Rhizome Yield, and Oleoresin and Total Gingerol Content of Ginger (*Zingiber officinale* Rosc.) Accessions from Southern Ethiopia

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Abstract

Knowledge of genetic variability and correlation among agronomic and quality traits is important for plant breeders to improve yield and quality of crops. To evaluate the performance and estimate the variability of ginger accessions, a total of 27 indigenous and 9 introduced accessions were tested at four locations in southern Ethiopia in 2007 using 6 × 6 lattice square designs with three replications. Oleoresin was determined using Sox Tec Extraction and total gingerol content was determined using High Performance Thin Layer Chromatography. The analyses of variance revealed significant ($p \leq 0.05$) differences among accessions for most traits studied. The mean fresh rhizome yield was 19.4, 12.2, 10.4 and t ha^{-1} at Tepi, Matala Hambecho, Parawocha and Hadaro, respectively. The range of oleoresin extracted with hexane was 2.75-6.25%, and total gingerol content ranged from11.5% to 30.0%. Broad sense heritability (73%) and genetic advance as percent of mean (29.41) were high for fresh rhizome yield. Path coefficient analysis indicated that the superseding component traits determining rhizome yield are rhizome length and number of fingers $rhizome^{-1}$. Thus, these traits should be given emphasis in improving rhizome yields.

Key Words: Custer, ginger, oleoresin, total gingerol, variability, *Zingiber officinale*

Introduction

One of the oldest known spice, ginger (*Zingiber officinale* Rosc.), has been used as a spice and medicine since several centuries. Ginger is indigenous to tropical India, South East Asia, Australia and Japan, with the main center of diversity in Indo-Malaysia (Purseglove, 1972). In India, ginger in its fresh and dried form has numerous uses in culinary and medicinal preparations. India and China are the world's largest producers and exporters of ginger. Other important producers are Jamaica, Nigeria, Sierra Leone, Thailand, and Australia (Purseglove, 1972; Jansen, 1981; Weiss, 2002).

The rhizome yields an essential oil that lacks the pungency. It is used in the manufacture of flavoring, essences and perfumery. An oleoresin is also extracted in which the full presence of spices is preserved for flavoring and medicinal purposes. The oleoresin contains the constituents that are responsible for pungency of ginger. Gingerol (especially 6-gingerol) is the most important pungent constituent of ginger. The other constituents include non-volatile phenols, shogoals and zingerone (Purseglove, 1972; Purseglove *et al*., 1981; Dawit *et al*., 2003). Ginger oleoresin is one of the most important quality parameters in the

international market because of the pungent principles present in the oleoresin. The oleoresin content and quality is affected by the rhizome origin, age of harvesting, drying (moisture content), extraction method and the solvent used for extraction. The common solvents used in extraction of oleoresin are acetone, ethanol, and di- or tri-chloroethane (Nigist and Brehanu, 1996; Weiss, 2002).

Ginger was introduced into Ethiopia in the early 13th century (Janson, 1981). In Ethiopia, the crop is often cultivated under sub-optimal conditions at altitudes of up to 2000 m above sea level and with rainfall of less than 1500 mm per year (Jansen, 1981; Anteneh *et al*., 2008). Most (99%) of ginger production was from the Southern Nations, Nationalities and Peoples Regional State (SNNP), and about 1% was from Oromia National Regional State (MoA, 2003). Ginger is increasingly becoming important cash crop in the South, Southwest and Northwest parts of Ethiopia (Girma and Digafie, 2004). The productivity of fresh rhizome ginger at the national level is 7.1 t ha^{-1} (MoA, 2003). In the SNNP, especially in Wolaita (Boloso Sore and Boloso Bombe Woredas) and Kembata and Hadiya Zones, ginger is a major crop. On average, farmers harvest about 20 t ha^{-1} of fresh rhizome. The crop has high productivity per unit area, is tolerant to drought and diseases, and is suitable for intercropping with crops like beans, maize and taro. Ginger can be dried and stored for a long period of time.

Some preliminary research conducted at Tepi indicated that both the indegenious and exotic ginger germplasms showed variability in their morphological characters, fresh rhizome yield, and essential oil and oleoresin content (Girma and Digafie, 2004). The accessions also showed variation in morphological, growth habits and rhizome characters. Rhizome yield is basically affected by the genotype, environment and crop management factors (Pruthi, 1998; Weiss, 2002). However, the oil and oleoresin content of rhizomes and their characteristic odor and pungency is genetically controlled. Differences in composition of freshly harvested rhizomes in Ethiopia have already been reported (Jansen, 1981; Weiss, 2002). As rhizomes mature, fiber, pungent constituents and volatile oil increase.

Although fresh rhizome yield and quality of ginger is affected by genetic, environmental and agronomic factors, no systematic multi-location tests have been conducted to exploit the genetic potential of the existing local and introduced germplasm. The objectives of the present study were to: i) estimate the phenotypic and genotypic variability for some quantitative traits of ginger accessions grown in Southern Ethiopia; ii) determine associations among yield and quality traits of ginger; and iii) identify accessions with high rhizome yield, and oleoresin and total gingerol content for variety development.

