Chapter 6

Evaluation of the Agronomic Performance of Vernonia (*Vernonia galamensis*) Germplasm

H. Shimelis and E.T. Gwata

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/55016

1. Introduction

Vernonia [*Vernonia galamensis* (Cass.) Less.; 2n = 18] is a relatively new crop in many parts of Africa. Most of *Vernonia* species occur in South America but more than 300 species from Africa have been described with most occurring in Ethiopia and Madagascar. Apart from these two countries, vernonia is also grown in Cape Verde, Eritrea, Mozambique, northern Tanzania and Senegal (Fig. 1). The greatest diversity of vernonia is found in east Africa while a single variety occurs in West Africa. The genus vernonia comprises of more than a thousand species which vary from annual herbs and shrubs to perennial trees (Baye *et al.*, 2001). There are six major subspecies namely *afromontana*, *galamensis*, *gibbosa*, *nairobensis*, *lushotoensis* and *mutomonesis*. Among these, *galamensis* shows the highest genetic diversity (Gilbert, 1986). It contains four botanical varieties namely *australis*, *ethiopica*, *galamensis* and *petitiana* (Gilbert, 1986).

The morphological characters of the Vernonia plant were described comprehensively by Perdue et al., (1986). The authors described Vernonia as herbaceous, usually annual, varying from small ephemerals 20 cm tall with a single flower head to robust rather diffusely branching somewhat shrubby plants which grow up to 5 m tall with many flower heads. The authors also noted that the stems branch only after the first flower head is formed and the inflorescence consists of a terminal flower head with lateral flower heads from the uppermost axils. The leaves alternate and are membraneous, 0.6-5.0 cm wide, up to 25 cm long (Perdue *et al*., 1986). The classification of the species into six subspecies is based on characters of the phyllaries (Perdue *et al*., 1986).

Vernonia could potentially grow as a seed oil crop in tropical and subtropical environments with frost-free and short-day length for flower initiation and development. For instance, the crop was grown successfully in Zimbabwe where seed yields varied from 1.7 to 2.5 t/ha during 1986 to 1987. Thus far there are no released cultivars of *V. galamensis.* Development of improved varieties and production technologies are still in the early stages. The present study is based on germplasm collections from Ethiopia, the center of diversity for *V. galamensis* var. *ethiopica*. The study identified agronomically promising genetic resources useful in further development of more productive cultivars. Further agronomic and utilization research on *V. galamensis* needs to continue before it can be fully-established as a new crop.

In the US Vernonia domestication and large-scale production an oilseed crop was limited due to short-day length requirement for flower initiation and development. In these environments, frosts following flowering inhibits complete seed development and maturity. The crop also performs poorly in areas with excessive moisture, poor soil drainage and insufficient length of growing season. Dierig and Thompson (1993) indicated several barriers that limit full domestication, cultivation and production in the United States such as day-neutrality, autofertility, non-dormant seed germination, good seed retention, increased uniformity of seed maturity, and high oil and vernolic acid contents (Dierig and Thompson 1993).

The successful production of the crop requires well-drained and porous soils. In contrast, in poorly-drained soils, terminal growth is severely retarded and can stop before flowering. The upper portion of the plant dies and branches subsequently grow from the base of the plant, but also wither and die without flowering. Soil with intermediate drainage will produce plants that develop a few flower heads, but with low seed yields. Vernonia seed is planted directly into the soil at a depth of 1 to 2 cm and spaced at 60 cm (intra-row) x 60 cm (inter-row). A firm, level and weed free seedbed is necessary for enhancing rapid establishment and good stand. The seed is relatively small and often with poor germination. Therefore deeper planting is discouraged.

Weed control is essential in the early field establishment due to the poor seedling vigor of Vernonia. The weeds are manually controlled and recommendations on chemical weed controls are not available. No herbicides are currently registered for use in Vernonia. In our studies Vernonia has no major serious diseases and insect pests threatening the crop. Vernionia heads should be harvested when the plants show complete leaf senescence. The seed stays on the heads of the plants for 30 to 45 days after ripening. Immediately after harvesting, the heads are threshed manually in order to obtain the seed.

Although vernonia is cultivated in many tropical countries, the full potential of the crop as an oilseed is yet to be exploited in Africa and elsewhere. It is potentially a useful industrial oil seed crop for the production of natural epoxy oil (Thompson *et al.,* 1994a; Mohamed *et al.,* 1999). The seeds of vernonia produce naturally exposidized oil consisting of vernolic acid, palmitic acid, linoleic acid, arachidic acid, linolenic acid and steraic acid (Carlson *et al.,* 1981; Ayorinde *et al.,* 1988). Vernolic acid is the dominant fatty acid. Because of the production of the naturally exposidized oil, the industrialized processing of this oil is inexpensive. It is also friendly to the environment largely because it does not emit volatile organic compounds. In addition, the oil can be stored at sub-zero temperatures.

Vernonia oil is used in a variety of ways in the chemical industry. The seed of this crop produces useful natural epoxy fatty acids that are better than artificial epoxy oils. In addition, the vernonia oil from the seed contains a wide range of fatty acids such as vernolic acid, linoleic

http://dx.doi.org/10.5772/55016

acid, oleic acid, palmitic acid and stearic acid which have industrial uses. The oil is useful in the manufacture of polyvinylchloride and structural polymers for the production of plastic materials (Mebrahtu *et al.*, 2009) and petrochemicals. The cake formed after oil extraction is high (43.75%) in crude protein and is suitable for animal feed.

Epoxy oils have wide industrial applications, such as in plasticizers, additives in flexible polyvinyl chloride, synthesis of epoxy resins, adhesives, and insecticides. The triglyceride oil rich in vernolic acid, is environmentally friendly, less expensive and less viscous compared to other artificial epoxy oils (Thompson *et al.*, 1994b; Mohamed *et al.*, 1999). Vernolic acid makes up 72 to 80% of the acids present in the seed oil. Vernonia oil also contains other fatty acids, such as linoleic acid (12–14%), oleic acid (4–6%), stearic acid (2–3%), palmitic acid (2–3%), and a trace amount of arachidic acid (Carlson *et al.*, 1981; Ayorinde *et al.*, 1988).

