The African Journal of Plant Science and Biotechnology ©2012 Global Science Books

Genetic Variability, Inter-Relationships and Path Analysis in Enset (*Ensete ventricosum*) Clones

Zerihun Yemataw[1] • Hussein Mohamed[2] • Mulugeta Diro[3] • Temesgen Addis[4*] • Guy Blomme[5]

[1] Southern Agricultural Research Institute, Areka Agricultural Research Center, P.O. Box 79, Areka, Ethiopia
[2] Hawassa Universities, Awassa College of Agriculture, P.O. Box 05, Hawassa, Ethiopia
[3] Capacity building for scaling up of evidence-based best practices in agricultural production in Ethiopia (CASCAPE), Addis Ababa, Ethiopia
[4] Southern Agricultural Research Institute, Awassa Agricultural Research Center, P.O. Box 06, Hawassa, Ethiopia
[5] Bioversity International, Uganda Office, P.O. Box 24384, Kampala, Uganda

Corresponding author: *** temesgen_addis@yahoo.com**

ABSTRACT

Enset (*Ensete ventricosum* (Welw.) Cheesman) is the most important staple food crop for millions of people living in southern and southwestern Ethiopia. Two hundred and forty enset clones collected from six zones in the southern region were established in 1999 at the Areka Agricultural Research Center to assess the magnitude of genetic variability, heritability of important characters, inter-relationships among characters and their direct and indirect effect on yield. The mean squares due to genotypes were highly significant ($P \leq 0.01$) for all the quantitative traits studied, suggesting the presence of substantial variability among the 240 enset clones. The phenotypic and genotypic coefficients of variation varied from 16.4% for plant height to 147.2% for *bulla* yield ha^{-1} y^{-1} and from 12.92% for pseudostem height to 138.41% for *bulla* yield ha^{-1} y^{-1}, respectively. Estimates of H' were lowest for fiber yield plant^{-1} (43.06%) and highest for maturity time (93.75%). The minimum genetic advance expectations were for pseudostem height (19.65%) and the maximum were for *bulla* yield ha^{-1} y^{-1} (267.35%). Fermented, squeezed *kocho* yield ha^{-1} y^{-1} was positively and significantly correlated with most of the traits, but negatively correlated phenotypically and genotypically with maturity time, *bulla* yield plant^{-1} and fiber yield plant^{-1}. Path coefficient analysis indicated that leaf sheath weight after decortication and central shoot weight before grating exerted positive direct effects on fermented, squeezed *kocho* yield ha^{-1} y^{-1}. A wide variation was observed between maximum and minimum values for most of the characters. The presence of wide variation in observed traits may point to opportunities for selecting enset clones with desirable characters.

Keywords: correlation, diversity, Ethiopia, genetic advance, heritability

INTRODUCTION

Enset, *Ensete ventricosum*, is a staple food crop for over 15 million people in south and southwestern Ethiopia (Brandt *et al*. 1997). Enset provides year-round food, fiber, animal feed and medicine (Brandt *et al*. 1997; Tesfaye 2002). The main food types obtained from enset are *kocho*, *bulla* and *amicho* (Spring *et al.* 1996). *Kocho* is the fermented starch that is obtained from decorticated (scraped) leaf sheaths and grated corms. *Bulla*, a starchy liquid, is obtained during scraping of leaf sheaths and grating of corms. The thick liquid is allowed to dry and this produces a white powder rich in starch. *Amicho* or boiled corm pieces, is consumed in a similar manner to other root and tuber crops (Brandt *et al.* 1997).

Information on phenotypic variation and its geographical distribution is important for genetic conservation, plant breeding and efficient utilization of plant genetic resources (Bekele 1996). Tabogie (1997) and Tsegaye (2002) reported a wide phenotypic variation among enset clones across a broad set of agro-ecological zones in southern Ethiopia.

Enset genotypic variation could provide desirable genes for crop improvement. Knowledge of the level of morphological diversity of enset across different agro-ecological zones and ethnic groups is important and therefore this study was conducted to assess the magnitude of genetic variability and heritability of important characters, inter-relationships among enset clones and their direct and indirect effect on yield.

MATERIALS AND METHODS

Description of the research area

The Areka research station is located at 7° 09′ N and 37° 47′ E and at an elevation ranging from 1,750 to 1,800 meters above sea level (masl). The Areka Agricultural Research Center is located in the Wolayta zone and is one of the research centers of the Southern Agricultural Research Institute. Areka has an average rainfall of 1,539 mm and a minimum and maximum mean temperature of 14.5 and 25.8°C, respectively. The soil is silty loam with a pH of 4.8 to 5.6 and low to medium organic matter content (2.65-5.67%) (Esayas 2003).