Materials and Methods

Plant materials

Thirty six ginger accessions (27 local and 9 introduced) obtained from Tepi Agricultural Research Sub-Center were used for the study (Table 1). One-year-old and 3-5 cm long rhizomes having at least one active bud were used as planting materials.

Experimental sites

The experiment was conducted at Hadaro in Kembata and Tembaro Zone, Parawocha (1602 m asl) in Boloso Bombay Wereda of Wolaita Zone, Matala Hambecho (1620 m asl) in Boloso Sore Werda in Wolaita Zone, and Tepi (1200 m asl) in Sheka Zone. The mean annual rainfall of the sites obtained from the nearest metrological stations is about 1375 mm at Parawocha,

1460 mm at Matala Hambecho and 1420 mm at Tepi. The sites represent major ginger producing areas in the SNNP. All the four sites have well drained loam soils.

Experimental design and management

The design was a 6 × 6 lattice with three replications. Each plot was 3.0 m long and 2.1 m wide with 7 rows/plot and 20 plants/row. There were 50 and 100 cm spacings between plots and replications, respectively. Rhizomes were planted in the second week of April and harvested between late November and mid December in 2007 depending on the locationt. The central five rows were harvested leaving two border plants from each edge of the row. The net plot size was 2.7 m × 1.5 m.. Other cultural practices were done according to the recommendation of Jimma Research Center (Girma and Digafe, 2004).

Data collection

Data were collected on individual plant and plot basis. Number of leaves plant^{-1}, number of fingers rhizome^{-1} and number of tillers hill^{-1}, leaf length (cm), leaf width (cm), rhizome length (cm) and plant height (cm) were assessed on five randomly selected plants plot^{-1}. Date of planting, date of emergence, number of plants plot^{-1}, days to maturity, total fresh and dried rhizome yield (t ha^{-1}) were recorded for each plot. A 2 kg sample of fresh rhizome was oven dried at 100^{o} C for 72 h. Dry rhizome yield plot^{-1} was obtained by multiplying the total plot fresh yield by the ratio of the oven dry weight to the fresh weight of the 2 kg sample rhizome.

Oleoresin content (w/w) and total gingerol contents for Tepi and Matala Hembecho were determined following the method of Mukhejee *et al* (2006)**.** Dried 100 g powdered rhizome samples were extracted by a typical reflux apparatus placing it on a water bath. Powdered rhizomes were soaked in a round bottom flask containing hexane solvent. The flask was then heated constantly for three hours to facilitate the extraction process, and the temperature of the water bath was maintained at 55 ºC. The round bottom flask was connected to a condenser such that any vapors given off were condensed. Once the extraction was over, the extract was filtered and the solvent was removed using Rota Evaporator to get dark viscose Oleoresin (Mukhejee *et al*, 2006).

Oleoresin (%) = (Weight of Oleoresin ÷ Sample weight) × 100

Then, the total gingerol content of the oleoresin was determined using Silica Gel-Coated Plate prepared using 65 ml of distilled water added into a flask 30 g powder Silica Gel. The slurry was then then prepared by shaking the mixture for 3-5 minutes. The slurry was spread on 20 cm × 30 cm plate by hand. The plates were allowed to dry overnight after tapping them for uniformity. Finally, the coated plate was activated by placing in an oven at 100 °C for one hour. Isolation and quantification of total gingerol was performed as follows.

Table 1. Source (local or introduced) and year of acquisition of the 36 ginger accessions tested

Cultivars /accession	Local/Introduced	Origin	Year of collection/ introduction
Ging 28/79	Introduced	Mauritius	1979
Ging 41/79	Introduced	Riodejonero(Brazil)	1979
Ging 316/73	Introduced	Surinam	1973
Ging 296/79	Introduced	Rafinfua	1979
Ging 25/86	Local	Gamu Gofa	1986
Ging 61/86	Local	Gamu Gofa	1986
Ging 10/86	Local	Gamu Gofa	1986
Ging 57/86	Local	Gamu Gofa	1986
Ging 84/00	Local	BenchMaji	2000
Ging 70/00	Local	Kafa-Yeki	2000
Ging 74/00	Local	Kafa-Sheko	2000
Ging 40/79	Introduced	Riodjenero(Brazil)	1979
Ging 141/73	Introduced	Australia	1973
Ging 190/73	Local	Maji	1973
Ging 24/86	Local	Gamu Gofa	1986
Ging 85/86	Local	Gamu Gofa	1986
Ging 45/86	Local	Gamu Gofa	1986
Ging 60/86	Local	Gamu Gofa	1986
Ging 64/00	Local	Kafa-Yeki	2000
Ging 305/72	Local	Wolaita	1972
Ging 61/00	Local	Kafa-Yeki	2000
Ging 26/86	Local	Gamu Gofa	1986
Ging 54/86	Local	Gamu Gofa	1986
Ging 56/86	Local	Gamu Gofa	1986
Ging 59/86	Local	Gamu Gofa	1986
Ging 53/86	Local	Gamu Gofa	1986
Ging 181/73	Local	Mizan Teferi	1973
Ging 39/79	Introduced	Australia	1979
Ging 083/00	Local	Kafa- Benchi maji	2000
Ging 75/00	Local	Kafa-Sheko	2000
Ging 62/00	Local	Kafa-Yeki	2000
Ging 01/99	Local	Gamu Gofa	1999
Ging 180/73	Local	Mizan Teferi	1973
Ging 16/86	Introduced	Main land(China)	1986
Ging 15/86	Local	Gamu Gofa	1986
Ging 38/79	Introduced	Australia	1979

