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Genotype by environment interaction of seed and oil yield in vernonia (*Vernonia galamensis* variety *ethiopica*)

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ABSTRACT

Vernonia (*Vernonia galamensis* variety *ethiopica*) is a potentially novel renewable source of natural epoxy oil. The objective of this study was to determine the genotype by environment interaction and to identify superior and stable genotypes of vernonia with high seed and oil yield. Field experiments were conducted during 2006, 2007 and 2008 at two localities namely, Gabaza and Syferkuil. Ten selected genotypes of vernonia were evaluated for seed yield, oil content and oil yield using the randomized complete block design with three replications. Significant interactions ($P \leq 0.05$) were detected among genotype by location for seed yield, oil content, oil yield and genotype by year for seed and oil yield. Genotype Vge-18 had the highest seed yield ranging between 3095 and 3337 kg/ha followed by Vge-17 yielding 3006–3137 kg/ha at Gabaza. These genotypes were also the best performers at Syferkuil where Vge-17 yielded 2915–3217 kg/ha followed by Vge-18 with 2819–3152 kg/ha. The superiority statistics allocated Vge-17 and Vge-18 as best yielding and stable genotypes. In both locations Vge-4 had increased seed oil contents at 43% (Gabaza) and 35% (Syferkuil). Other promising genotypes with high seed oil content were Vge-33 at Gabaza (40–43%) and Vge-3 at Syferkuil (34–35%). Genotypes with the highest oil yields were found to be Vge-18 (1117–1370 kg/ha) at Gabaza and Vge-4 with yields of 885–922 kg/ha at Syferkuil. Overall, Vge-17 and Vge-18 were identified as having the highest seed yield, while Vge-4 and Vge-3 yielded the highest seed oil content with average stability. These genotypes could be used for direct large scale production or strategic breeding of vernonia in these or similar environments.

1. Introduction

Epoxy oils have several industrial applications such as in plasticizers, additives in flexible polyvinyl chloride (PVC), epoxy resins, adhesives, insecticides and crop-oil concentrates (Thompson et al., 1994a; Mohammed et al., 1999). Industries produce epoxy oils by modifying petrochemicals and through epoxidation of oils from seeds of soybean (*Glycine max* L.) and linseed (*Linum ustitatissimum* L.) (Ray, 1994). Artificially epoxidized oil is expensive and contains volatile organic solvents with high emission to the environment during processing and end use.

Vernonia (*Vernonia galamensis* [Cass.] Less.; $2n = 18$) is a potentially novel and alternative industrial oil seed crop for the production of natural epoxy oil (Thompson et al., 1994a, 1994b; Mohammed et al., 1999). It is naturally distributed in tropical Africa including Ethiopia, Kenya and northern Tanzania. The species comprises six subspecies viz. *afromontana, galamensis, gibbosa, nairobensis, lushotoensis* and *mutomonesis*. Subspecies *galamensis* shows high genetic diversity and includes four botanical varieties: *australis*, *ethiopica*, *galamensis* and *petitiana* (Gilbert, 1986).

The seeds of *V. galamensis* subsp. *galamensis* variety *ethiopica* M.G. Gilbert produce triglyceride oil rich in vernolic acid, a naturally epoxidized fatty acid which is environmentally friendly, less expensive and less viscose compared to other artificial epoxy oils (Thompson et al., 1994b; Mohammed et al., 1999). Vernolic acid composes 72–80% of the fatty acids present in the seed oil. Other fatty acids in the oil include 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 its natural habitat vernonia thrives as a weed under marginal low seasonal rainfall and poor soil fertility (Gilbert, 1986). No major pests and diseases have been recorded on vernonia. Production of vernonia as an alternative industrial seed crop in low input tropical and subtropical environments therefore, could serve as a source of

Abbreviations: OC, oil content; OY, oil yield; P_i, superiority statistics; R, Rank.

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Table 1
Descriptions of vernonia lines used in the study.

Lines	Geographic location and coordinate	Flower color
Vge-3	Bedeno, (09°06′N, 41°38′E)	White
Vge-4	Bedeno, (09°06′N, 41°38′E)	Purple
Vge-12	Harar Zuria, (09°19′N, 42°07′E)	White
Vge-16	Gelemso, (08°49′N, 40°31′E)	Purple
Vge-17	Gelemso, (08°49′N, 40°31′E)	Purple
Vge-18	Gelemso, (08°49′N, 40°31′E)	Purple
Vge-19	Gelemso, (08°49′N, 40°31′E)	Purple
Vge-30	Areka (06°48′N, 037°43′E)	Purple
Vge-32	Areka (06°48′N, 037°43′E)	Purple
Vge-33	Areka (06°48′N, 037°43′E)	Purple

raw material for natural epoxy oil production. The crop may possibly diversify the current crop husbandry practice, thereby reducing a potential crop failure.

The cultivar superiority statistics (Lin and Binns, 1988) help to identify stable and superior genotypes across the test environments. The superiority statistics (P_i) compares the yield difference among a set of genotypes against a reference genotype with the maximum yield within each test environment. Accordingly a superior and wide adaptable genotype will have low P_i with a performance near the maximum in different test environments (Lin and Binns, 1988; Helgadóttir and Kristjánsdóttir, 1991).

