; 7	Brown planthopper (BPH), *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae)	Seedling –resistance; antibiosis, tolerance; tolerance; tolerance; tolerance	Soundararajan et al. (2004)
Bread wheat (*Triticum aestivum*)	SNP	*QYr.osu-5A*	5A	Stripe rust races	Resistance in adult plants to predominant stripe rust races	Liu et al. (2016)
Maize (Zea mays L.	RFLP	Htnl	8	Setospaeria turcica	Resistance	Simcox et al. (1993)
Wheat (*Triticum aestivum* L.)	DArT	*QStb.2A*	2A	*Septoria tritici* blotch (STB)	High level of resistant	-
Wheat (*Triticum aestivum* L.)	microsatellite markers	Stb8	7b	Septoria tritici leaf blotch (STB), caused by the ascomycete Mycosphaerella graminicola	Resistance to STB	Adhikari et al., (2003)

plants among which the pod borers (*Helicoverpa* spp.), leaf miners (*Liriomyza cicerina*), bruchid weevils (*Callosobruchus* spp.), cowpea aphid (*Aphis craccivora*), cutworms (*Agrotis* spp.), and armyworms (*Spodoptera* spp.) are the most important insects reported (Sharma et al., 2007; Li et al., 2015). According to Worku et al. (2012), there are four species of stem borers that infect the maize plant in Ethiopia while in Africa the African stalk borer (*Busseola fusca* Fuller), the spotted stem borer (*Chilo partellus* Swinhoe), the pink stem borer (*Sesamia calamistis* Hampson) and the sugarcane borer (*Eldana saccharina* Walker) are the major insects reported to attack maize (Mailafiya and Degri, 2012). Abate et al., (2015) reported three species of stem borers (*viz*. *B. fusca*, *C*. *partellus* and *S. calamistis*) which are known to be distributed across maize growing agro-ecologies in Ethiopia though *B. fusca* and *C. partellus* are reported as the most economically important stem borers in Ethiopia (Demissie et al., 2014).

Globally, yield loss from insects have been estimated at 14% for all important crops (Poehlman, 2013), which results from insects sucking cell sap or eating away various plant parts as well as through transmission of various diseases. According to Chaudhry et al. (1989), leaf roller/webber is a serious pest of sesame, which causes 15 to 20% damage to the crop at vegetative stages and 10 to 15% at productive stages. Significant yield losses (50%) were recorded in legumes including faba bean, field pea, chickpea and lentil from some aggressive storage insect pests like *C*. *chinensis* (*Damte* and Dawd, 2003). Gwinner et al. (1990) and Tabu et al. (2012) reported losses due to storage insect pests particularly due to adzuki bean beetle which are greater in tropical and subtropical regions than in the temperate areas. Reports from Ali and Tibebu (1993) and Tebkew and Mohamed (2006) indicated that the adzuki bean beetle caused losses of up to 50% in chickpea in Ethiopia.

Insect and disease management in Ethiopia

Conditioning of grain by forced air dryers, use of different storage structures, application of botanicals or insecticides and use of resistance varieties are effective in reducing damage from grain storage pests. Among the various cultural methods tested in Ethiopia for storage pest management, solar heating of maize grain placed on a black polyethylene sheet and covered with a translucent plastic sheet for at least five sunny days caused significantly higher (72%) mortality of maize weevil (*S. zeamais*) (Abreham, 2003 & Demissie et al, 2012). Botanical products were also effective for protecting stored grain from insect damage. Treatment with leaves of *Eucalyptus globulus*, *Schinese molle*, *Datura stramonium*, *Phytolacca dodecandra*, and *Lycopersicum esculentum* were observed to cause high adult maize weevil mortality (Abraham, 2003). In Ethiopia, the botanicals Mexican tea powder (*Chenopodium umbrosiodes* L.), triplex and neem seed powder (*Azadirchata indica*) cause high percentage of adult maize weevil mortality, reduced progeny emergence and lower grain damage (Girma et al., 2008a, b). A laboratory experiment to evaluate the use of inert dust, cotton seed and Ethiopian mustard seed oils *(Brassica carinata),* against Angomois grain moth (Sitotroga cereallela) concluded that cotton and

Ethiopian mustard seed oils exhibit strong toxic activity at concentration levels less than or equal to 0.2% (v/w) (Fekadu & Girmay, 2015).