Ginger oleoresin (100 m) was applied on High Performance Thin Layer Chromatograph (HPTLC) in the form of band. The plates were placed in a jar containing hexane/ethyl acetone (4:1) as developing solvent system. The plates were pulled out when the solvent front had reached at the top. Three yellow bands with retention factor (Rf) value between 0.5-0.8 representing total gingerols were scratched from the plate and collected into a flask tow to which 30 ml of acetone was added. The samples were recovered from a silica gel by filtiration. Total gingerol was obtained using the following formula:

$$\text{Total gingerol (\%)} = (Sr \div Sb) \times 100$$

Where Sr = sample recovered from silica gel and Sb = Sample applied on HPTLC in the form of band.

Data analyses

The efficiency of simple lattice design over randomized complete block design was tested and found to be not significant for all the traits studied. Hence, analyses of variances were performed based on randomized complete block design using SAS software (SAS, 2001). Petinent procedures of the same statistical software were used for partitioning of variance components, and for linear correlation, cluster and discriminant analyses.

Broad sense heritability (%) was computed according to Hill *et al*. (1998) as follows:

$h^2 = \sigma^2_g / \sigma^2_p \times 100$

Where: $\sigma^2 g$ = genotypic variance; $\sigma^2 p$ = phenotypic variance

Expected genetic advance (GA) (Falconer, 1981) was calculated as:

$$GA = (k)\ (\sigma_p)\ (h^2)$$

Where, K = constant based on selection intensity; σ_p = phenotypic standard deviation and h^2 = heritability in broad sense.

Genetic advance as a percent of mean was computed as:

$$GA\ (\%\ of\ mean) = (GA/\overline{X}) \times 100$$

Where $\overline{X}$ = grand mean of the trait

Linear correlation analyses were performed to investigate the degree of phenotypic and geneotypic relationships among the tarits evaluated.

Path analysis helps to identify traits for indirect selection of economic traits (Gravois and Helms, 1992) such as rhizome yield which are difficult, slow and expensive for direct selection. In this study, path analysis was carried out for five traits that were statistically significant in the combined analysis of variance. Dry weight and total gingerol were not included in this analysis because it was intended to see direct and indirect effects of other agronomic traits on fresh rhizome yield.

Cluster analysis is a multivariate analysis used to group genotypes or accession in to homogenous sets based on their similarityFor classification we need some measure of similarity or closeness or distance. It divides data into meaningful groups (clusters) based on information found in the data that describes the genotypes and their relationships. The objective of clustering is that the genotypes within a group be similar to one another and different from the genotypes in other groups. The greater the similarity (or homogeneity) within the group and the greater the difference between groups, the better or more distinct the clustering is (Hill *et al*., 1998). In the present study, cluster analysis was performed for the accessions using the mean of the 12 traits over four locations.

Results and Discussion

The analyses of variance of quantitative traits considered at individual locations revealed statistically significant accession differences in fresh rhizome yield and rhizome dry weight at all four locations; for tillers $hill^{-1}$ at Hadaro, Tepi and Parawocha; for plant height, leaf length, leaf width, leaf area and rhizome diameter at Matala Hembecho and Parawocha and for number of fingers $rhizome^{-1}$ and rhizome length at only Hadaro (data not shown). The highest fresh rhizome yield (28.9 t ha^{-1}) was observed for the accession Ging16/86 (34*) at Tepi. The lowest yield (4.8 t ha^{-1}) was observed for accession Ging75/00(30*) at Hadaro, which was also the lowest mean giving amomg the locations (6.8 t ha^{-1}). Similar work done under Ethiopian condition confirmed that

the average fresh rhizome yield varied between 11.6 and 21.4 t ha^{-1} (Girma and Digafie, 2004). Janson (1981) also reported rhizome yields up to 38.0 t ha^{-1} in Ethiopia. The average fresh rhizome yield in all Indian origin genotypes varied from 7-10 t ha^{-1}; although a yield up to 40 t ha^{-1} has been reported from experimental plots (Pruthi, 1998). Weiss (2002) reported average fresh rhizome yield in India up to 150 t ha^{-1} from selected cultivars of ginger.