Experimental materials

A total of 240 enset clones which were collected from Wolaita, Kembata, Hadiya, Sidama, Gamo Gofa, Gurage and Dawro zones were included in this study. Corms of these enset clones were buried at the experimental field of the Areka Agricultural Research Center during the 1999-2000 rainy seasons for sucker production. One year after sucker multiplication, four suckers of similar size were taken from each clone and planted using a spacing of 3 m × 1.5 m between rows and plants, respectively. A clone was represented by a non-replicated plot consisting of two plants at the middle of the plot. The two plants were used as replications to estimate experimental error.

Received: 3 March, 2012. Accepted: 3 July, 2012.

Original Research Paper

Data collection and analysis

A total of 22 quantitative traits were used for characterization: 1. Maturity time (MT) (years): number of years from transplanting to harvesting; 2. Plant height (PH) (m): measurement from ground level to the tip of the longest leaf at flowering; 3. Pseudostem height (PSH) (m): measurement from ground level to the start of the petioles; 4. Pseudostem circumference (PSC) (m): measurement at the middle height of the enset pseudostem; 5. Number of functional leaves (LN): the number of 50% green and 50% unrolled leaves; 6. Leaf length (LL) (m): measurement of all functional leaves from end of the petiole to the tip of the leaf and their mean taken; 7. Leaf width (LW) (m): measurement of the widest part of all functional leaf blades just below flag leaf and their mean taken; 8. Number of decorticatable leaf sheaths (LSN): count of all decorticatable leaf sheathes obtained from each plant at harvest; 9. Leaf sheath weight before decortication (LSBD) (kg): weight of all leaf sheathes for each plant before decortication and measured before decortication; 10. Leaf sheath weight after decortication (LSAD) (kg): weight of pulp for each plant after decortication and measured after decortication; 11. Central shoot weight before grating (CSBG) (kg): the weight of central shoot after the inflorescence was removed and measured before grating; 12. Corm weight before grating (COBG) (kg): the weight of corm after fibrous roots removed and measured before grating; 13. *Bulla* yield plant^{-1} (BA) (kg): the small amount of water-insoluble starchy product separated from *kocho* by squeezing the liquid. Measured by weighing all the starchy product of a plant; 14. Fiber length (FL) (m): length measured after *kocho* decortication; 15. Fiber yield plant^{-1} (FA) (kg): fiber yield measured by weighing all the fiber left soon after decorticating the leaf sheath and exposing to sun light; 16. Fermented unsqueezed *kocho* yield (USQKA) (kg): the unfermented *kocho* yield left in the pit for some time; usually 30 days; for fermentation. The fermented *kocho* was measured for its weight before squeezing; 17. Fermented squeezed *kocho* yield (SQKA) (kg): the fermented *kocho* yield was squeezed by applying human force to reduce its water content as much as possible; 18. Unfermented *kocho* yield (UFK) (kg): *kocho* yield, which is the mixture of decorticated leaf sheath, grated central inflorescence-bearing shoot and corm, immediately after processing. The measured *kocho* yield plant^{-1} was finally converted to hectare^{-1} year^{-1} base using the formula:

$$\text{Kocho yield (Kg ha - 1 yr - 1)} = \frac{\text{Kocho Yield per plant x 10000m}^2}{\text{No of years to maturity x plot area (m}^2)}$$

The same formula was used to convert the *bulla*, fiber, fermented unsqueezed and fermented squeezed *kocho* yields on a yield hectare^{-1} year^{-1} basis.

The data were collected from two individual plants per clone.

Table 1 ANOVA, coefficient of variation (CV), and coefficient of determination (R^2) for 22 traits assessed in 240 enset clones gown at Areka.

SV	DF	MT	PH	PSH	PSC	LN	LL	LW	LSN	LSBD	LSAD	CSBG
Clones	239	2.39***	1.51***	0.19***	0.09***	7.44***	0.67***	0.09***	23.88***	1212.7***	292.68***	66.57***
Error	240	0.15	0.34	0.09	0.03	3.06	0.16	0.006	9.9	253.9	80.38	20.85
CV		9.35	10.67	17.79	14.86	17.43	12.08	11.51	17.44	27.67	31.90	31.25
R^2		0.94	0.82	0.67	0.74	0.71	0.81	0.93	0.72	0.83	0.79	0.76
SV	**DF**	**COBG**	**BA**	**FL**	**FA**	**USQKA**	**SQKA**	**UFK**	**USQKB**	**SQKB**	**BB**	**FB**
Clones	239	354.73***	0.12***	0.14***	0.08***	262.21***	142.52***	513.46***	97.9***	46.21***	0.95***	0.02***
Error	240	41.21	0.03	0.15	0.05	51.3	28.34	85.81	17.5	48.25	0.12	0.01
CV		23.65	61.10	15.57	72.22	26.62	29.27	24.26	28.3	30.43	71.7	67.6
R^2		0.89	0.81	0.82	0.63	0.84	0.83	0.86	0.85	0.84	0.89	0.65