The use of chemical insecticides in the form of sprays, fumigant or dusts against different pests has been common in Ethiopia. In some parts of the country about 70% of the farmers treated their grains with synthetic chemicals (Tadesse 2005).

Resistant crops

Using resistant varieties as component of an integrated pest management is considered as best and cheapest best method to control insect in agricultural production system. Genetic resistance refers to the ability of some genotypes to give higher yields than susceptible varieties at the same initial level of insect attack under similar environmental conditions (Russell, 2013).

Shaheen et al. (2006) stated that improving the genetic resistance of the host plant is considered to be an effective management options for the pets damage on the crops. As an integrated pest management tactic, host-plant resistance entails the intentional use of resistant crop varieties, alone or in combination with other tactics, to reduce the impact of herbivores on crop yield or quality (Stout, 2014). Resistance crops might be found in taxonomic groups that are more or less distantly related to the crop, such as the cultivar itself, commercial cultivars, landraces, wild progenitors, related species and genera (Balconi ET AL., 2012).

A complete resistance was reported in cultivated and germplasm of haricot bean, field pea, cowpea, black gram and chickpea (Keneni et al., 2012) while Dogimont (2010) reported a high level of bruchid resistance from the cultivated rice bean (*Vigna umbellata*). Some accessions of cultivated common bean with moderate levels of resistance to *A. obtectus* and *Z. subfasciatus* were identified by and used in breeding programs to generate partially resistant materials adapted to East African production conditions (Kusolwa, 2007). In stored grains several factors lead to the production of resistance against infestation by storage insect pests, which include the tightness of the glumes in unmilled rice which serve as physical barrier working against penetration by insects; hardness of seeds to make insect penetration more difficult and seed size, as large grain legumes provide more surface area for oviposition and larval development than small-size grains (Chanbang et al., 2008).

Resistant varieties for field crop pests

Since 2005 to 2010, over 200,000 wheat varieties, accessions, and advanced breeding materials were screened for resistance to Ug99 and its derivative races at Njoro, Kenya, and Ethiopia and resistant genotypes were identified (Singh et al., 2011). Screening of 26 sesame breeding lines in Turkey to Fusarium wilt disease indicated, sanliurfa-63189 was the most resistant genotype (Kavak and Boyda, 2006). “Birkan”,Çamdibi, WS-143, WS-313 were classified as resistant. “Birkan”, a recently released cultivar for large seed and high yield was resistant to the *Fusarium* wilt disease (Silme and Cagirgan, 2010). Screening of maize against maize stem borer, Sultan followed by Akbar was found to be the most tolerant varieties. El-Bramawy and Wahid (2009) reported sesame genotypes S2 and H4, originated from a selection and hybridization respectively, seem to be stable for wilt disease. These authors also indicated the sesame genotypes such as Mutants 8, U N. A 130, H 1 and S1 kept their resistance classes during the two successive seasons. A research conducted to test genetic resistance of maize inbreed lines against northern corn leaf blight (NCLB), southern corn leaf blight (SCLB), *Curvularia* leaf spot (CLS), gray leaf spot (GLS), common rust, and southern rust indicated that, five lines, 313, Chang 7-2, Qi 319, Qi 318, and Shen 137 were resistant to the five diseases tested while lines OH 43, X178, Qi 318, Za C546, 8065, 81565, 313, CAL99, and B 151 were found resistant or moderately resistant to southern rust (Wang et al., 2014).

Resistant varieties for storage pests

Screening against *S. zeamais* showed that out of the thirteen maize varieties, only one BHQP-542 was resistant (Abebe et al., 2009). Experiments conducted on hybrid maize varieties for maize weevil and large grain borer identified six resistant hybrids (CKPH08037, CKPH08041, CKPH08012, CKPH08024 and CKPH08026) and two moderately resistant hybrids (CKPH08038, CKPH09004) to the large grain borer (Teffera *et al* 2013). Maize genotypes, resistant to the maize weevil included AW8047, INT-A, Pob-62TLWF-QPM, TUXEPENO C6, USB, Golden Valley (Demissie et al., 2012).