In spite of its multiple uses, the cultivation and commercialization of vernonia is limited by several factors. Firstly, the seed of vernonia does not attain maturity uniformly. Secondly, the pods shatter easily at maturity leading to significant yield loss. Thirdly, the vernonia plant is generally tall. To date, the crop has not been adapted to mechanized harvesting, seed threshing and cleaning. The harvesting and seed processing are carried out manually.

Due to the high oil and vernolic acid content and its relatively low shattering nature, subsp. *galamensis* var. *ethiopica* has been the major focal point of research aimed at domestication and commercialization of the crop. Viable production of vernonia as an alternative industrial crop in marginal tropical and subtropical areas by smallholder or commercial farmers hinges on the identification of suitable varieties that are adapted to the prevalent cropping systems. Alternatively, improved cultivars that are high yielding could also be adopted by farmers. However, there is a dearth of information on the agronomic performance of the current germplasm of vernonia. There are no improved cultivars adapted to the dryland tropical areas in southern Africa such as the Limpopo Province (South Africa). In such areas, vernonia could provide a source of raw materials for agro-processing industries. In addition, vernonia cultivation could provide a significant diversification of the existing cropping systems in the region. In the Limpopo Province of South Africa for instance, the climate is semi-arid and characterized by low mean annual rainfall (300 to 600 mm) with a predominantly sandy-loam soil with reduced fertility (Thomas, 2003). The rainfall pattern is highly variable in some ecotopes in the area (Mzezewa *et al.*, 2010). These harsh agro-ecological conditions could be suitable for the domestication of vernonia and detailed investigations in the agronomic performance of the species would be necessary before large-scale production of the crop in the area is recommended to growers. Therefore objectives of this Chapter are three-fold. The first section focuses on the evaluation of the agronomic performance of *V. galamensis* var. *ethiopica* that was conducted in the in Limpopo Province of South Africa. The second section focuses on the selection of germplasm for high-quality and high-quantity oil that may be used further in strategic breeding of the crop aimed at developing an alternative industrial oil crop in the region and similar environments. The third segment of the Chapter examines the implications and recommendations for cropping systems particularly in the dry land areas in southern Africa.

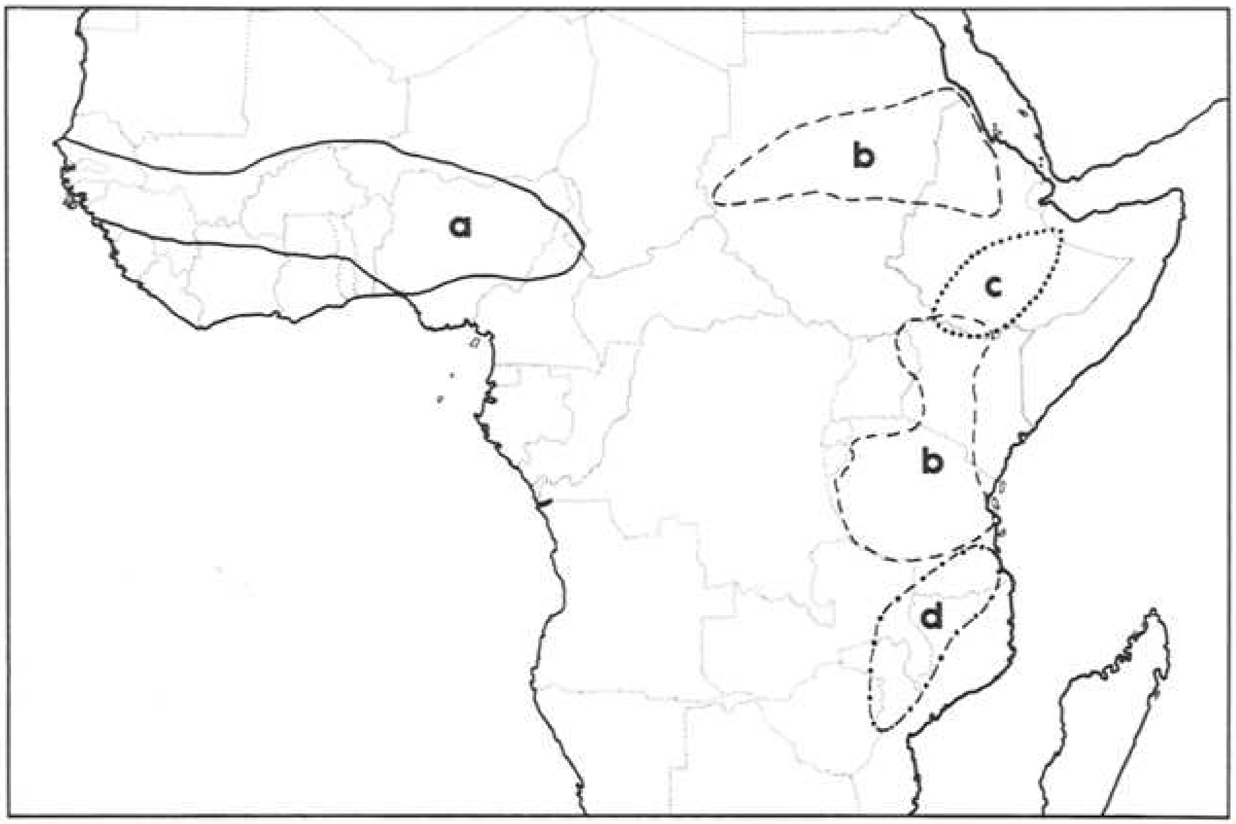

Figure 1. The general distribution of *V. galamensis*. a = West Africa region (Extending from Guinea through Ivory Coast, Mali, Bukino Faso, Ghana to Nigeria) b = Sudan, Kenya and Tanzania region; c = central-southern Ethiopia; d = 4 Malawi, Mozambique and eastern Zimbababwe region). (Source: Adapted from Perdue et al., 1986).