***, **, *, ns = significant at 0.1%, 1%, 5%, and non significant, respectively. SV = source of variation, DF = degrees of freedom, CV = coefficient of variation, R^2 = Coefficient of determination, MT = maturity time, PH = plant height, PSH = pseudostem height, PSC = pseudostem circumference, LN = leaf number, LL = leaf length, LW = leaf width, LSN = leaf sheath number, LSBD = leaf sheath weight before decortication, LSAD = leaf sheath weight after decortication, CSBG = central shoot weight before grating, COBG = corm weight before grating, BA = *bulla* yield per plant, FL = fiber length, FA = fiber yield per plant, USQKA = fermented unsqueezed *kocho* yield per plant, SQKA = fermented squeezed *kocho* yield per plant, UFK = unfermented *kocho* yield per hectare, USQKB = fermented unsqueezed *kocho* yield per hectare per year, SQKB = fermented squeezed *kocho* yield per hectare per year, BB = *bulla* yield per hectare per year, FB = fiber yield per hectare per year.

Table 2 Mean squares for 22 quantitative traits of 240 enset clones from six zones.

Traits	Gamo Gofa (df=33)	Gurage (df=29)	Dawro (df=26)	Sidama (df=40)	Kembata & Hadiya (df=71)	Wolaita (df=35)
MT (y)	2.42**	1.59**	2.47**	2.23**	2.74**	2.4**
PH (m)	1.2**	1.21	2.63**	1.19**	1.43**	1.74**
PSH (m)	0.24	0.12	0.25*	0.12**	0.23**	0.15**
PSC (m)	0.14	0.05**	0.14**	0.09**	0.05**	0.09*8
LN	4.67	5.07	8.24**	7.61**	8.62**	8.85**
LL (m)	0.57**	0.95**	1.1**	0.47**	0.56**	0.65**
LW (m)	0.01**	0.62**	0.04**	0.02**	0.01**	0.02**
LSN	14.57**	76.47	14.83**	17.53**	14.76**	21.55**
LSBD (kg)	1029.5**	967.96**	1511.7**	1567.42**	1106.59**	1176.158**
LSAD (kg)	251.09**	352.13**	363.54**	331.68**	271.38**	238.6**
CSBG (kg)	154.15**	52.47	67.79**	57.92**	43.01**	52.41**
COBG (kg)	404.55**	354.6**	508.54**	405.51**	326.31**	193.2**
BA (kg)	0.04	0.02	0.06**	0.02**	0.33**	0.02
FL (m)	0.07	0.04**	0.08**	0.13**	0.29	0.06**
FA (kg)	0.21**	0.04	0.076	0.08**	0.05**	0.08**
USQKA (kg)	275.45**	232.56**	360.42**	414.22**	175.86**	202.76**
SQKA (kg)	155.83**	129.64**	236.67**	184.06**	110.34**	88.51**
UFK (t ha^{-1}y^{-1})	362.45**	477.03*	465.65**	657.15**	548.39**	486.49**
USQKB (t ha^{-1}y^{-1})	61.42**	102.14**	89.9**	150.76**	87.53**	95.38**
SQKB (t ha^{-1}y^{-1})	30.01**	50.72**	59.33**	67.25**	38.42**	39.74**
BB (t ha^{-1}y^{-1})	0.11	0.1	0.05**	0.14**	2.91	0.08*
FB (t ha^{-1}y^{-1})	0.08**	0.01	0.01	0.02**	0.01**	0.01

**,*, = significant at 1%, 5%, df = degrees of freedom of clones, MT = maturity time, PH = plant height, PSH = pseudostem height, PSC = pseudostem circumference, LN = leaf number, LL = leaf length, LW = leaf width, LSN = leaf sheath number, LSBD = leaf sheath weight before decortications, LSAD = leaf sheath weight after decortications, CSBG = central shoot weight before grating, COBG = corm weight before grating, BA = *bulla* yield per plant, FL = fiber length, FA = fiber yield per plant, USQKA = fermented unsqueezed *kocho* yield per plant, SQKA = squeezed *kocho* yield per plant, UFK = unfermented *kocho* yield, USQKB = fermented unsqueezed *kocho* yield per hectare per year, SQKB = fermented squeezed *kocho* yield per hectare per year, BB = *bulla* yield per hectare per year, FB = fiber yield per hectare per year.