Similarly, Demmisie et al. (2013b) reported one quality protein maize (QPM) inbred line (CML-142) as resistant and three (CML-144/144-7-b (F2)-4-2-1-1-1-1-1, POOL 15QPFS-693-B-2-B-#-B-B-B-# and CML-149) QPM lines were moderately resistant to *Sitophilus zeamais.* Resistant against Sitotroga *cerealella* among the twelve wheat genotypes based on progeny emergency showed genotypes IBW-97103 and IBW-97083 had significantly lower grain damage and IBW-97103 had significantly lower weight loss compared to all other genotypes. Characterization of 130 chickpea genotypes by Keneni et al. (2011) in Ethiopia indicated one genotype exhibited complete resistance to adzuki bean beetle; whereas, improved genotypes showed considerably higher susceptibility particularly, in terms of number of eggs per female, adults emerged and seed weight loss. Eker et al. (2018), from their laboratory experiment reported that, Desi type chickpea exhibits better resistance characteristic to *callosobruchus chinensis* than the Kabuli type which means the Kabuli accessions in which their seeds are characterized by creamy colored, smooth surface and ram's shape are more preferred by the insect than the Desi type. Demissie et al. (2014) screened maize varieties to sitotroga cerealla under no-choice test method showed that pratap makka-5 was found the most resistance varieties. Tefera and his colleagues in 2013 screened 25 maize hybrids against S. zeamais and one hybrid, CKPH08004, showed resistance.

Methods of breeding for resistance crops

The traditional approach to the development and use of resistant varieties in integrated pest management involves four steps: screening (evaluation of crop germplasm for resistant genotypes), categorization (assignment of resistance phenomena to the categories of antibiosis, antixenosis, and tolerance), breeding (introduction of genes responsible for resistance into agronomically acceptable backgrounds), and implementation (integration of resistant varieties into management programmes) (Stout, 2014). Singh et al. (2002) indicated that backcross breeding technique is the most appropriate breeding method for transferring the cytoplasm from one parent to another using the parent from which the cytoplasm is to be transferred as the female if the seed resistance is under cytoplasmic gene effects. Jena and Mackill (2008) reported that Marker-assisted backcross breeding has been used to effectively integrate major genes or quantitative trait loci with large effect into widely grown varieties and pyramiding the different resistance genes using MAS provides opportunities to breeders to develop broad-spectrum resistance for diseases and insects. Depending on the mode of inheritance and the number of genes controlling resistance under a given condition, the different selection methods (that is, mass, bulk, pedigree and backcross methods, *etc.* or their modifications) can be applied. Generally, developing farmers' knowledge and their existing practices on cultivars resistant to diseases and pets can help farmers to adopt new cultivars as easy as possible.

Conclusions

Plants at field and harvested produce need to be growing healthy and stored safely and scientifically in order to maintain its original quality while avoiding any spoilage by storage pests. In this case, effective management practice could have positive consequences for poverty alleviation, food security, nutrition status, and increases household income for the smallholder farmer in developing countries. Appropriate insecticide use will continue to play an important role in insect control, but nonchemical alternatives remain a safer and more environmentally beneficial approach for tropical farmers. Improved crop production and quality through breeding to screen resistant varieties have tremendous impact for sustainable crop production in the world in general and in Ethiopia in particular. Many varieties of the same grain species appear to be less suitable than others for insect development, and are often described as being "resistant" (or in fact, less susceptible) to insect attack. The development of insect resistant plants is therefore an important objective of plant breeding strategies with relevant implications for both farmers and the seed and agrochemical industries. The conventional approach of germplasm screening against major biotic stresses enables one to identify sources of biotic stress tolerance genes, which can then be utilized in the breeding programs through MAS. Different scholars indicated that genetic sources of pest tolerance have been reported in different crop species, which could be used further for different breeding purposes. The development of molecular markers and mapping technology enables researchers to identify genes or QTLs of interest traits and transfer from unadapted genetic backgrounds into modern cultivars via the process of MAS. To ease breeding for resistance to the major biotic stresses in Ethiopia, rapid and well–designed introgression of specific biotic stress tolerance genes into cultivars, germplasm, introduced and developed improved varieties can ensure pronounced genetic gain. Ways of introducing and integrating recent advances in biotechnology with the conventional breeding approaches should be researched and implemented.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Evaluation of constraints in production of root and tuber crops in Ethiopia: Overview of policy neglected climate resilient food security crops