2. Agronomic performance of *Vernonia* germplasm

In this field evaluation, 36 accessions of *Vernonia galamensis* subsp. *galamensis* var. *ethiopica* (Table 1) were obtained from the Biodiversity Institute (Ethiopia). The eastern and south-eastern region of Ethiopia is considered as a natural habitat for *V. galamensis* subsp. *galamensis* var. *ethiopica* (Gilbert, 1986) in which this botanical variety is believed to be most diverse. The habitat is located at an altitude of 700 to 2400 m and receives little seasonal rainfall (about 200 mm). The soils are poor (infertile). Prior to the study, the homozygosity of each accession was maintained through three cycles of selections (Shimelis *et al.*, 2008). In this study, the field experiments were established in Limpopo Province of South Africa under rain fed conditions during the 2006, 2007 and 2008 growing seasons. Experiments were established at two localities namely at Syferkuil (23˚ 84' S and 29˚ 71' E) and Gabaza. Syferkuil is situated at an altitude of 1261.6 m above sea level (asl). It has annual maximum temperature ranging from 28-30 °C and receives an average annual rainfall of 468 mm. This site has sandy loam soil, of the Hutton form, Glenrosa family, with the pH ranging from 6 - 6.2. While Gabaza (23° 50′ S 30° 10′ E) has an altitude of 1100 m asl with an annual average rainfall of 600 mm. At Gabaza the annual temperature ranges from 15 - 37 ºC and with clay-loam soil. In general, soil, climatic, and biological conditions of the two locations varies considerably. However, both locations are not prone to frost and hence suitable representative agro-ecologies conducive for Vernonia production in the Limpopo region.

Each experiment was laid out as a partially balanced lattice design with six incomplete blocks replicated three times. Each block was (21.6 m^2) 3 m wide x 7.2 m long and consisted of two rows spaced at 0.6m apart. Within the row, the seeds were planted at 0.6 m from each other. During planting and flower head initiation, fertilizer (12.5% N, 8.3% P, 4.2% K and 0.5% Zn) was split applied manually at a rate of 30 kg ha^{-1} (Shimelis *et al.*, 2008). In literature, there are no reports on fertilizer response and nutrient requirement in *V. galamensis*. Preliminary observations in Ethiopia showed that the application of 150 kg/ha nitrogen enhances lodging. Thus only a maintenance amount of 20 kg/ha for N and P each was supplied (Baye et al. 2001).

2.1. Agronomic measurements

The agronomic traits that were measured included the duration (in days) to 50% flowering (50%DF), the number of productive primary heads (PPH) per plant, the number of productive secondary heads (PSH) per plant, the thousand seed weight (1000-SW) and seed yield (SY). Measurements for each accession were done on 10 plants that were selected randomly and tagged in each block within a replication. In both seasons (2005 and 2006) the field evaluation was conducted during the summer (January to June) cropping season.

Oil content (OC) (based on dry seed weight) was measured. Total lipid (TL) was extracted from ground seeds following the method of Folch *et al.* (1957), with a chloroform to methanol ratio of 2:1. An antioxidant, butylated hydroxytoluene, was added at a concentration of 0.001% to the chloroform–methanol mixture. Total extractable fat was determined gravimetrically and expressed as percent fat (%F) (w/w) per 100-g sample. The fatty acid composition was determined after transesterification of the extracted lipid by the addition of tri-methyl sulphonium hydroxide (Butte, 1983) and quantified using the gas chromatograph technique (Shimelis *et al.,* 2008). Because of insignificant variations between the two seasons, the average of the data sets over the two seasons was used for statistical analysis. The data sets for each quantitative character were analysed using the SAS GLM procedure for a fixed model with the SAS software version 9.1.3 (SAS 2004) followed by mean separation using Fisher's protected LSD. Phenotypic correlations between agronomic traits, oil content and fatty acids were determined using simple Pearson correlation.

The results of this evaluation showed significant differences among *V. galamenisis* var. *ethiopica* accessions for agronomical traits, oil and fatty acids content. The crop thrived at the location indicating its adaptation to the prevailing arid conditions (Fig. 2). Accessions Vge-10 and Vge-19 were relatively early flowering requiring 88 d to attain 50% flowering. In contrast, the accessions Vge-15 and Vge-36 flowered late (>140 d) (data not shown). In terms of plant height, four accessions namely Vge-18, Vge-19, Vge-25 and Vge-30 were relatively short, averaging about 133.6 cm. This indicated that the Vge-19, which was collected from eastern region of Ethiopia (Table 1), could be selected for both earliness and reduced height. In similar studies involving *V. galamenisis,* Angelini *et al.* (1997) and Bhardwaj *et al.,* (2000) reported variations

Accession Code	Place of Origin	Location
Vge-1 Vge-2 Vge-3 Vge-4	Bedeno	09°06′ N, 41°38′ E
Vge-5 Vge-6 Vge-7 Vge-8	Melkabelo	09°12′ N, 41°25′ E
Vge-9 Vge-10 Vge-11 Vge-12	Harar Zuria	09°19′ N, 42°07′ E
Vge-13 Vge-14 Vge-15	Metta	09°25′ N, 41°34′ E
Vge-16 Vge-17 Vge-18 Vge-19	Gelemso	08°49′ N, 40°31′ E
Vge-20 Vge-21 Vge-22	Yirgalem	06°42′ N, 038°21′ E
Vge-23 Vge-24 Vge-25 Vge-26	Leku	06°52′ N, 038°27′ E
Vge-27 Vge-28 Vge-29	Awassa	06°52′ N, 038°27′ E
Vge-30 Vge-31 Vge-32 Vge-33	Areka (06°48′ N, 037°43′ E)	Areka (06°48′ N, 037°43′ E)
Vge-34 Vge-35 Vge-36	Arsi-Negele	(07°00′ N, 038°35′ E)

Source: Adapted from Shimelis *et al.,* 2008

Table 1. Vernonia germplasm evaluated at the University of Limpopo Experimental Farm (Syferkuil).

in duration to flowering and plant height. In comparison with the other accessions, Vge-19 obtained a high number of PPH (72). On the other hand, accession Vge-11 showed a relatively high number of PSH (35) per plant (Table 2).