Analysis of variance (ANOVA)

The data of all assessed traits were analysed using the SAS software package (SAS 2002). The genotypic and phenotypic coefficients of variation (GCV and PCV) for each trait were calculated using the following formulae:

$$GCV = (\sigma^2 g/\text{grand mean of character}) * 100$$

$$PCV = (\sigma^2 p/\text{grand mean of character}) * 100$$

Broad sense heritability and expected genetic advance (gain) with one cycle of selection were estimated for each character using variance components as described by Allard (1960):

$$\text{Heritability, } H^2 = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

$$\text{Genetic advance as percent of mean, } GAM = (GA/\tilde{Y}) \times 100$$

where GA = genetic advance and $\tilde{Y}$ = mean of the trait for all clones.

The estimates of phenotypic and genotypic correlation were obtained by using the formula given by Singh and Chaudhury (1985). Direct and indirect path coefficients were calculated by Dewey and Lu (1959).

Table 3 Average values for plant growth and yield traits of highly performing enset clones evaluated at the Areka Agricultural Research Center.

Clone name	MT	PH	PSH	PSC	LSN	LSBD	LSAD	CSBG	COBG	USQKA	SQKA	UFK	USQKB	SQKB
Adame-ado	3.78	6.87	1.85	1.51	20.5	123.5	56.5	18.25	43.25	52	41.5	66.72	29.41	23.41
Anikefiye	3.07	5.75	1.67	1.54	22.5	96.5	59.5	17	24.5	49	35.5	70.1	33.98	24.58
Ashura	4.8	5.75	1.8	1.42	20.5	97	46.5	17	63	45.5	37.5	59	21.67	17.6
Beshera	5.17	7.17	2.4	1.95	21.5	121	67	60.5	72.5	74	51	83.56	30.69	21.31
Bishato	3.3	6.95	2.15	1.32	21.5	97.5	53	27	37.75	53	36	76.21	34.29	23.2
Bishkanchiwe	3.17	6.58	2.05	1.36	25.5	84.5	48.5	21	29.25	46	32.5	66.72	30.99	21.84
Bulle	3.06	6.9	2.15	1.24	17	75	48	24	32.5	41	26	72.86	28.59	18.13
Bumbe	4.24	6.63	1.9	1.37	19	87	40	25.5	46	53.25	39.75	56.65	27.02	20.15
Chelako	2.8	6.19	1.73	1.59	21.5	73.5	37.5	17.5	21.5	33.75	24	57.94	25.56	18.18
Derassa-dimela	3.71	7.3	2.15	1.25	22	144	64	20.5	44.5	66.5	43.5	74.66	38.49	25.18
Digomerza	2.84	7.46	2.1	1.58	18.5	125	61	22.5	44.5	54	34	95.51	40.29	25.32
Fenchariya-yepa	4.73	7.36	2.45	1.68	20.5	125	61	18.5	55.5	52.5	38	62.95	24.45	17.66
Gena	3.37	6.13	1.65	1.4	20.5	92	49	18.5	46.5	54.5	33.5	72.21	34.11	21.24
Gena-3	3.34	6.45	1.65	1.37	16.5	87.5	44.5	21	34	41	29.5	65.06	26.67	19.18
Gerbo	2.54	5.85	1.45	1.38	26	103	44	27.5	22.5	38	24.5	78.2	31.63	20.37
Goderia	3.24	6.6	2.12	1.27	18.5	79.5	38	27	28.75	38	27	61.88	25.08	17.83
Keberichie	2.58	6.12	1.7	1.46	22.5	85.5	38.5	18	20	35.5	27.5	62.69	29.1	22.55
Walantiche	4.25	6.2	1.85	1.63	20	80	43.25	30	88	83.5	44.5	81.8	42.34	22.58
Yegendiye	3.48	6.08	1.6	1.48	23	85.5	53	27.5	37	46	31	73.21	28.63	19.41
Yekimech	3.51	5.93	1.85	1.39	23	86.5	55.75	23.25	35	53	33	70.09	32.24	20.27

MT = maturity time, PH = plant height, PSH = pseudostem height, PSC = pseudostem circumference, LSN = leaf sheath number, LSBD = leaf sheath weight before decortication, LSAD = leaf sheath weight after decortication, CSBG = central shoot weight before grating, COBG = corm weight before grating, USQKA = fermented unsqueezed *kocho* yield per plant, SQKA = squeezed *kocho* yield per plant, UFK = unfermented *kocho* yield, USQKB = fermented unsqueezed *kocho* yield per hectare per year, SQKB = fermented squeezed *kocho* yield per hectare per year.