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The objective of the current study was to examine the major constraints in production of root and tuber crops in Ethiopia with emphasis on identifying the policy gaps. This appraisal was based on survey report of Central Statistical Agency (CSA) for the period of 2011 to 2015. Data of CSA report was chosen for the current study with the view to gain an overview of policy packages in root crops in contrast with other major crops. Based on the current assessment, a continuous increase in cultivation acreage has been registered. This contributes to the significant increase in volume of annual productions. The production status in the nation however remains far below its potential limit. Several constraints are responsible for this among which poor access to improved seed and pesticide, unforeseen climatic conditions, weed, diseases and pest problems are the major ones. These factors have caused a significant damage of cultivated land (43,503 ha) for the past five years. Off this, weed, diseases and pests coupled with other biotic factors have accounted for about 40% of this damage. This is mainly due to lack of policy attention to these crops. For instance, improved seed coverage from 2011 to 2015 was even less than 1% of the total cultivated area. Similar policy problems are also evident for pesticide coverage and extension package and these represents only 14 and 17% of the total acreage, respectively. The policy so far has focused mainly on cereals. However, the cereal centered policy so far was unable to reduce rural food insecurity and in fact this problem even got worse and worse over time. Thus, it is essential to reorient this policy by the upcoming plan. Root and tuber crops are among the neglected climate resilient food security crops in Ethiopia requiring an immense policy focus. This will substantially contribute to improve the livelihoods of resource poor farmer's in the changing climate.

Key words: Root and tuber crops, constraints, food security, policy packages, Central Statistical Agency (CSA) survey.

INTRODUCTION

Root and tubers contribute a major share of traditional food system in Ethiopia. The principal root and tuber crop in Ethiopia include enset, potato, taro, yams, anchote, cassava, tannia, and sweet potato (EIAR, 2015).

Currently, many of these crops are used as a major staple diet in South and Southwestern part of Ethiopia.

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In a country with dominating agrarian economy like Ethiopia, ensuring food security is one of the most important objectives to be attained by the agriculture system. For the past several years, the country has tried to implement “agricultural-lead development strategies” to realize the preceding objective. However, success is very modest and lacks the sort of dynamism needed to bring a pattern of development that could lead to sustainable reduction of rural poverty and food insecurity (Samuel, 2006). In view of the existing deficit of food crops in the nation, increasing the production and productivity of the root and tuber crop is a key alternative.

There are many realistic reasons for encouraging root and tuber production in Ethiopia. First and most importantly, they are one of the most adaptable staples to address food security for millions of people, and produce more food per unit area of land. This may have a meaningful contribution to avoid chronic food insecurity in Ethiopia. Second, they are nutritionally rich staple foods that contribute protein, vitamins (A and C), zinc, and iron towards the dietary demands of the society (Sanginga and Mbabu, 2015; EIAR, 2015). However, the nation still suffers from malnutrition, for example, vitamin A deficiency (EIAR, 2015). The third realistic reason is that some of these crops are suitable for double cropping. For example, potato and sweet potato are one of the short cycling crops with three to four months cropping cycle which are well suited to the double cropping particularly in rain-fed systems (EIAR, 2015; Sanginga and Mbabu, 2015). Fourth, these crops insure sustainable food availability throughout the year. In this case root and tuber crops even with longer cropping cycles are quite essential. The longer cropping cycle crops such as yam, cassava and enset for instance play a vital role for annual cycle of food availability. In addition, most of these crops are the known climate resilient crops withstanding the unforeseen climatic conditions. For instance, enset is one of the drought tolerant food security crops, where it supplements human calorie requirements of around 20 million people in Ethiopia. The crop also has an enormous potential in other regions of sub-Saharan Africa, where it is known only as a wild plant (Olango et al., 2015).

Ethiopia has possibly the highest potential for root and tuber crop production than any country in Africa. This can be explained by the fact that wide ranges of opportunities are available in Ethiopia since the nation has abundant natural resources and favorable agro-ecological conditions that are suitable to grow a number of crop species including root and tuber crops. Meanwhile, the root and tuber sector has never reached its full potential of production that it has in avoiding the problem of malnutrition and in supporting food insecurity. Several factors are responsible for this, among which lack of adaptable high yielding variety, shortage of good quality planting material and inability to control biotic factors (disease and pest) are listed as a primary limiting factor in most earlier reports (EIAR, 2015; Ephrem, 2015; Helen, 2016). Most of these crops have also faced with research and policy neglect for the past several years (Tamiru et al., 2007). Moreover, the contribution of root and tuber crops to the national gross domestic product (GDP) is not well known. Very few reports deal with aspects of root and tuber crops production in Ethiopia. Inadequate storage, transportation and marketing facilities are the other constraints of root and tuber crops production in Ethiopia.