The effects due to locations were highly significant ($p<0.05$) for all characters except for oleoresin and gingerol contents. The mean performance of fresh rhizome yield at Hadaro, Parawocha, Matala Hembecho and Tepi was 6.7, 10.4, 12.2 and 19.4 t ha^{-1}, respectively (Table 3). The dry weight also followed a similar trend withrespective mean dry weight of 1.4, 2.1, 2.3, and 4.5 t ha^{-1}. In general, Tepi was the most favorable location for the performance of the tested accessions whereas Hadaro was the least favorable. The possible reason for the extremely low yield at Hadaro was serious moisture stress during planting and the low and uneven distribution of rainfall during the growing period. The amount of rainfall during the growing period was 1878 mm at Tepi, 1378 mm at Parawocha, 1547 mm at Matala Hambecho and 1009 mm at Hadaro. The differences among accessions were also significant for plant height, number of leaves $plant^{-1}$, number of tillers $hill^{-1}$, number of fingers $rhizome^{-1}$, rhizome length, and fresh and dry rhizome yield. The rest of the traits including leaf length, leaf width, leaf area, rhizome diameter and oleoresin content showed no significant accession differences (Table 2). Of 14 accessions that performed better than the overall mean, only two are introduced cultivars. Dry weight revealed more or less the same trend, and of 15 accessions that performed better than the overall mean dry weight, only three were introduced accessions.

Oleoresin content among accessions showed significant difference ($p\leq0.05$) both at Tepi and Matala Hembecho. At Matala Hembecho, the mean oleoresin content was 2.75% for Ging41/79 and 6.50% for Ging74/00 with a mean of 4.31%. At Tepi, oleoresin content of the accessions varied from 2.75-6.25% with location mean value of 3.96 %. This result is in line with the results reported by Nigist and Berhanu (1989), Pruthi (1998) and Tiwari, (2003b) who indicated that oleoresin content of ginger varied from 4.07-10.40%. The total gingerol content of accessions varied from 11.3-30.5% with a mean of 21.07%. The lowest and highest total gengerol content was recorded from local accessions. Out of 36 accessions only five have lower values (15-25%) of total gingerol content than the International Market Standard; and four of the accessions have higher values.

Variability among Accessions

The fresh rhizome yield showed significant accession differences (Table 2), and its value was between 7.9 t ha^{-1} for accession Ging84/00(9) and 16.8 ha^{-1} for the accession Ging16/86(34) with overall mean of 12.2 t ha^{-1} (data not shown). The dry weight of rhizome ranged from 1.4-3.8 t ha^{-1} in the same order as that of fresh rhizome yield with overall mean of dry weight of 2.6 t ha^{-1}.

In the combined ANOVA, accessions showed significant differences in plant height, leaves $plant^{-1}$, tillers $hill^{-1,}$ number of fingers $rhizome^{-1}$, rhizome length, and fresh and rhizome yield (Table 2).

The variance component of genotype by environment interaction was lower than the genotypic variance in all the traits considered indicating that these traits showed similar trends across locations since genetic effect is heritable and has much more effect on selection (Table 3).

Table 2. Combined analysis of variance for yield and other agronomic traits of 36 ginger accessions evaluated at four locations in 2007

Trait	Location (L) df=3 (1)	Accession (A) df = 35	L × A df = 1059 (35)	Rep/L df= 4(2)	Error Df =140 (70)	Mean	CV (%)	R^2
PH	15437.36*	32.55*	20.12*	460.8	14.87	41.61	9.27	0.96
LPP	306.16*	2.78**	1.51	49.00**	1.53	12.59	9.84	0.86
LW	2.17**	0.03ns	0.02*	0.09*	0.01	1.8	6.8	0.83
LA	8978.75**	40.62ns	34.53*	339.57**	24.52	39.92	12.4	0.91
TPH	452.00**	12.48**	4.45**	34.42**	2.11	7.6	19.12	0.89
NF	2146.38**	15.60*	10.28ns	217.08ns	8.72	17.29	17.07	0.88
RL	420.87**	4.27**	2.21ns	26.41**	1.94	11.48	12.13	0.87
YDH	2043670450**	31130841**	8233698**	104655236**	3299102	12245	14.83	0.95
DW	128959023**	1790480.60**	561787.51**	2780776.90**	285469.1	2583.5	20.68	0.93
RD	12.54**	0.35ns	0.29ns	2.73**	0.28	3.67	14.47	0.70
OLl	0.93ns	2.01ns	1.50ns	5.87*	1.004	4.132	24.25	0.66

* and **-significant at P≤0.05 and P≤0.01, respectively; ns = non-significant at P≤0.05.
PH= plant height (cm), LPP = leaves/plant, LW = leaf width (cm), LA = leaf area (cm^2), TPH = tillers/hill, NF = number of fingers/rhizome, RL = Rhizome length (cm), YDH = fresh rhizome yield (t ha^{-1}), DW = dry weight (t ha^{-1}), RD= Rhizome diameter, OL = Oleoresin content, Rep = Replication, CV = coefficient of variation, and df = degree of freedom and df in brackets are for oleoresin content