Accession Code	Agronomic Trait					
	50%DF (d)	PHT (cm)	PPH	PSH	1000-SW (g)	SY (kg/ha)
Vge-17	93.33	143.00	58	27	1.68	3126.09
Vge-18	98.33	131.60	53	25	2.07	3016.86
Vge-19	87.67	133.26	72	30	1.98	2871.00
Vge-16	93.33	151.00	60	31	1.84	2904.34
Vge-12	98.33	150.27	53	21	2.31	2706.00
Vge-4	98.33	164.73	35	16	2.58	2695.44
Vge-30	100.00	135.00	55	14	3.54	2658.48
Vge-25	111.00	134.73	63	14	3.27	2647.26
Vge-11	99.33	151.80	62	35	2.49	2640.00
Vge-27	116.33	156.00	56	16	2.62	2587.20
Mean	99.60	145.14	57	23	2.44	2785.27

Table 2. Agronomic performance of the best 10 (based on seed yield) vernonia accessions that were evaluated for six traits during 2005 and 2006 in Limpopo Province (South Africa). (50%DF = number of days to 50% flowering; PHT = plant height; PPH = number of primary productive heads; PSH = number of secondary productive heads; 1000-SW = one thousand seed weight; SY = seed yield).

Under these agro-ecological conditions at the testing location, some of the germplasm was more productive in terms of the number of mature seed heads than reported by Bhardwaj *et al*,. (2000) who found twice as many immature seed heads (60 – 80) compared to mature seed heads (20 - 43) per plant. The seed yield was relatively high in accession, Vge-17, Vge-18, and Vge-19 averaging about 3.0 t ha^{-1} (Table 2). This was consistent with findings from other researchers working with germplasm of vernonia originating from east Africa (Thompson *et al*., 1994a; Mohamed *et al*., 1999; Baye *et al*., 2001). The duration to flowering as measured by 50%DF showed a poor association with 1000–SW but the number of PPH showed significant positive correlations with both seed yield and the number of productive secondary seed heads suggesting that improved seed yield in this species could be achieved through simultaneous selection of increased number of productive heads.

The oil analysis indicated considerable variation in the seed oil content with accession Vge-4 attaining the (35.86%) (Table 3). The observed variation in oil content in this study concurred with observations from other similar studies (Mohamed *et al*., 1999; Angelini *et al*., 1997). The fatty acid profiles showed vernolic acid (VA) content ranging from 72.21 to 77.06% (Table 3). Four accessions from the eastern region of Ethiopia (Vge-6, Vge-8, Vge-9, and Vge-11) and two

Figure 2. *Vernonia galamensis* var. *ethiopica* thriving at a semi-arid location at Syferkuil (Limpopo Province, South Africa).

from the south (Vge-25 and Vge-35) obtained superior yield of vernolic acid. In addition, there was considerable variation in the proportion of individual fatty acids among the accessions. For instance, the stearic acid in accession Vge-33 was about 73% of the palmitic acid but was almost equal (95%) to quantity of stearic acid in the accession (Fig. 3).

In similar studies, VA content was low (Angelini *et al.,* 1997; Mohamed *et al.,* 1999; Bhardwaj *et al.,* 2000). Linoleic acid ranged from 12.05 to 14.73%. The highest oil yield (966.58 kg ha^{-1}) was observed for accession Vge-4 which jointly with accession Vge-18 produced good seed yield. A significant positive correlation between 1000-SW and seed oil content was found indicating that the accessions with relatively heavier seed contained increased levels of oil content. However, there were poor associations between oil yield and other traits.

While the information regarding the heritability of these traits in vernonia is fragmentary at best, the variation and association between agronomic traits with seed oil and fatty acids suggested that there is merit in exerting effort aimed at the genetic improvement of these traits in vernonia. This could help in diversifying the existing African cropping systems since vernonia can be used as a cash crop in the production of natural epoxy oils. Industries produce epoxy oils by modification of petrochemicals and epoxidation of oils from seeds of soybean [*Glycine max* (L.) Merr.] and linseed (*Linum ustitatissimum* L.). However, artificially epoxidized oil is expensive and contains volatile organic solvents with high emission to the environment during processing and use. The release of volatile organic solvents into the air causes environmental pollution. In addition, the oil is highly viscous and cannot be stored below 0°C. The natural oil from vernonia has unique properties due to its non-volatility and low viscosity.

Accession Code	Trait			
	SO	VA	LA	OA
Vge-4	35.86	75.37	13.52	4.55
Vge-3	34.19	72.99	13.19	5.09
Vge-32	33.11	75.88	13.56	3.99
Vge-33	30.89	75.19	14.09	4.18
Vge-30	30.85	75.97	13.66	3.86
Vge-21	29.46	74.29	13.19	5.40
Vge-6	29.40	77.06	12.58	4.16
Vge-31	29.29	75.70	14.36	4.51
Vge-22	29.18	72.21	12.81	5.16
Vge-34	29.16	76.17	12.05	3.78
Mean	31.14	75.08	13.30	4.47

Table 3. Mean response of oil content and fatty acid composition (%) among the best 10 (based on seed oil) of vernonia that were evaluated during 2005 and 2006 in Limpopo Province (South Africa). (SO = seed oil; VA = Vernolic acid; VA = Linoleic acid; OA = oleic acid).