Keeping in view all these points, assessment and analysis of the production trend and the constraints in production of root and tuber crops in Ethiopia are urgently needed. This is because such assessment helps to understand the nature of policy packages for root crops in contrast to major crops. Thus, the primary objective of the current study was to examine the major constraints in production of root and tuber crops for the period of 2011 to 2015. The second objective was to assess the policy gaps that these crops have faced over the same period. Finally, this study was designed to suggest possible actions to overcome for the problems identified in this assessment.

RESEARCH METHODOLOGY

The current evaluation is a quantitative and non-experimental study where survey reports of Central Statistical Agency (CSA) was used as a major source of secondary data. CSA report was chosen for the present inquiry because; it allows us to gain an overview of policy packages in root crops in relation with other major crops. Hence, data on production trend and constraints in production of root crops from 2011 to 2015 were considered for this study. From the major constraints in production of root crops, the biotic factors were purposefully selected and the averages of these data were used to compare the extent of damage caused by this factor. Other production constraints such as access to important inputs were also considered in this assessment. Accordingly, important policy package such as access to improved seed, extension packages and access to pesticide in root crops were compared with the packages realized for other major crops. For avoiding outliers problem in comparison process, only one tenth of these packages for cereal and the total packages for the remaining major crops were taken.

Data analysis

All the data obtained from the report of CSA survey were subjected to analysis of variance using Statistical Analysis Software (SAS, version 9.1.3). Mean comparisons were made using a least significant difference (LSD) test at 5% probability level.

RESULTS AND DISCUSSION

Root and tuber crops production trend in Ethiopia, 2011-2015

Regardless of their importance in Ethiopia, root and tuber crops have been seen as the secondary to non-cereal

Table 1. Actual Area Harvested, Annual Production and Yield for Root Crops Total and Major Root Crops from 2011-2015, Meher Season (CSA, 2016).

Parameter	Area harvested in thousand hectare					Average	Mean annual increase in area harvested (%)				Average
	2011	2012	2013	2014	2015		2011-2012	2012-2013	2013-2014	2014-2015	
Root crops, total	199.89	203.96	209.89	216.67	213.77	208.84	2.03	2.9	3.24	-1.34	1.71
Major root crops											
Potato	59.51	74.93	66.74	67.36	70.13	67.73	25.92	-10.93	0.92	4.12	5.01
Taro	39.69	41.34	42.66	48.66	48.52	44.17	4.14	3.19	14.07	-0.28	5.28
Sweet potato	51.31	41.63	53.37	59.27	41.41	49.40	-18.86	28.19	11.05	-30.76	-2.61
	Annual production in million metric ton					**Average**	**Mean annual increase in volume of production (%)**				**Average**
	2011	**2012**	**2013**	**2014**	**2015**		**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	
Root crops, total	16.71	36.31	41.61	54.61	39.98	37.84	117.22	14.63	31.26	-26.79	34.11
Major root crops											
Potato	4.75	8.63	7.85	9.22	9.43	7.98	81.59	-9.08	17.43	2.32	23.11
Taro	3.15	11.18	11.93	14.49	12.11	10.57	254.58	6.78	21.39	-16.40	66.59
Sweet potato	3.90	11.85	17.83	27.01	13.72	14.86	203.75	50.43	51.54	-49.20	64.13
	Yield (ton/ha)					**Average**	**Mean annual increase in yield (%)**				**Average**
	2011	**2012**	**2013**	**2014**	**2015**		**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	
Root crops, total	8.36	17.79	19.82	25.21	18.7	17.98	112.9	11.39	27.14	-25.79	31.41
Major root crops											
Potato	7.98	11.52	11.76	13.68	13.45	11.68	44.21	2.11	16.37	-1.73	15.23
Taro	7.94	27.04	27.98	29.78	24.98	23.54	240.49	3.48	6.42	-16.17	58.55
Sweet potato	7.6	28.46	33.4	45.58	33.44	29.70	274.37	17.36	36.46	-26.64	75.39

crops. Mean annual production of root and tuber crops in Ethiopia for the period of 2011 to 2015 was over 37.84 million metric tons (Table 1). A continuous increase in volume of production has been registered for root crops for the period from 2011 to 2014. The increase in volume of production was mainly brought about by the increase in the total area harvested. This was supported by a strong and significant correlation of annual production with area cultivated (r = 0.91*), in which it accounts for about 82% of the increase (Table 2). In Ethiopia, yield per hectare of root and tuber crops for the period of 2011 to 2015 was increased on average by 31.4%. This was mainly brought about by the mean increase in yield per hectare of major root and tuber crops among which sweet potato and taro accounts for about 134% of the increase (Table 1). On the other hand, the average yield of potato in Ethiopia for the period of 2010 to 2015 was 11.68 ton ha^{-1}. This is far below the level realized at global (19.15 t ha^{-1}) level (FAOSTAT, 2014).