Table 4 Estimates of means, ,ranges, standard errors (SE), ,phenotypic coefficient of variance (PCV), genotypic coefficient of variance (GCV, heritability (%) in broad sense (H^2b), genetic advance (GA) and genetic advance as percent of the mean (GAM) for 22 quantitative morphological characters in 240 enset clones grown at Areka

Traits	Mean ± SE	Range		σ^2_g	σ^2_e	σ^2_p	PCV	GCV	H^2b	GA	GAM
		Minimum	Maximum								
MT (y)	4.22 ± 0.05	2.1	7.55	1.2	0.08	1.28	26.81	25.96	93.90	2.18	51.66
PH (m)	5.50 ± 0.05	2.33	7.65	0.64	0.17	0.81	16.4	14.57	78.87	1.46	26.6
PSH (m)	1.74 ± 0.02	0.88	2.90	0.05	0.05	0.10	18.28	12.92	52.30	0.34	19.65
PSC (m)	1.17 ± 0.01	0.58	2.04	0.03	0.01	0.04	17.1	14.8	65.70	0.28	23.93
LN	10.05 ± 0.10	4.5	17	2.27	1.53	3.80	19.4	14.99	59.71	2.4	23.88
LL (m)	3.37 ± 0.03	0.73	4.71	0.28	0.08	0.36	17.8	15.7	76.97	0.95	28.19
LW (m)	0.70 ± 0.01	0.37	3.68	0.04	0.003	0.046	30.64	28.57	92.96	0.41	58.57
LSN	18.36 ± 0.19	11.00	48.50	7.80	4.95	12.76	20.20	15.21	61.67	4.50	24.51
LSBD (kg)	57.58 ± 1.26	10.00	144.00	504.46	124.80	629.26	43.56	39.00	80.17	41.43	71.95
LSAD (kg)	28.10 ± 0.64	3.00	67.00	113.54	39.3	152.83	44.00	37.92	74.29	18.92	67.33
CSBG (kg)	14.61 ± 0.30	2.00	60.50	22.87	10.46	33.33	39.51	32.73	68.62	8.16	55.85
COBG (kg)	27.14 ± 0.64	5.00	88.00	154.89	20.62	175.52	48.81	45.85	88.25	24.08	88.72
BA (kg)	0.29 ± 0.01	0.11	1.44	0.05	0.015	0.067	89.25	77.11	76.48	0.41	141.38
FL (m)	1.14 ± 0.01	0.11	1.72	0.06	0.015	0.07	23.21	21.49	78.60	0.44	38.59
FA (kg)	0.30 ± 0.01	0.11	1.39	0.02	0.025	0.04	66.67	47.14	43.06	0.18	60.00
USQKA (kg)	26.90 ± 0.57	4.75	83.5	107.23	25.76	132.98	42.87	38.49	80.63	19.15	71.20
SQKA (kg)	18.19 ± 0.42	2.75	51.00	57.64	14.18	71.82	46.60	41.74	80.26	14.01	77.02
UFK (t ha^{-1} y^{-1})	38.18 ± 0.81	7.10	95.51	226.8	42.93	269.74	43.02	39.44	84.08	28.45	74.51
USQKB (t ha^{-1} y^{-1})	14.79 ± 0.35	1.92	42.34	42.96	8.77	51.73	48.63	44.32	83.04	12.30	83.16
SQKB (t ha^{-1} y^{-1})	9.87 ± 0.24	1.29	25.32	19.55	4.53	24.08	49.72	44.79	81.2	8.21	83.18
BB (t ha^{-1} y^{-1})	0.49 ± 0.03	0.01	7.08	0.46	0.06	0.52	147.2	138.41	88.15	1.31	267.35
FB (t ha^{-1} y^{-1})	0.16 ± 0.006	0.04	0.99	0.006	0.006	0.01	62.5	48.41	49.24	0.11	62.5

MT = maturity time, PH = plant height PSH = pseudostem height, PSC = pseudostem circumference, LN = leaf number, LL = leaf length, LW = leaf width, LSN = leaf sheath number, LSBD = leaf sheath weight before decortication, LSAD = leaf sheath weight after decortication, CSBG = central shoot weight before grating, COBG = corm weight before grating, BA = *bulla* yield per plant, FL = fiber length, FA = fiber yield per plant, USQKA = fermented unsqueezed *kocho* yield per plant, SQKA = fermented squeezed *kocho* yield per plant, UFK = unfermented *kocho* yield, USQKB = fermented unsqueezed *kocho* yield per hectare per year, SQKB = fermented squeezed *kocho* yield per hectare per year, BB = *bulla* yield per hectare per year, FB = fiber yield per hectare per year

RESULTS AND DISCUSSION

The ANOVA revealed that the mean squares for clones/ genotypes were highly significant ($P \leq 0.01$) for all the quantitative traits studied, suggesting the presence of substantial variability among the 240 enset clones (**Table 1**). Amplified Fragment Length Polymorphisms have been employed to characterize 146 enset clones from southern and southwestern Ethiopia to assess genetic relationships among the clones, identify duplicate accessions, and investigate regional variation (Negash 2001). Within the 146 clones, 21 duplication groups consisting of 58 clones were identified based on the AFLP data. In other words, 37 clones, or 25% of the collection, consisted of duplicated clones (Negash *et al*. 2002).