The Limpopo Province of South Africa has semi-arid climate with a low mean annual rainfall ranging from 300 to 600 mm and a predominantly sandy loam soil with reduced fertility (Thomas, 2003). Preliminary investigations indicated that climatic and edaphic situations favor domestication of vernonia in the Province (Shimelis et al., 2008). Detailed investigations under target production environments are, however, required to maximize its genetic potential and to make specific recommendations pertaining to the best performing genotypes with specific or wider adoption for seed and oil yield. The objective of this study was to determine genotype by environmental interaction of seed and oil yield in vernonia using selected lines in Limpopo province. Wide adapted genotype with high and stable seed and oil yield could be identified for direct production or strategic breeding of the crop.

2. Materials and methods

2.1. Study sites

Field experiments were conducted in the Limpopo Province of South Africa under rainfed 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) in the Capricorn District and Gabaza in the Mopani District. Syferkuil is situated at an altitude of 1261.6 m above sea level (asl). It has an annual maximum temperature ranging from 28 to 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 to 6.2. While Gabaza (23° 50′ S 30° 10′ E) is located at an altitude of 1100 m asl with an annual average rainfall of 600 mm and has a clay loam soil type. The annual temperature of Gabaza ranges between 15 and 37 °C. In general, the soil, climatic, and biological conditions of the two locations varies considerably.

2.2. Growing plants and experimental design

Ten vernonia lines of the *ethiopica* variety, originally obtained from the Biodiversity Institute/Ethiopia, were selected. The list of these selected lines and their geographical locations and coordinates are indicated in Table 1. The lines were collected from southern and eastern Ethiopia, which is believed to be the center of diversity of this variety.

The field studies were designed in the randomized complete block design with three replications. Each genotype was sown in six rows of a 3×4 m plot with inter- and intra-row spacing at 60 cm. During planting and flower head initiation fertilizer was split-applied at a rate of 30 kg/ha. This fertilizer contained 12.5% N, 8.3% P, 4.2% K and 0.5% Zn (Omnia Fertilizer Limited). It was manually incorporated into the soil by hoeing around plants.

2.3. Data collection and analyses

At maturity both primary and second heads were harvested per plot and seeds threshed. Seed yield was measured in gram per plot and converted to kilogram (kg) per hectare (ha). Yield was recorded in three replicates over three years and at two localities.

The oil content was determined at the University of the Free State on the basis of dry seed weight from the three replicates of each line. Total lipids were quantitatively extracted from a ground 0.5 g seed sample according to the method described by Folch et al. (1957), using chloroform and methanol in a ratio of 2:1. An antioxidant, butylated hydroxytoluene, was added at a concentration of 0.001% to the chloroform:methanol mixture. A rotary evaporator (50 °C) was used to dry the fat extracts under vacuum and were dried overnight in a vacuum oven at 50 °C, using phosphorus pentoxide as moisture adsorbent. Total extractable fat content was determined gravimetrically and expressed as % fat (w/w) per 100 g sample. Oil yield was then converted and expressed in kg/ha as the product of seed yield and percentage oil content.

Seed yield, oil content or oil yield were subjected to combined analyses of variance (ANOVA) using the SAS statistical program (SAS Institute, Cary, NC, 2004) and Agrobase (2005). Mean comparisons among lines were performed using the least significant difference (LSD) test procedure at a 5% level of significance. The degrees of relatedness between seed yield, oil content and oil yield on genotypes were expressed as *R*-square values from each ANOVA. The coefficient of variation (CV) were computed and expressed as a percentage (Snedecor and Cochran, 1989). The cultivar superiority statistics (Lin and Binns, 1988) was calculated as $P_i = \sum_{j=1}^{n}(X_{ij} - M_j)^2/2n$; where P_i = superiority index of the *i*th genotype, X_{ij} = yield response of *i*th genotype in the *j*th environment, M_j = the maximum yield response obtained among all the genotypes in the *j*th environment and n = number of environments.

3. Results and discussion

Results indicated significant interaction ($P \leq 0.05$) among genotype by location for seed yield, seed oil content and oil yield (Table 2). A significant genotype by year interaction was detected for seed as well as oil yield (Table 2). Thus, differential responses of genotypes were discerned for the traits when tested across locations or years.

Table 3 summarizes the mean seed yield and rank lines across locations and years. At Gabaza, genotype Vge-18 was identified as having the highest seed yield with 3095–3337 kg/ha, followed by Vge-17 that yielded 3006–3137 kg/ha. No statistical significant differences were found among these genotypes, except in 2008 (Table 3). These genotypes also ranked the highest with regard to performance at Syferkuil, where Vge-17 yielded 2915–3217 kg/ha, followed by Vge-18 yielding 2819–3152 kg/ha. The genotypic superiority statistics allocated Vge-17 and Vge-18 as the highest yielding and most stable performers across locations and years (Table 4). The coefficients of determination (R^2) for seed yield varied between 88.82% and 95.38%. Seed yield could be explained considerably by genotypic differences (Table 3).