Area expansion in root crops compared with other major crops, 2011 to 2015

The highest expansion in mean area harvested was observed for cereal crops while the lowest expansion in mean area harvested was observed

Table 2. Pearson correlation coefficient for annual production, area harvest, pesticide coverage and improved seed coverage (CSA, 2016).

Parameter	Improved seed coverage	Pesticide coverage	Area cultivated	Annual production
Improved seed coverage	1	0.53488[ns]	0.32737[ns]	0.24279[ns]
Pesticide coverage	-	1	0.89793*	0.67895[ns]
Area cultivated	-	-	1	0.90627*
Annual production	-	-	-	1

Ns: Non-significant at 5% probability level, *Significant at 5% probability level.

Table 3. Average of Actual Area Harvested for Root Crops in Relation with Other Crops and Area Harvested in Major Root Crops from 2011-2015, Meher Season (CSA, 2016).

Major crops	Average of actual area harvested (ha)	Major root crops	Average of actual area harvested (ha)
Cereals	9,831,455[a]	Potato	67,735[a]
Pulses	1,686,829[b]	Taro	44,174[b]
Oilseeds	846,061[c]	Sweet potato	49,325[b]
Root crops total	208,835[d]	-	-
LSD0.05	200,294	LSD0.05	9416
CV (%)	4.6	CV (%)	12

Means within a column followed by the same letters are not significantly different at 5% probability level.

for root crops total. Among the major root crops the highest actual area harvested was observed in potato. However, area expansion in taro and sweet potato varied non-significantly over the past five years (Table 3). The current scenario clearly indicates that the expansion in major root crops did not reach their full potential of production. Meanwhile, there is a possibility to increase the production level beyond the existing potential. This is due to the fact that most of these crops are suitable for double cropping. For example, potato and sweet potato are one of the short cycling crops with three to four months cropping cycle which are well suited to the double cropping particularly in rain-fed systems. Others such as yam, cassava, and enset are the known climate resilient food security crops, but they are also faced with policy problems. When faced with such problems, one may rightfully ask: why are crop improvements strategies in root crops stagnating? Additionally, the scenario observed especially for the period of 2011 to 2015, initiates us to evaluate this inquiry? The detailed explanation for the current question is explained subsequently.

Constraints in production of root crops in Ethiopia

Poor access for important inputs

The production status in root crops is low by national standards, mainly due to lack of important inputs. Lack of wide adaptive improved varieties, shortage of good quality planting material and lack of pesticides are the major production problems in Ethiopia. For example, for the period from 2011 to 2015, only few farmers have got an access to improved seed. This represents only 0.8% of the total cultivated area in the country. In addition, pesticide coverage accounts for only 14% of the total cultivated acreage over the same period (Table 4). This problem is further worsening due to weak extension systems and delays in distributing the important inputs. Moreover, seed multiplication efforts matching cultivars to production environments and customer desire is still not having the desired scale (EIAR, 2015).

Table 4. Access to important inputs for root crops, from 2011 to 2015, Meher Season (CSA, 2016).

Crop	Policy packages	Policy packages realized over the past five years (ha)					Average
		2011	2012	2013	2014	2015	
Total root crops	Actual area harvested	199,900	203,958	209,880	216,672	213,767	208,835
	Improved seed coverage	*	2,418	1,713	2,871	2,602	2,401
	Pesticide coverage	21,613	23,774	26,476	36,915	40,645	29,885
	Extension package	17,392	30,308	40,991	45,446	42,460	35,319

*Data not accessed.

Table 5. Actual damage recorded in root crops for the period from 2011 to 2015, Meher Season (CSA, 2016).

Damage caused by biotic factors	Average damage (ha)	Damage caused by abiotic factors	Average damage (ha)
Pests (Locust, Bird and other)	6,015[a]	Frost	4,409
Crop disease	2,135[c]	Short of rain	8,376
Weeds	3,783[bc]	Too much rain	5,487
Other	5,277[ab]	Hailstone	7,725
$LSD_{0.05}$	2,199	$LSD_{0.05}$	Ns
CV (%)	37	CV (%)	150

Means within a column followed by the same letters are not significantly different at 5% probability level. Ns: non -significant, the CV for abiotic factor is reduced to 15% on log transformed data.