ANOVA carried out per zone revealed the presence of highly significant ($P \leq 0.01$) variation among enset clones that was observed for 20 qualitative traits for the Kembata, Hadiya and Sidama zones (**Table 2**). The enset clones from Dawro, Wolaita, Gamo Gofa and Gurage showed significant differences for 19 (86.36%), 18 (81.82%), 16 (72.73%) and 13 (59.09%) of the 22 quantitative traits, respectively. Fiber yield did not show significant variation in the clones from Gurage, Dawro, Kembata and Hadiya zones.

The genotypes 'Digomerza', 'Derassadimela', 'Anikiefaye', 'Adame addo' and 'Bishato' had the highest values for fermented squeezed *kocho* yield ha^{-1} $year^{-1}$ (**Table 3**). The clone 'Digomerza', is a high yielding and early maturing type, while the clones 'Derassadimela', 'Bishato' and 'Anikiefaye' are high yielding and of intermediate maturity. Enset clones that are early maturing, medium to high yielding and intermediate maturing with a high yielding potential were found to be promising for *kocho* yield. 'Gena' is the most widely distributed enset clone and is under production in five of the seven zones. Tabogie (1997) reported that 'Gena' is one of the highest yielding clones, producing up to 16.9 ha^{-1} $year^{-1}$ of *kocho*. 'Gena' and the remaining 11 high yielding enset clones mentioned (**Table 3**) should be studied further, both in regional and national yield trials, in order to release better yielding and stable clones for wider adaptation.

A wide variation was observed between maximum and minimum values for most of the characters (**Table 4**). The wide variation in observed traits may point to opportunities for selecting enset clones with desirable characters. The wide range in each of the traits studied offers broad opportunities for selecting parents of interest in breeding programs to develop varieties suitable for different agro-ecologies of the country. Similar results were obtained by Tabogie (1997), who studied the variability of 88 enset clones for *kocho* yield. The author reported a wide variability in *kocho* yield ranging from 2.69 to 24.71 t ha^{-1} y^{-1}.

The phenotypic coefficient of variation was higher than the genotypic coefficient of variation for all the assessed traits (**Table 4**). The PCV ranged from 16.4 for plant height to 147.2 for *bulla* yield ha^{-1} y^{-1} and the genotypic coefficient of variation ranged from 12.92 for pseudostem height to 138.41 for *bulla* yield ha^{-1} y^{-1}. Nevertheless, there was a close relationship between phenotypic and genotypic coefficients of variation for all traits. Closeness of the two coefficients of variation indicates the importance of the genotype/genetic makeup in determining the phenotypic traits. In general, enset clones used in this study were phenotypically as well as genotypically diverse, which points to the existence of a large diversity in enset for quantitative characters.

Our finding is in line with Shumbulo (2008), who studied ginger accessions for yield and oleoresin content in southern Ethiopia and reported that a large portion of phenotypic variance was accounted for by genetic components for traits such as number of tillers, leaves per plant and total fresh rhizome yield per plot.

High heritability and genetic advance for unfermented *kocho* yield (84.08%) indicate an additive gene action and,

Table 5 Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients for selected traits of Enset clones at Areka.