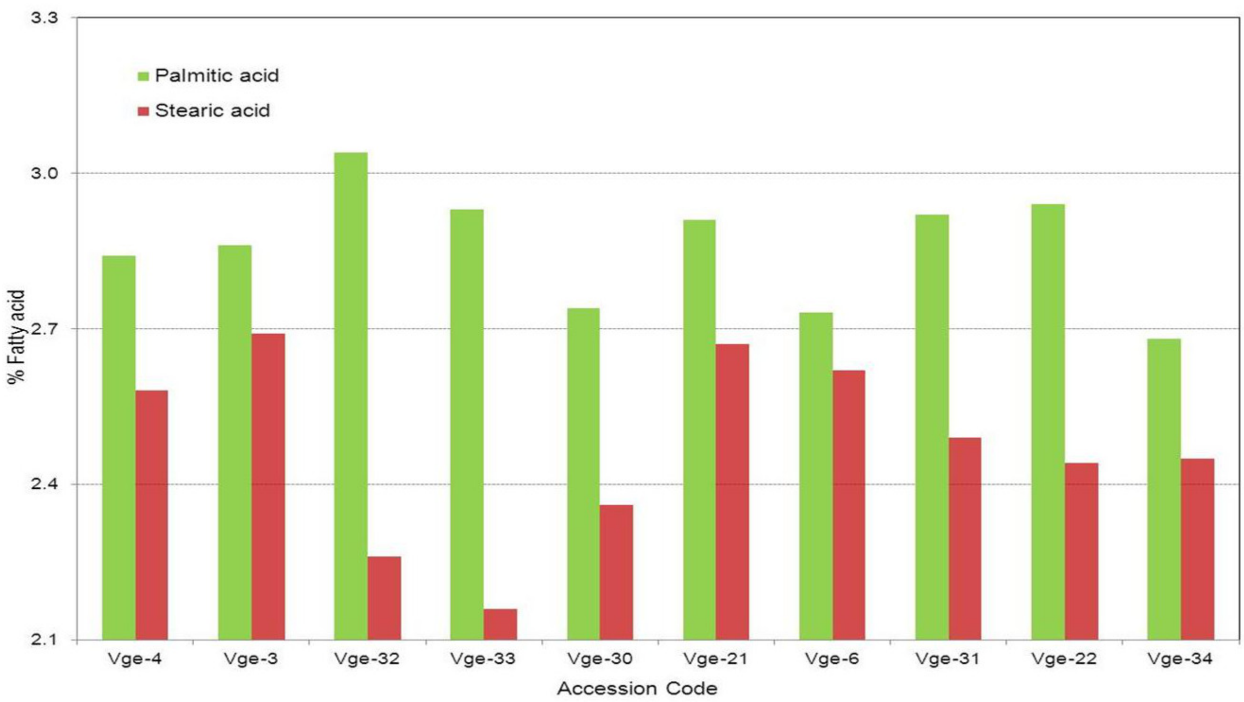

Figure 3. Palmitic and stearic acid levels among selected 10 accessions of vernonia that were evaluated during 2005 and 2006 in Limpopo Province (South Africa).

According to Ray (1994), when used as a solvent in alkyd-resin paint, the natural oil becomes part of the dry paint surface due to its reactive dilutant properties, preventing emission of volatile organic solvents. Vernolic acid from plants was first discovered and isolated from *V. anthelmintica* (L.) Wild., native to India (Gunstone, 1954). This species had excessive seed shattering, which prevented its further development. The collection and subsequent evaluation of V. *galamensis* was found promising because of the quantity and quality of the seed oil and seed retention (Carlson *et al.,* 1981; Thompson *et al.,* 1994b; Perdue, 1988). The germplasm identified in this evaluation is currently being used in the strategic improvement of vernonia to maximize seed yield and oil content as an alternative crop in the province and similar environments.

3. Environmental influence on agronomic performance

In its natural habitat, vernonia thrives as a weed under marginal low rainfall and poor soil fertility (Gilbert, 1986). There are no major pests and diseases that limit the production of this crop. Therefore, vernonia is an alternative industrial crop particularly in low input tropical cropping systems such as prevalent in the semi-arid environments in southern Africa. Typically, the marginal areas are inhabited by smallholder growers who have limited resources for crop production. Crop failure due to moisture deficits in these areas is common. However, diversification of the cropping systems often reduces the risks of crop failure.

This component of the study examined the genotype x environment (Helgadóttir and Kristjánsdóttir, 1991; Lin and B inns, 1988) interaction of seed and oil yield in vernonia using 10 selected lines. Field experiments were established as described above (see Section 2). At maturity, both primary and secondary heads were harvested per plot. The seed yield was measured in three replicates over three years and at two locations. The oil content, total lipids and extractable fat content were determined and analysed as described above.

The results showed significant interaction ($P \leq 0.05$) between genotype x location for seed yield, seed oil content and oil yield (Table 4). Differential responses of the genotypes for the traits were detected across locations or years. At Gabaza, genotype Vge-18 obtained the highest seed yield (3337 kg/ha) during the 2008 cropping season (Table 5). Similarly, Vge-18 and Vge-17 attained relatively high seed yield at Syferkuil. The presence of genotypic variability and genotype x environment interaction for seed yield in vernonia was reported in other studies (Thompson *et al.,* 1994a; Mohammed *et al.,* 1999; Baye *et al.,* 2001). These authors found variations in seed yield among *Vernonia galamensis* collections from East Africa that ranged from 60 to 2800 kg/ha. In this study, accession Vge-17 also showed stable performance across locations and years (Table 5). At Gabaza, accession Vge-4 obtained higher yield than at Syferkuil (Table 6). The relatively high oil yield in Vge-18 was attributed partly to the high seed yield. The study found significant variations in seed yield (1990–3337 kg/ha), oil content (25–43%) and oil yield (675–1370 kg/ha) among *V. galamensis* var. *ethiopica* selections when tested across two the locations over a three year period under the agro-ecological conditions in Limpopo province (South Africa).

Source of Variation	df	Mean Square		
		Seed Yield	Oil Content	Oil Yield
Genotypes (G)	9	115901.58**	255.24**	94298.67**
Locations (L)	1	167944.80**	4450.54**	3988343.47**
Years (Y)	2	203707.89**	17.43**	62339.18**
G x L	9	52895.19**	75.33**	89664.68**
G x Y	18	25766.95*	3.25ns	8245.82*
L x Y	2	36358.72ns	1.70ns	6375.82ns
G x L x Y	18	7332.29ns	2.82ns	3382.90ns
Replication within L and Y	12	24812.48	2.22	4996.08
Error	108	13304.50	3.18	3753.20
Total	179			

* = significant at the 5% probability level

** = significant at the 1% probability level

ns = not significant at the 5% probability level

Table 4. Mean squares for seed yield, of oil and oil yield among 10 selected Vernonia accessions evaluated over three cropping seasons in in Limpopo Province (South Africa).