This compels farmers to continue to grow local, low yielding varieties that are susceptible to disease and pests. In support of this argument, Helen (2016) reported that the use of local varieties is one and the most important factors which contribute to the low yield of potato in Ethiopia. This is because the local varieties are susceptible to late blight and of course low yield potential. Low yield of cassava due to shortage of improved cultivars are also reported by Tesfaye et al. (2013). Recent reports by Birhanu et al. (2014) confirmed that lack of improved sweet potato varieties suitable for different agro-ecologies and resistant to insect pests are some of the factors that hinder the crop expansion. Many developing countries lack efficient systems for the regular multiplication and distribution of certified seed tubers (Lutaladio et al., 2009).

Disease and pest problems

Diseases and insect pests and problem are another major constraint in production of root and tuber sector. From the total area covered by root crops in the past five years, about 43,503 ha of the cultivated land was damaged by different factors (CSA, 2016). Off this, about 17,210 ha of the cultivated land was damaged by biotic factors. Among these biotic factors, pest has caused a significant damage, in which it represents over 40% of this damage. However, it was statistically at par with the damage caused by other biotic factors. Disease and weed problems were equally threatening the production of root crops over the same period (Table 5). Various earlier works have also reported the major disease and pets that threaten the production of root crops in Ethiopia. Major insect pests of root crop in Ethiopia include aphids, tuber moths, leaf miners, green mite, beetle, butterfly, hornworm and weevil (Ferdu et al., 2009). Pests such as weevil and butterfly on sweet potato, tuber moth on potato and green mite and red spider mite on cassava greatly hampered the productivity of these crops (Tesfaye et al., 2013; Ermiyas et al., 2013; EIAR, 2015). Major diseases of root and tuber crops in Ethiopia include late blight, virus and bacterial wilt (Ephrem, 2015; Helen, 2016; EIAR, 2015). Late blight constitutes the most serious threat to increased potato production. Second to late blight in importance, particularly in warmer, more humid regions, is bacterial wilt. It hampered the productivity of enset and potato in south and southwestern, Ethiopia. Currently, a country wide establishment of bacterial wilt on potato was reported by more recent reports.

Policy related problem

Over the past two decades, Ethiopia has pursued a range of policies and investments to boost agricultural production and productivity, particularly with respect to the major staple foods that are critical to reducing poverty in the country. A central aim of this process has been to

Table 6. Policy packages implemented for cereal, pulse, oilseed and root crops from 2011-2015, Meher Season (CSA, 2016).

Crop type	The average policy package realized (ha)		
	Improved seed coverage	**Pesticide coverage**	**Extension package**
Cereals	97,101[a]	268,633[a]	325,980[a]
Pulses	9,541[b]	115,687[b]	189,038[b]
Oilseeds	6,451[b]	22,949[c]	90,480[c]
Total major Root crops	2,401[b]	29,885[c]	35,319[d]
$LSD_{0.05}$	12,059	25,582	39,195
CV (%)	30.3	17	18

Means within a column followed by the same letters are not significantly different at 5% probability level.

increase the availability of improved seed, chemical fertilizers, and extension services for small-scale, resource-poor farmers, particularly those cultivating staple food crops (Spielman et al., 2012). However, policies and investments on agricultural production and productivity primarily focused on cereals (FDRE, 2016). Comparable policy problem was also apparent in this evaluation. For example, from 2011 to 2015, the highest improved seed coverage was observed for cereals. While, the lowest improved seed coverage was observed from root crops over the same period. As a result, farmer-based seed systems are still common. In addition, crop protection strategies in root crops are also regarded as secondary non-cereal. For instance, the pesticide coverage was even far lower than pulses shown in Table 6. Root crops are also face with poor extension packages for the past five years. The average extension packages used for root crops were significantly lower than realized for other major crops (Table 6).

This is the result of research and policy neglect that root crops have been faced for the past several years. In the past several years, policy priority has been given to cereal crops. In support of this, Birhanu et al. (2006) reported that the primary emphasis of extension system has been focused on cereal crops and little attention was given to other subsectors. In addition, Spielman et al. (2012) reported that the national extension programs so far were a top-down type which lacks sort of dynamism to exploit the production potential and have not yet allowed the emergence of a dynamic demand driven system. With a few notable exceptions such as Ethiopia most developing countries have policies toward the root and tuber sector, and especially small-scale producers (Lutaladio et al., 2009). Moreover, these crops are faced with research neglect and very few reports deal with aspects of root and tuber crops production in Ethiopia. Most of the references on these subjects are often scant and fragmentary.