Character	SQKB	MT	PH	PSH	PSC	LN	LL	LW	LSN	LSBD	LSAD	CSBG	COBG	BA	FL	FA
SQKB	1	-0.45	0.72*	0.49	0.74*	0.61	0.63	0.42	0.64	0.79**	0.84**	0.74*	0.42	-0.14	0.48	-0.39
MT	0.43*	1	-0.27	0.01	0.03	-0.65	-0.27	-0.17	-0.35	-0.22	-0.26	-0.32	0.43	-0.15	-0.02	0.33
PH	0.6**	-0.24	1	0.91**	0.7	0.51	0.93**	0.29	0.5	0.82**	0.83**	0.64	0.52	0.07	0.38	-0.34
PSH	0.32	0.02	0.77**	1	0.56	0.31	0.84**	0.21	0.49	0.73	0.7	0.51	0.66	0.12	0.29	-0.18
PSC	0.58**	0.009	0.58**	0.4**	1	0.41	0.7	0.39	0.52	0.88**	0.91**	0.82**	0.77*	0.05	0.28	-0.29
LN	0.47**	-0.52	0.43**	0.23**	0.35**	1	0.55	0.17	0.62	0.51	0.53	0.56	0.08	0.2	0.13	-0.29
LL	0.54**	-0.23	0.87**	0.65**	0.57**	0.45**	1	-0.03	0.47	0.76*	0.75*	0.69	0.46	0.077	0.36	-0.33
LW	0.38*	-0.16	0.3*	0.18**	0.34**	0.18**	0.03	1	0.22	0.38	0.45	0.3	0.15	-0.01	0.12	-0.07
LSN	0.48**	-0.28	0.36**	0.22**	0.37**	0.44**	0.37**	0.18	1	0.7	0.63	0.46	0.16	0.02	0.16	-0.41
LSBD	0.73**	-0.21	0.7**	0.49**	0.72**	0.41**	0.68**	0.36**	0.55**	1	0.94**	0.76*	0.54	0.07	0.28	-0.35
LSAD	0.77**	-0.25	0.67**	0.44**	0.71**	0.4**	0.64**	0.41**	0.49**	0.91**	1	0.8*	0.58	0.099	0.23	-0.39
CSBG	0.65**	-0.28	0.51**	0.32**	0.61**	0.41**	0.53**	0.27**	0.36**	0.66**	0.71	1	0.5	0.07	0.12	-0.33
COBG	0.39*	0.39*	0.45**	0.46**	0.61**	0.06	0.4*	0.14	0.15	0.51**	0.51**	0.39**	1	-0.07	0.21	-0.125
BA	-0.12	-0.15	0.05	0.04	-0.01	0.12*	0.04	-0.02	0.002	0.03	0.05	0.05	-0.05	1	-0.7	0.3
FH	0.4*	-0.02	0.33	0.2**	0.2	0.11*	0.31*	0.11	0.14	0.27**	0.22**	0.13	0.17	-0.57**	1	-0.24
FA	-0.27	0.24*	-0.23	-0.11	-0.15	-0.2	-0.21	-0.05	-0.22	-0.24	-0.24	-0.2	-0.09	0.15	-0.2	1

** and * = significant at 1% and 5%, respectively. SQKB = squeezed *kocho* yield per hectare per year, MT = maturity time, PH = plant height, PSH = pseudo stem height, PSC = pseudo stem circumference, LN = leaf number, LL = leaf length, LW = leaf width, LSN = leaf sheath number, LSBD = leaf sheath weight before decortication, LSAD = leaf sheath weight after decortication, CSBG = central shoot weight before grating, COBG = corm weight before grating, BA = *bulla* yield per plant FL = fiber length, FA = fiber yield per plant.

Table 6 Estimates of genotypic direct effects (bold and diagonal) and indirect effects (off diagonal) of traits on fermented squeezed *kocho* yield/ha/year of 240 enset clones grown at Areka.

	r_g	MT	LFSTHAD	CSBG	COBG	FL	LL	LFSTHNO
MT	-0.448	**-0.376**	-0.131	-0.064	0.1004	-0.077	0.077	-0.047
LFSAD	0.845	0.098	**0.501**	0.161	0.135	0.085	-0.221	0.085
CSBG	0.743	0.119	0.397	**0.203**	0.114	0.047	-0.199	0.061
COBG	0.427	-0.164	0.294	0.1008	**0.23**	0.078	-0.136	0.023
FL	0.485	0.007	0.114	0.025	0.048	**0.374**	-0.108	0.023
LL	0.637	0.099	0.38	0.139	0.108	0.138	**-0.292**	0.065
LSNO	0.638	0.131	0.317	0.092	0.039	0.063	-0.14	**0.135**
R^2	**0.92**		**Resid**	**0.08**				

rg = correlation coefficient, MT = maturity time, LFSTHAD = leaf sheath after decortication, CSBG = central shoot weight before grating, COBG = corm weight before grating, FL = fiber length, LL = leaf length, LFSTHNO = leaf sheath number, R^2 = residual effect hence, possible trait improvement through selection. Garedew (2006) also reported high heritability with high phenotypic and genotypic coefficients of variation in tuber weight/hill and tuber number/hill for the indigenous crop *Plectranthus edulis* (Vatke) Agnew.

The high genetic advance observed in this study indicates that fast improvement can be made in most of the traits. For example, by combining the top 5% of the 240 clones (12 clones with the highest *kocho* yield), it is predicted that *kocho* yield can be improved by 8.21 t ha^{-1} y^{-1}. Any heterosis observed in such crosses could be fixed by vegetative propagation. Sexual and vegetative reproduction in enset can both be used to the advantage of the breeder.