The present study indicated that broad sense heritability varied from 38.2% for plant height to 73.6% for fresh rhizome yield (Table 3). Relatively higher heritability values were observed for dry rhizome weight (68.6%) and tillers $hill^{-1}$ (64.4%). It was observed that the maximum genotypic coefficients of variation were supported by high estimates of heritability. In line with this, Tiwari (2003a) reported that high heritability in pseudostem height and number of tillers $plant^{-1}$ was associated with high genetic coefficient of variation for ginger cultivars studied in India. Chattopadhayay *et al.* (2004) reported maximum heritability (88.5%) for weight of secondary rhizome followed by plant height (83.3%), fresh rhizome yield (79.9%) and number of secondary finger (72.1%) in ten turmeric cultivars studied in India. Genetic advance indicates the degree of gain in a character obtained under a particular selection and helps the breeder to predict the extent of improvement that can be achieved in different characters. High heritability followed by high genetic advance should always be considered for successful improvement.

Estimates of genetic advance varied from 0.55 for leaves $plant^{-1}$ to 2.9 t ha^{-1} for fresh rhizome yield (Table 3). The genetic advance as percent of mean varied from 3.8% for plant height to 25.9% for dry rhizome weight. It was observed that fresh rhizome yield with the highest heritability (73.6%) had the highest genetic advance (2988.88 t ha^{-1}). Rhizome dry weight and tiller $hill^{-1}$ showed similar trend in heritability and genetic advance. The genetic advance as percent of mean was also relatively higher for dry weight (25.8%), fresh rhizome yield (24.4%) and tillers $hill^{-1}$ (21.8%), and this is in line with their respective heritability (Table 3). In India, a study with 54 turmeric cultivars revealed that cured yield, weight of fresh mother rhizome and number of secondary fingers had high heritability and genetic advance (Rae *et al*., 2004). This indicates that selection for the traits like fresh rhizome yield and dry weight is easier than selection for other characters.

Table 3. Estimates of means, ranges, variance components, PCV, GCV, broad sense heritability (%) (h^2), genetic advance (GA), and genetic advance as percent of the mean (GA) for seven traits of 36 ginger accessions (Based on the combined data across four locations)

Parameter	PH	LPP	TPH	NF	RL	YDH	DW
Mean	41.61	12.59	7.60	17.30	11.48	12245.81	2583.50
± SE	± 1.92	± 0.61	± 0.75	± 1.47	± 0.69	± 908.17	± 267.14
Range	38.45 - 46.59	11.72 - 14.14	5.88 - 12.20	13.70 - 20.25	10.10 - 13.14	7959.3-16785.1	1451.5 - 3857.20
σ^2_g	1.55	0.15	1	0.66	0.25	2862143	153586.60
σ^2_{ge}	1.31	0.01	0.58	0.39	0.07	1233649	69079.60
σ^2_e	1.86	0.19	0.26	1.09	0.24	412387.8	35683.64
σ^2_p	4.07	0.37	1.56	1.95	0.53	3891355.2	223810.1
PCV	4.85	4.69	16.43	8.07	6.36	16.11	18.31
GCV	3.00	3.17	13.17	4.71	4.42	13.81	15.17
h^2	38.20	45.70	64.40	34.10	48.30	73.60	68.60
GA	1.58	0.55	1.65	0.98	0.73	2988.88	668.77
GA (% of mean)	3.81	4.41	21.77	5.67	6.33	24.41	25.88

PH= plant height (cm), LPP = leaves/plant, TPH = tillers/hill, NF = number of fingers/rhizome, RL = Rhizome length (cm), YDH = fresh rhizome yield (t ha^{-1}), and DW = dry weight (t ha^{-1}),

Hence, improvement in these characters can be brought through simple selection. One cycle of selection, using 5% selection intensity, can advance fresh rhizome yield by almost 3.0 t ha^{-1} and dry weight by about 0.7 t ha^{-1}. To realize this predicted genetic advance >200 accessions should be evaluated and the superior 5% advanced to the next generation. Vegetative propagation makes the utilization of genetic advance easier.

Trait correlations

In general, the phenotypic coefficients of correlation (below the diagonal) were less than the genotypic coefficient of correlation (above the diagonal) (Table 4). Fresh rhizome yield was positively correlated with all other characters except oleoresin. This indicates that high yielding genotypes are not necessarily high quality and crossing is required to combine these two traits. Fresh rhizome yield showed significant positive phenotypic correlation with plant height (0.59), number of leaves $plant^{-1}$ (0.67), number of fingers $rhizome^{-1}$ (0.56), rhizome length (0.68) and dry weight (0.93). Dry weight also showed positive and significant correlation with most of the traits except number of tillers $hill^{-1}$. This indicates that taller plants with more number of leaves and long rhizomes having many fingers will give higher fresh rhizome yield. In *Plectranthus edulis* (Vatke) Agnew, Woyessa (2006) reported that tuber yield $hill^{-1}$ was significantly and positively correlated with plant height, stem girth, number of branches, tuber diameter and number of tubers $hill^{-1}$. Similar studies in India indicated that plant height, leaf length, thickness of primary and secondary rhizome and number of secondary rhizomes had significant positive association with rhizome yield in turmeric (Tamar *et al*., 2003). Salem *et al*. (2001) showed that phenotypic coefficients of correlation between most of the characters of Egyptian black cumin were positive. In contrast, oleoresin content was negatively correlated with most of the characters except tillers $hill^{-1}$ and plant height. This agrees with the results of Adam (2006) who reported that essential oil was negatively correlated with secondary branch and 1000 seed weight but positively correlated with plant height