Socio-economic problems

Compared to other food crops, production of root and tuber crops is capital-intensive, requiring the purchase of large quantities of bulky seed and the application of high-cost inputs such as pesticides. In many areas of the country, such problems limit the expansion of root and tuber crops production. Small-scale producers have weak and limited access to markets. Agricultural markets world-wide are characterized by market structures, both quantitative-aggregation, storage, and processing facilities, and qualitative-quality standards, information services, logistics for distribution of agricultural products. Many of these structures do not exist in Ethiopia for root and tuber crops distribution. Most of such products have good value in form of fresh product but there are challenges in marketing associated with transportation and storage facilities to maintain quality. The high costs of transportation, makes small producers to sell most of their product at local markets.

Contribution towards addressing the problem

FAO has been supporting the root and tuber subsector in Ethiopia for five year since 2009. The institute aimed to increase and sustain the production and utilization of these crops. The institute working with national partners (EIAR, RARIs and Universities (Haromaya and Jimma)) has been actively involved in providing conducive conditions for resource poor farmers to grow root and tuber crops sustainably and profitably. Some of the projects supported by FAO include scaling up of root and tuber crops diversification and food security support to drought affected communities. The effort made by FAO results in establishment of root and tuber crop nurseries and cooperatives to produce improved planting materials. Other project such as the international potato center (CIP) has also started working on root and tuber crops subsector in Ethiopia since 1985. The CIP project made significant contributions towards root and tuber crops production and expansion in Ethiopia. This project specific emphasis was given to produce high quality planting materials especially for potato and sweet potato. Similar efforts were made by Graduation with Resilience to Achieve Sustainable Development (GRAD) to support the root and tuber subsector. GRAD identified the potato as an important commodity for household consumption and for generating income. To enable access to improved seeds, GRAD initiated and promoted community based potato seed multiplication using model farmers. In collaboration with researchers, three potato varieties (Belete, Jalenie and Gudenie) were promoted. GRAD facilitated market linkages by engaging the private sector; for example, the Balemlay Special Enjera and Food Flour Manufacturing Industry (BSEFMI) in Bahir Dar.

Conclusion

This assessment examined production constraints and major policy gaps in the production of root and tuber crops in Ethiopia from 2011 to 2015. Even though total production of root and tuber crops have registered a continuous increase within these period, it is mainly attributed to expansion of the area cultivated than increase in productivity. Several factors are responsible for productivity stagnation of root and tuber crops in Ethiopia but the major constraints related to lack of policy attention and package given for these crops in comparison to other major crops. For instance, only few Ethiopian farmers have access to improved seed (0.8% of total acreage) and pesticide coverage (14% of total acreage) for root and tuber crops. No institutionally recognized organization produces and provides improved varieties of such crops; all varieties used at farmer level are susceptible to disease and pests. For this reason, disease and pests coupled with other biotic factors resulted in a significant damage of cultivated land (17,210 ha). Off this, the damage caused by pest, accounts for over 40% of the total damage. Such policy neglect is also evident for extension packages and this package represents only 17% of cultivated area. Thus, calls great attention to raise the country's food self-sufficiency through production of root and tuber crops. To increase the productivity of root and tuber crops, policy attention should be given for the major constraints in production of root and tuber crops.

SUGGESTED ACTIONS

The way forward for root and tuber crops intensification in Ethiopia will include a number of priority areas. First and most importantly, deep reforms should be needed in the extension system. In this regard, policy reorientation emerges as a key alternative and hence, to focus on more responsive, demand driven and climate resilient food security crops. These approaches will require greater flexibility within the current system, which can be accomplished only by investing time, effort, and resources in changing the cultures and practices of the extension system. Second, the lack of adequate quantities of clean seed is needed to be improved. Third, the sector faces a growing challenge from more aggressive strains of disease and pests and Ethiopia has a limited capacity to control the disease through pesticide application. Continued research on resistance breeding and integrated disease and pest management strategies is essential. Finally, improving the incomes of small scale growers depends on increasing demand driven opportunities and developing value chains which include all market chain actors, from input suppliers to consumers. Linking farmers to markets, especially high-value supermarkets and restaurant chains, can substantially increase the profitability of the root and tuber sector.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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