Accession Code	Seed Yield (kg/ha)											
	Gabaza						Syferkuil					
	2006	**Rank**	**2007**	**Rank**	**2008**	**Rank**	**2006**	**Rank**	**2007**	**Rank**	**2008**	**Rank**
Vge-3	2275.07	10	2300.11	10	2208.75	10	2072.87	10	1993.42	10	1989.67	10
Vge-4	2409.91	8	2518.33	7	2552.83	8	2620.49	6	2649.83	6	2517.41	7
Vge-12	2918.67	4	2761.67	5	2903.33	4	2732.00	4	2688.79	4	2860.58	4
Vge-16	2922.00	3	2880.33	3	3064.33	3	2783.00	5	2674.00	5	2867.08	3
Vge-17	3085.00	2	3006.33	2	3137.33	2	3217.03	1	2914.74	1	3179.42	1
Vge-18	3118.75	1	3095.33	1	3337.33	1	2990.29	2	2818.75	2	3152.29	2
Vge-19	2791.75	5	2774.00	4	2899.60	5	2872.00	3	2718.00	3	2806.00	5
Vge-30	2623.74	6	2623.74	6	2623.74	6	2623.83	7	2450.00	7	2621.49	6
Vge-32	2385.33	9	2477.33	8	2503.00	9	2345.28	8	2420.67	8	2503.67	8
Vge-33	2442.41	7	2414.00	9	2525.75	7	2375.08	9	2203.33	9	2488.89	9
Mean	2697.26		2685.12		2772.60		2663.19		2553.15		2698.65	

Table 5. Mean seed yield among 10 selected vernonia accessions that were evaluated over three cropping seasons at Gabaza and Syferkuil in Limpopo Province (South Africa).

Accession Code	Oil Content											
	Gabaza						Syferkuil					
	2006	Rank	2007	Rank	2008	Rank	2006	Rank	2007	Rank	2008	Rank
Vge-3	41.95	4	40.11	5	40.47	9	34.33	2	34.69	2	35.27	1
Vge-4	42.55	1	42.28	1	46.62	3	34.78	1	34.81	1	35.14	2
Vge-12	42.16	3	41.25	4	41.80	6	28.12	6	27.38	6	27.27	7
Vge-16	39.83	7	39.04	9	42.02	4	26.33	7	27.15	6	29.30	6
Vge-17	26.37	10	26.33	10	27.56	10	24.69	10	24.60	7	24.61	10
Vge-18	35.82	9	39.94	8	41.04	8	25.88	8	25.70	10	25.27	9
Vge-19	41.42	5	39.96	7	41.84	5	25.57	9	25.50	8	26.75	8
Vge-30	41.32	6	41.32	3	41.32	7	31.17	4	30.65	9	32.00	5
Vge-32	38.99	8	42.00	2	42.77	2	33.22	3	34.09	4	33.22	3
Vge-33	42.17	2	40.25	6	43.22	1	30.50	5	30.65	3	32.52	4
Mean	39.26		39.23		40.36		29.46		29.52	5	30.14	

Table 6. Mean oil content among 10 selected vernonia accessions that were evaluated over three cropping seasons at Gabaza and Syferkuil in Limpopo Province (South Africa).

In a separate study conducted in the greenhouse, Shimelis *et al.*, (2006) reported similar variation in oil content variation (24–29%), vernolic acid (73-77%), linoleic acid (12-14%), oleic acid (3.5-5.5%), palmitic acid (2.4-2.9%) and stearic acid (2.3-2.8%). These findings demonstrated the genetic potential of vernonia as an alternative industrial oil crop in the region. The crop could eventually supersede petrochemicals and oils that are artificially epoxidized and emit volatile organic solvents which pollute the environmental.

4. Cultivar selection criteria

Further analyses of the genotypic correlations and path analysis (Wright, 1934; Li, 1956; Dewey and Lu, 1959; Bhatt, 1973; Kang *et al.*, 1983) in order to determine relationships between seed yield and seed oil content with other important agronomic traits among the 36 diverse accessions of vernonia (*V. galamensis* var. *ethiopica*) were carried out (Shimelis and Hugo, 2011). The information derived from such analyses is useful in identifying the best indirect selection criteria and optimizing the efficiency of selecting particularly for increased seed yield and oil content in vernonia.

A relatively high direct path coefficient value (0.49) and a highly significant genotypic correlation ($r_g = 0.81$, $P < 0.01$) were exhibited between seed yield and the number of PPH. This association from the direct path value indicates that PPH can be utilized as the first principal selection criterion for improving seed yield among these accessions. In addition, the analysis indicated that selecting for increased number of primary heads would tend to reduce simultaneously the duration to maturity as well as plant height in contrast with selecting directly for 50%DF and plant height. The analysis also showed that improvement in oil content in vernonia can be obtained through the simultaneous selection of lines that display high seed yield and seed weight. If only genotypic correlations were considered, early flowering, short plant stature and high number of productive heads could be useful selection criteria for achieving high seed yield in *V. galamensis* var. *ethiopica*.

There is no adequate information regarding associational studies on the agronomic traits in vernonia. Bhardwaj et al. (2000) reported non-significant correlations among seed yield and oil content while Baye and Becker (2005) reported a positive correlation between seed yield and seed weight in vernonia. In summary, selection for increased number of PPH is recommended as the principal selection criterion for improving seed yield in this species. The selection for 1000-SW and increased seed yield can be regarded as major selection criteria for enhancing oil content in *V. galemanesis*.

5. Prospects for genetic improvement of Vernonia

The main findings from the research work done so far suggest that some of the production and commercialization of the species can be addressed through a combination of conventional and molecular breeding approaches. For instance, plant height can be reduced routinely using standard modern plant breeding approaches. Similarly, the dehiscence of the heads can also be improved through breeding. This has been demonstrated in several other field crops (Kadkol et al., 1989; Morgan et al., 2000). Moreover, source of shattering resistance were identified in *V*. subsp. *galamensis* var. *ethiopica.* According to Morgan *et al.*, (1988), in rapeseed, increased shatter resistance is desirable partly because it can delay harvesting in order to allow more even maturing of seeds and decrease the incidence of chlorophyll contamination from immature seeds in extracted oil. The variability in the traits of economic interest such as seed yield and oil yield of vernonia indicated that there is potential to select for increased levels of these traits. In other species, oil yield was manipulated through plant breeding approaches (Cahoon. 2003; Cahoon et al., 2007; Wittkop et al., 2009).