in black cumin. Similar result was also reported by Rae *et al.* (2004). They found that the quality character curcumin content, essential oil and oleoresin had negative correlation with cured yield in turmeric. Moreover, tillers hill^{-1} showed very weak correlation with most of the characters except number of fingers rhizome^{-1}. This indicates that the tillering capacity of genotypes has significant effect on number of fingers rhizome^{-1} (Table 4).

The genotypic correlations of fresh rhizome yield were positive and significant with all other characters except oleoresin content and number of tillers hill^{-1} (Table 4). This indicates that selection for traits such as plant height, number of leaves plant^{-1} and fingers rhizome^{-1},and rhizome length will improve fresh rhizome yield. The correlation between oleoresin content with all other traits studied was negative and weak except with number of fingers. Tillers hill^{-1} also showed significantly positive correlation with number of fingers rhizome^{-1}, and negative correlation with other traits like plant height, leaves plant^{-1} and rhizome length. This implies that selecting plants with many tillers will result in taller plants with more number of leaves and longer rhizomes, and thereby high fresh rhizome yield.

Table 4. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients for selected traits of ginger accessions

	PH	LPP	TPH	NF	RL	YDH	DW	OL
PH		0.955**	-0.171	0.145	0.910**	0.732**	0.777**	-0.066
LPP	0.540**		-0.276	0.716**	0.839**	1.000**	1.000**	-0.273
TPH	-0.055	-0.128		0.784**	-0.129	0.139	-0.068	0.111
NF	0.238	0.374*	0.365*		0.413**	0.797**	0.713**	-0.432**
RL	0.548**	0.518**	-0.080	0.420*		0.894**	0.761**	0.180
YDH	0.593**	0.674**	0.065	0.555**	0.676**		0.970**	-0.099
DW	0.558**	0.652**	-0.084	0.503**	0.596**	0.928**		-0.135
OL	0.090	-0.092	0.237	-0.004	-0.008	-0.030	-0.084	

**&*-significant at 1% & 5%, respectively. PH = Plant height (cm), LPP = leaves/plant, TPH-tillers/hill, NF = number of fingers/rhizome, RL = rhizome length (cm), YDH = fresh rhizome yield (kg/ha), DW = dry weight (kg/ha), OL-oleoresin content (w/w %)

Path coefficient analysis

At the phenotypic level, plant height, leaves plant^{-1}, number of fingers rhizome^{-1} and rhizome length exerted better positive direct effect on fresh rhizome yield, whereas tillers hill^{-1} had relatively weak direct effect on fresh rhizome yield (Table 5). All the five traits considered had positive direct effect on fresh rhizome yield though the degree varies. The direct effect of leaves plant^{-1} (0.33) and that of rhizome length (0.30) were the strongest. The direct effect of tillers hill^{-1} (0.06) on fresh rhizome yield took the highest share to its phenotypic correlation coefficient (0.06) indicating that the contribution *via* other traits is minimum. The direct effect of plant height (0.20) was low but its cumulative effect was contributed by its indirect effect through traits like leaves plant^{-1} and rhizome length. Therefore, using only plant height as selection criteria may not end up with high yielding genotypes. Similar work done in India on ten promising turmeric cultivars indicated the existence of positive direct phenotypice effects of weight of primary and secondary fingers on fresh rhizome yield (Chattopadhyay *et al*., 2004).

At the genotypic level, number of fingers rhizome^{-1} (0.49), rhizome length (0.58) and leaves plant^{-1} (0.25) exerted direct positive

effect on fresh rhizome yield whereas the direct effect of plant height (-0.14) and tillers hill^{-1} (-0.12) was negative (Table 5). Woyessa (2006) reported negative genotypic direct effect of plant height on tuber weight hill^{-1} in *Plectranthus edulis* (Vatke) Agnew. Likewise, Chattopadhyay *et al*. (2004) reported that leaf length, leaf breadth and weight of primary finger had significant positive effect on total rhizome yield in ten turmeric cultivars studied in India.

Rhizome length exerted the highest positive direct effect (0.59) on fresh rhizome yield and exerted positive indirect effect *via* number of fingers rhizome^{-1} and leaves plant^{-1} whereas its indirect effect *via* plant height was negative (Table 5). Number of fingers^{-1} rhizome had the next highest positive direct effect (0.49) and also positive indirect effects on fresh rhizome yield through leaves plant^{-1} (0.18) and rhizome length (0.24).