Genotypic coefficients of correlation, in general, were higher than the corresponding phenotypic coefficients of correlation (**Table 5**, above and below diagonal, respectively) indicating little influence of environment on any inherent association among the traits studied. The phenotypic and genotypic coefficients of correlation indicated that squeezed *kocho* yield ha^{-1} y^{-1} was positively correlated with most of the characters. This shows that selection for *kocho* yield can be done through selection of those traits with which it is strongly correlated (**Table 5**). This is in agreement with Tabogie (1997) who reported that *kocho* yield was positively and significantly correlated with plant height, pseudostem circumference, leaf sheath number and leaf sheath weight.

Among the studied traits, leaf sheath weight after decortication (0.501 kg), fiber length (0.374 m), central shoot weight before grating (0.203 kg) and corm weight before grating (0.23 kg) exerted direct positive effects on squeezed *kocho* yield t ha^{-1} y^{-1} (**Table 6**). Selection of early maturing clones with heavier leaf sheaths, central shoots and corms, and bearing longer leaves, is expected to lead to the identification of clones with high *kocho* yield. Tabogie (1997) stated that leaf sheath weight had the highest direct effect on *kocho* yield.

CONCLUSION

The clones showed clear variability in their yield and other agronomic and genetic characters. Enset clones from the same area showed variability, indicating the presence of genetic diversity. From evaluation of mean performance and correlation studies it could be concluded that the genotypes were selected by farmers for their fermented squeezed *kocho* yield. The existence of diverse genetic potential should encourage collection, conservation and production of these promising clones across the region. Twenty high-yielding clones have been identified and crossing between these elite clones and further selection in their progeny will provide an opportunity to obtain new enset populations with high yield and other desirable characters. Heterotic crosses should be maintained by vegetative propagation.

ACKNOWLEDGEMENTS

The authors would like to thank the Southern Agricultural Research Institute and the Canadian International Development Agency for their financial support.

REFERENCES

Allard R (1960) *Principles of Plant Breeding*, John Wiley and Sons Inc. New York, 485 pp

Bekele F (1996) A sampling of the phenotypic diversity of cocoa in the Cocoa Gene Bank of Trinidad. *Crop Science* **36**, 57-64

Brandt S, Spring A, Hiebsch C, McCabe S, Tabogie E, Diro M, Wolde-Michael G, Yntiso G, Shigeta M, Tesfaye S (1997) *The 'Tree Against Hunger'. Enset-based Agricultural Systems in Ethiopia*, American Association for the Advancement of Science, Washington, DC, 56 pp

Dewey D, Lu K (1959) A correlation and path coefficients analysis of components of crested wheat grass seed production. *Agronomy Journal* **51**, 515-518

Esayas A (2003) *Soils of Areka Agriculture Research Center*, Technical paper No. 77

Garedew W (2006) Morphological characterization and divergence analysis of *Plectranthus edulis* (Vatke) Agnew collection in Ethiopia. MSc thesis, Hawassa University, Hawassa, Ethiopia, 81 pp

Negash A, Tsegaye A, Van Treuren R, Visser B (2002) AFLP analysis of *Ensete* clonal diversity in south and southwestern Ethiopia for conservation. *Crop Science* **42 (4)**, 1105-1111

SAS (2002) Statistical Analysis Systems SAS/STAT user's guide Version 9 Cary NC: SAS Institute Inc. USA

Shumbulo A (2008) Evaluation of Ginger (*Zingiber officinale* Rosc.) accessions for yield and oleoresin in Southern Ethiopia. MSc thesis, Hawassa University, Hawassa, Ethiopia, 84 pp

Singh R, Chaudhary B (1985) *Biometrical Methods in Quantitative Genetic Analysis*, Kalyani Publishers, New Delhi, 318 pp

Spring A, Haile B, Tesfaye S, Abebe Y, Amaldegn A, Wolde-Michael G, Tabogie E, Surur O, Tsegaye A, Shimeles S, Habte T, Menjeye T, Tadesse T (1996) Enset farming system in southern region, Ethiopia: report on a rapid rural appraisal in Guragie, Hadiya and Sidama zones. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Addis Ababa, Ethiopia, mimeo 83 pp

Tabogie E (1997) Morphological characterization of enset (*Ensete ventricosum* (Welw) Cheesman) clones and the association of yield with different traits. MSc thesis, School of Graduate Studies, Alemaya University, Alemaya, Ethiopia, 89 pp

Tesfaye B (2002) Studies on landrace diversity, *in vivo* and *in vitro* regeneration of enset (*Enset ventricosum* Welw.). PhD dissertation, Humboldt University, Berlin, Germany, 129 pp

Tsegaye A (2002) On indigenous production, genetic diversity and crop ecology of enset (*Ensete ventricosum* (Welw.) Cheesman). PhD dissertation, Wageningen University, The Netherlands, 197 pp