The various modern molecular tools that are applied in plant breeding (Li *et al.*, 2010; Paux *et al.*, 2010; Ramalema *et al.*, 2010; Raman *et al.*, 2010; Zhao *et al*; 2007; Slade *et al.*, 2005; Sharma *et al.*, 2001; Tanksley *et al.*, 1989) also offer exciting prospects for the genetic improvement of vernonia. While the development and use of transgenic field crops for food remains controversial in many parts of the world partly because of the perceived risks on human and animal health, transgenic cultivars of vernonia that are high yielding in industrial grade oils should probably find some support even among the critics of the technology. Shimelis *et al.*, (2006) showed the feasibility of raising vernonia in a sheltered environment such as a greenhouse where, to all intents and purposes, undesirable gene flow (for instance from transgenic vernonia) can be prevented. High value crops, particularly horticultural and ornamental species, are routinely produced in controlled environments in many parts of the world.

The demand in the petro-chemical industries for the high quality of oils from this crop is likely to attract capital investment into the marketing and commercial production of vernonia in the marginal areas in Africa. Value addition industries for vernonia such as those for producing bio-based chemicals (Hatti-Kaul *et al.*, 2007) in the region, would be useful for economic development.

In conclusion, we believe that there is merit in investing in the genetic enhancement of vernonia in Africa since the oils from the seed of this crop have numerous advantages over comparative by-products from other crops. There is ample evidence that the crop is adapted to the harsh agro-ecological conditions prevalent in Limpopo Province and beyond. Likely, improved cultivars that are non-shattering, high yielding and mature uniformly will be adopted more widely by growers in the region.

Acknowledgements

The authors would like to express gratitude to their respective Institutions and the National Research Foundation (South Africa) for the financial support that was used to fund this work. The assistance with graphics and typing rendered by Ms Muno Gwata is gratefully acknowledged.

Author details

H. Shimelis[1] and E.T. Gwata[2]

1 University of KwaZulu-Natal, African Center for Crop Improvement, Scottsville, South Africa

2 University of Venda, Department of Plant Production, Limpopo, South Africa

References

[1] Agrobase. (2005). Agrobase generation II user's manual. Agronomix Software, Manitoba, Canada.

[2] Angelini, L.G., Moscheni, E., Colonna, G., Belloni, P., and Bonari, E. (1997). Variation in agronomic characteristics and seed oil composition of new oilseed crops in central Italy. Ind. Crops Prod. 6,313–323.

[3] Ayorinde, F.O., Osman, J.G., Shepard, R.L. and Powers, F.T. (1988). Synthesis of azelaic acid and suberic acid from *Vernonia galamensis* oil. J. Am. Oil Chem. Soc. 65,1774–1776.

[4] Baye, T. and Becker, H. (2005). Genetic variability and interrelationship of traits in the industrial oil crop *Vernonia galamensis*. Euphytica 142, 119–129.

[5] Baye, T., Kebede, H. and Belete, K. (2001). Agronomic evaluation of *Vernonia galamensis* germplasm collected from eastern Ethiopia. Ind. Crops Prod. 14,179–190.

[6] Bhardwaj, H.L., Hamama, A.A., Rangappa, A. and Dierig, D.A. (2000). *Vernonia* oilseed production in the mid-Atlantic region of the United States. Ind. Crops Prod. 12,119–124.

[7] Bhatt, G.M. (1973). Significance of path coefficient analysis in determining the nature of character association. Euphytica 22,338–343.

[8] Butte, W. (1983). Rapid method for the determination of fatty acid profiles from fats and oils using trimethyl sulphonium hydroxide for transesterifi cation. J. Chromatogr. 261,142–145.

[9] Carlson, K.D., Schneider, W.J., Chang, S.P. and Princen, H. (1981). *Vernonia galamensis* seed oil: A new source for epoxy coatings. *In*: Pryde, E.H., Princen, L.H. and Mukherjee, K.D. (eds). New Sources of Fats and Oils. Am. Oil Chem. Soc., Champaign, IL., pp. 297–318.

[10] Cahoon, E.B. (2003) Genetic enhancement of soybean oil for industrial uses: prospects and challenges. AgBioForum 6,11–13.

[11] Cahoon, E.B., Shockley, J.M., Dietrich, C.R., Gidda, S.K., Mullen, R.T. and Dyer, J.M. (2007) Engineering oilseeds for sustainable production of industrial and nutritional feedstocks: solving bottlenecks in fatty acid flux. Curr. Opin .Biotechnol. 10, 236–244.

[12] Dewey, D.R. and Lu, K.H. (1959). Acorrelation and path coefficient analysis of components of crested wheat grass seed production. Agron. J. 51,515–518.

[13] Dierig, D.A., Coffelt, T.A., Nakayama, F.S. and Thompson, A.E. (1996). Lesquerella and vernonia: oilseeds for arid lands. *In*: J. Janick (ed). Progress in New Crops. ASHS Press, Alexandria, VA. pp. 347-354.

[14] Folch, J., Lees, M. and Sloane-Stanley, G.H. (1957). A simple method for the isolation and purification of total lipids fromanimal tissue. J. Biol. Chem. 226,497–509.

[15] Gilbert, M.G. (1986). Notes on East African Vernonieae (Compositae). A revision on the *Vernonia galamensis* complex. Kew Bull. 41,19–35.

[16] Gunstone, F.D. (1954). Fatty acids: Part II. The nature of the oxygenatedacids present in *Vernonia* anthelmintica (Willd.) seed oil. J. Chem. Soc. (May), 1611–1616.

[17] Hatti-Kaul, R., Ulrika-Törnvall, U., Gustafsson, L. and Börjesson, P. (2007). Industrial biotechnology for the production of bio-based chemicals – a cradle-to-grave perspective. Trends Biotechnol. 25,119–124.

[18] Helgadóttir, A. and Kristjánsdóttir, T. (1991). Simple approach to the analysis of G×E interactions in a multilocational spaced plant trial with timothy. Euphytica 54,65–73.

[19] Kadkol, G.P., Halloran, G.M. and MacMillan, R.H. (1989). Shatter resistance in crop plants. Crit. Rev. Plant Sci. 8,169-188.

[20] Lin, C.S. and Binns, M.R., 1988. A superiority measure of cultivar performance for cultivar×location data. Can. J. Plant Sci. 68,193–198.

[21] Li, C.C. (1956). The concept of path coefficient and its impact on population genetics. Biometrics 12,190–210.

[22] Li, R., Yu, K., Hatanaka, T.and Hildebrand, D.F. (2010). Vernonia DGATs increase accumulation of epoxy fatty acids in oil. Plant Biotechnol. J. 8,184–195.