Plant height (-0.13) and tillers hill^{-1} (-0.12) revealed negative direct effect on fresh rhizome yield. The higher positive genotypic correlation of plant height with fresh rhizome yield was due to its indirect effect *via* rhizome length. Moreover, the highest share of genotypic correlation of leaves plant^{-1} was largely contributed by its indirect effect through rhizome length (0.49) followed by its indirect effect through number of fingers rhizome^{-1} (0.35). Path analysis at genotypic level revealed that plant height, leaves plant^{-1} and number of fingers rhizome^{-1} exerted relatively better indirect effect through rhizome length. Thus, rhizome length can be used as either direct or indirect selection criteria to improve fresh rhizome yield. Selecting the tallest plants and those with many tillers hill^{-1}, without a simultaneous watch on other traits may lead to accessions with reduced fresh rhizome yield. On the other hand, selecting plants with long rhizome bearing many fingers will increase fresh rhizome yield.

Table 5. Estimates of phenotypic and genotypic direct effects (bold and diagonal) and indirect effects (off- diagonal) of traits *via* other independent traits on fresh rhizome yield of 36 ginger accessions grown at four locations

Trait	PH	LPP	TPH	NF	RL	$r_{p/}$ r_g
a) Estimates of phenotypic direct and indirect effects on fresh rhizome yield						
PH	**0.1958**	0.1778	-0.0030	0.0568	0.1657	0.5931
LPP	0.1058	**0.3292**	-0.0070	0.0892	0.1566	0.6737
TPH	-0.0107	-0.0420	**0.05523**	0.0870	-0.0241	0.0654
NF	0.0466	0.1230	0.0201	**0.2386**	0.1270	0.5554
RL	0.1073	0.1706	-0.0044	0.1002	**0.3023**	0.6760
Residual	0.3216					
b) Estimates of genotypic direct and indirect effects on fresh rhizome yield						
PH	**-0.1351**	0.2408	0.0210	0.0709	0.5341	0.7317
LPP	-0.1290	**0.2521**	0.0341	0.3507	0.4921	1.0000
TPH	0.02304	-0.0697	**-0.1232**	0.3841	-0.0754	0.1388
NF	-0.01956	0.1806	-0.0967	**0.4897**	0.2425	0.7966
Residual	0.0505					

PH = Plant height (cm), LPP = leaves/plant, TPH = tillers/hill, NF = number of fingers/rhizome, RL = rhizome length (cm), $r_{p/}$ r_g = phenotypic or genotypic correlation coefficient

Cluster analysis

The 36 ginger accessions were grouped into five clusters using 12 quantitative traits and average linkage clustering method (Fig.1).

Accessions from different areas of Southern parts of the country and even introduced cultivars have grouped in the same clusters and accessions collected from the same area have been distributed over clusters. This gives a clue that different accessions of ginger may be cultivated in a given area and even a particular accession could be cultivated over wide area. Thus, intensive collection and conservation work should be given due attention to maintain germplasm and to use it for further improvement of ginger.

Cluster I consisted of 21 of the 36 accessions evaluated (Fig.1). The accessions are mostly from Gamu Gofa and Kafa areas and it also included five introduced cultivars from India, Brazil, Mauritius and Australia. Accessions in this cluster are relatively short to intermediate in their height (38.8 - 44.7 cm with mean height of 41.19 cm); narrow leaved and relatively smaller leaf area (19.1 - 22.2 cm^2 with mean of 20.6 cm^2) and are intermediate in their fresh rhizome yield (10.2– 12.8 t ha^{-1} with mean of 11.4 t ha^{-1}) (Table 6). Their relative oleoresin content was also low to medium (3.00 - 5.38 with mean of 4.26%).

Cluster II contained 10 accessions out of which nine are local collections mainly from Gamu Gofa, Kafa, Mizan Teferi and one accession introduced from Australia (Fig.1). The accessions in this cluster were characterized by having the 2nd highest mean fresh rhizome yield (14.2 t ha^{-1}) with lower oleoresin content (3.50-4.50%) but moderately high plant height (39.6 - 46.6 cm) (Table 6).

Cluster III contained only two accessions both introduced from Brazil and Surinam (Fig.1). They had low to medium plant height (38.5 and 42.2 cm with the cluster mean of 40.3 cm) and relatively lower leaf length and area (Table 6). They were lower yielders (9.5–9.6 t ha^{-1}) with mean of 9.5 t ha^{-1} and low in oleoresin content (3.00-3.75%) with mean of 3.38%).

Cluster IV similarly contained two accessions (Fig.1.), one introduced from China and local accession from Gamu Gofa, had taller plants with cluster mean of 45.50 cm (Table 6). Accessions of this cluster had longer leaves, and larger leaf area (22.07-22.52 cm^2 with mean of 22.30 cm^2). They were the highest yielders (16.4 –16.8 t ha^{-1}) with average of 16.6 t ha^{-1}. Accessions in this cluster were the best in their cluster means for all the traits considered except oleoresin content. They were the 2nd best in their oleoresin content (4.63-5.13%) with average of 4.88%. These two accessions need further investigation for future variety development.

Cluster V contained only one accession (Fig. 1) that has shorter plant height (38.8 cm) and narrow leaves (Table 6). It was the least in fresh rhizome yield (7959 kg/ha) and contain the highest oleoresin content (5.25%). It was a local collection from Benchi Maji.

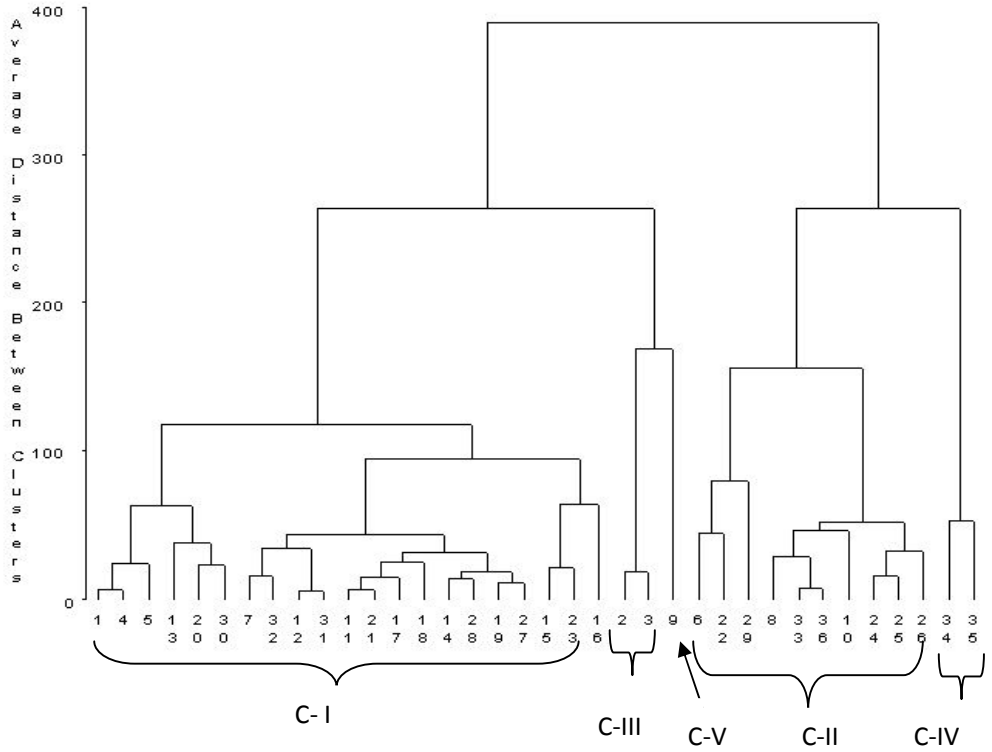

Fig.1. Dendogram showing the five clusters of 36 ginger accessions using 12 traits

Table 6. Cluster means of 36 ginger accessions evaluated at four locations for 12 traits

Traits	I	II	III	IV	V
Plant height (cm)	41.19	42.24	40.31	45.50	38.80
Leaves per plant	12.36	13.03	12.18	13.39	12.13
Leaf length (cm)	15.37	15.45	15.06	16.04	14.84
Leaf width (cm)	1.78	1.82	1.81	1.84	1.79
Leaf area (cm^2)	20.63	21.37	20.53	22.30	20.28
Tillers per hill	7.69	7.61	6.35	7.96	7.44
Number of fingers	17.09	18.02	16.13	18.74	13.70
Rhizome length (cm)	11.27	11.96	10.50	12.68	10.50
Rhizome diameter (cm)	3.60	3.82	3.54	3.92	3.35
Total rhizome yield (t ha^{-1})	11.3	14.1	9.5	16.6	7.9
Dry weight ((t ha^{-1}))	2.4	2.9	2.0	3.7	1.4
Oleoresin (% w/w)	4.26	3.75	3.38	4.88	5.25

The distance between clusters was very small for I and III (27.27) followed by II and IV (33.11) and I and II (34.14), whereas maximum distances were between clusters IV and V (266.80) followed by clusters III and IV (185.80) and II and V (174.11) (Table 7). Crossing of accessions from those clusters with high inter-cluster distance is expected to produce more genetic variability and desirable recombinants than those with smaller inter-cluster distances. Therefore, crossing accessions, for example, from clusters IV with that of V, III with IV, and II with V

Table 7. Pair wise generalized square distance (D^2) of five clusters for 36 ginger accessions

Cluster	I	II	III	IV	V
I	-	34.14	27.27	93.75	68.77
II			89.35	33.11	174.11
III				185.80	61.39
IV					266.80

will result recombinants having more genetic variability for the desired characters. On the other hand, crossings between accessions of cluster I and III or II and clusters II and IV may not result in accessions with desirable recombinants since the inter cluster distance between them was relatively smaller.

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