[23] Kang, M.S., Miller, J.D. and Tai, P.Y.P. (1983). Genetic and phenotypic path analyses and heritability in sugarcane. Crop Sci. 23,643–647.

[24] Mebrahtu, T., Gebremariam, T., Kidane, A. and Araia, W. (2009). Performance of *Vernonia galamensis* as a potential and viable industrial oil plant in Eritrea: yield and oil content. Afric. J. Biotechnol. 8,635-640.

[25] Mohamed, A., Mebrahtu, T. and Andebrhan, T. (1999). Variability in oil and vernolic acid contents in the new *Vernonia galamensis* collection from East Africa. *In*: Janick, J. (ed). Proc. Perspectives on New Crops and New Uses. ASHS. Press, Alexandria, VA. pp. 272–274.

[26] Morgan, C.L., Bruce, D.M., Child, R., Ladbrooke, Z.L. and Arthur, A.E. (1998). Genetic variation for pod shatter resistance among lines of oilseed rape developed from synthetic *B. napus*. Field Crops Res. 58,153-165.

[27] Morgan, C.L., Ladbrooke, Z.L., Bruce, D.M., Child, R. and Arthur, A.E. (2000). Breeding oilseed rape for pod shattering resistance. J. Agric. Sci. 135,347-359.

[28] Perdue, R.E. (1988). Systematic botany in the development of *Vernonia galamensis* as a new industrial oilseed crop for the semi-arid tropics. Symb. Bot. Ups. 24,125–135.

[29] Perdue, R.E., Carlson, K.D. and Gilbert, M.G. (1986). *Vernonia galamensis* potential new crop source of epoxy acid. Econ. Bot. 40, 54–68.

[30] Paux, E., Faure, S., Choulet, F., Roger, D., Gauthier, V., Martinant, J.P., Sourdille, P., Balfourier, F., Le Paslier, M.C., Chauveau, A., Cakir, M., Gandon, B. and Feuillet, C. (2010). Insertion site-based polymorphism markers open new perspectives for genome saturation and marker-assisted selection in wheat. Plant Biotechnol. J. 8,196–210.

[31] Ramalema, S.P., Shimelis, H, Ncube. I, Kunert, K.K. and Mashela, P.W. (2010). Genetic analysis among selected vernonia lines through seed oil content, fatty acids and RAPD DNA markers. Afric. J. Biotechnol. 8,117-122.

[32] Raman, H., Stodart, B., Ryan, P., Delhaize, E., Emberi, L., Raman, R., Coombes, N. and Milgate, A. (2010). Genome wide association analyses of common wheat (*Triticum aestivum* L) germplasm identifies multiple loci for aluminium resistance. Genome 53,957-966.

[33] Ray, D.T. (1994). Development of new oilseed crops in the USA. *In*: Hennink, S., van Soest, L.J.M., Pithan, K. and Hof, L. (eds.) Proc. Alternative Oilseed and Fibre Crops for Cool and Wet Regions of Europe, COST 814 Workshop. p. 26–33.

[34] Wageningen, Netherlands. 7–8 Apr. 1994. European Cooperation in the Field of Scientifi c and Technical Research.

[35] SAS Institute. (2004). Base SAS 9.1.3: Procedures guide. SAS Inst., Cary, NC.

[36] Sharma, H.C., Sharma, K.K., Seetharama, N. and Ortiz, R. (2001). Henetic transformation of crop plants: risks and opportunities for the rural poor. Curr. Sci. 80,1495-1508.

[37] Shimelis, H. and Hugo, A. (2011). Determination of selection criteria for seed yield and seed oil content in Vernonia (*Vernonia galamensis* variety *ethiopica*). Ind. Crops Prod. 33,436–439.

[38] Shimelis, H.A., Labuschagne, M.T. and Hugo, A. (2006). Variation of oil content and fatty acid compositions among selected lines of *Vernonia* (*Vernonia galamensis* variety *ethiopica*. S. Afric. J. Plant Soil 23,62–63.

[39] Shimelis, H., Mashela, P. and Hugo, A. (2008). Performance of *Vernonia* as an alternative industrial oil crop in Limpopo Province of South Africa. Crop Sci. 48,236-242.

[40] Slade, A.J., Fuerstenberg, S.I., Loeffler, D., Steine, M.N. and Facciotti, D. (2005). A reverse genetic, nontransgenic approach to wheat crop improvement by TILLING. Nature Biotechnol. 23,75-81.

[41] Tanksley, S.D., Young. N.D., Paterson, A.H. and Bonierbale, M.W. (1989). RFLP mapping in plant breeding: new tools for an old science. Biotechnol. 7,257-264.

[42] Thomas, R. (2003). Crop production in the Limpop Province. In: Nesamvuni, A.E., Oni, S.A, Odhiambo, J.J.O. and Nthakheni, N.D. (eds.) Agriculture as a cornerstone of the economy of the Limpopo Province: A study commissioned by the Economic Cluster of the Limpopo Provincial Government under the Leadership of the Department of Agriculture, Limpopo, Polokwane.

[43] Thompson, A.E., Dierig, D.A., Johnson, E.R., Dahlquist, G.H. and Kleiman, R. (1994a.) Germplasm development of *Vernonia galamensis* as a new industrial oilseed crop. Ind. Crops Prod. 3,185–200.

[44] Thompson, A.E., Dierig, D.A. and Kleiman, R. (1994b). Characterization of *Vernonia galamensis* germplasm for seed oil content, fatty acid composition, seed weight, and chromosome number. Ind. Crops Prod. 2,299–305.

[45] Wittkop, B., Snowdon, R.J. and Friedt, W. (2009). Status and perspectives of breeding for enhanced yield and quality of oilseed crops for Europe. Euphytica 170, 131-140.

[46] Wright, S., (1934). The method of path coefficients. Ann. Math. Stat. 5,161–215.

[47] Zhao, J., Paulo, M-J., Jamar, D., Lou, P., van Eeuwijk, F., Bonnema, G., Vreugdenhil, D. and Koornneef, M. (2007). Association mapping of leaf traits, flowering time, and phytate constent in *Brassica rapa*. Genome 50,963-973.