Genet Resour Crop Evol (2019) 66:545–554
https://doi.org/10.1007/s10722-018-0719-1

NOTES ON NEGLECTED AND UNDERUTILIZED CROPS

Centrapalus pauciflorus (Willd.) H. Rob. neglected potential oil crop of Ethiopia, agro-morphological characterization

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Received: 5 July 2018 / Accepted: 7 November 2018 / Published online: 16 November 2018

Abstract Vernonia (*Centrapalus pauciflorus*) is a potential novel industrial crop due to high demand to its natural epoxidised oil, which can be used for the manufacturing of polyvinyl chloride, adhesives, petrochemicals, cosmetic and pharmaceutical products. The study was conducted by focusing on cultivation, utilization, morphological description and distribution in order to provide a clue for germplasm conservation and further research using 80-accessions of *C. pauciflorus* that grown in alpha-lattice design with two replications at Melka Werer and Wondo Genet Agricultural Research Centers. The seed yield and yield components of accessions grown at Wondo Genet Agricultural Research Center exhibited higher than those grown at Melka Werer Agricultural Research Center due to prolonged vegetative and reproductive growth. Seed yield per hectare was positively associated ($P \leq 0.\ 05$) with a number of heads per plant (r = 0.72), number of seeds per head (r = 0.50) and seed yield per plant (r = 0.47). The path coefficient analysis also showed that the number of heads per plant exhibited the highest positive direct effect on seed yield per hectare. These genetic variabilities reveal that the existence of variations in the material used, and have a good chance of improvement through selection. Since cultivation and commercialization of *C. pauciflorus* are limited by factors such as non-uniform maturity, seed shattering, plant height, not adapted to mechanized harvesting, seed threshing, and modern molecular tools should be applied for genetic improvement of the crop, in traits such as plant height, uniform maturity and seed retention.

Keywords Accession · Correlation coefficient · Cultivation · Path coefficient · Vernolic oil

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Introduction

Vernonia (*Centrapalus pauciflorus* (Willd.) H. Rob., 2n = 2x = 18) belongs to the family Asteraceae (Compositeae), is a potential novel industrial crop due to high demand to its natural epoxidised oil (Thompson et al. 1994c; Baye et al. 2001; Baye 2002; Baye and Becker 2004a, b; Mebrahtu et al. 2009; Shimelis et al. 2011). It is known as ironweed, and locally also named as “Dunfare”, “Fechatu”, “Ferenkudela”, “Kefatheogie”, “Metaboko” and “Noya”, different names in different localities (Baye et al. 2001). The genus *Centrapalus* contains more than 500 species that have two major centers of origin (South America and tropical Africa) most of which have bitter-tasting leaves (Favi et al. 2008). According to Robinson (1999) the Old World Vernonia be transferred to other genera, African annual or perennial herb, better referred to as the genus *Centrapalus* Cass., as *Centrapalus pauciflorus* (Willd.) H. Rob. (syn.: *Conyza pauciflora* Willd., *Cetrapalus galamensis* Cass., *Vernonia galamensis* (Cass.) Less.). The species *C. pauciflorus* is limited in distribution to primarily Eastern African countries such as Ethiopia, Eriteria, Kenya and North Tanzania (at present, one variety has been found in Western Africa) (Shimelis and Gwat 2013; Thompson et al. 1994a). Hence, Ethiopia is considered as the center of origin and diversity for *C. pauciflorus* of subsp. *galamensis* var. *ethiopica* M. Gilbert (Thompson et al. 1994c; Perdue et al. 1986), and it was first identified by Perdue in 1964 along the Harar-Jijiga road, Eastern Ethiopia (Perdue et al. 1986). Later, it is recognized that South and Southeastern part of Ethiopia was another natural habitat for this plant (Perdue et al. 1986; Thompson et al. 1994b). Regarding its ecology, *C. pauciflorus* is naturally grown as a weed in a valley or depression in disturbed field, river banks, on the road side and it is growing wild along with acacia trees or in the forest (Baye and Becker 2005a, b; Shimelis et al. 2008; Shimelis and Gwat 2013). In Eastern and south eastern Ethiopia, plants were found in farm lands, in the forest, in the compounds of mosques and churches (Baye and Becker 2005a, b). It is also restricted to areas with well-drained soil and well defined seasons with relatively warm climate (Shimelis and Gwat 2013).

Centrapalus pauciflorus is an economically important crop; it is a new and novel oil performance (Baye et al., 2005; Baye and Becker 2004a, b; Shimelis et al. 2011). The seed of this plant is rich in naturally occurring epoxidized vernolic fatty acids (72–80%) (Mills 1999) and other essential fatty acids such as linoleic acid (12–14%), oleic acid (4–6%), palmitic acid (2–3%), stearic acids (2–3%) and trace amounts of arachidic acid (< 2%) (Thompson et al. 1994a, b, c; Baye et al. 2005). Oils rich in epoxy fatty acids are useful in paint industries to reduce emissions of volatile organic compounds, which is environmentally friendly, less expensive and less viscose compared to other artificial epoxy oils (Bhardwaj et al. 2007). This oil is also useful in the manufacturing of polyvinyl chloride, adhesives, insecticides, petrochemicals, cosmetic and pharmaceutical products (Baye and Becker 2004a, b; Shimelis et al. 2011).

Despite the favorable geo-climatic conditions for the cultivation of *C. pauciflorus* and, its importance as a source of raw material for agro-processing industries (Baye et al. 2001). In Ethiopia, the plant is neglected and considered only as a wild weed colonizing disturbed areas and bare agricultural lands (Baye 2002). As a result, the crop is not cultivated in any of the collection sites and/or elsewhere in the country. Moreover, lack of attention, negligence in research and conservation, priority has been given to other major crop plants while the potential industrial value of *C. pauciflorus* is underestimated and underexploited. The plant is also under threat of continued genetic erosion. In addition, its cultivation and commercialization is significantly hindered by non-uniform seed maturity, tall plant height, seed shattering and lack of appropriate technologies for mechanical harvesting, seed threshing and cleaning (Perdue et al. 1986; Baye and Becker 2004a, 2005a, b; Shimelis et al. 2008). This study is therefore initiated for the systematic, intensive evaluation and characterization of *C. pauciflorus* accessions by focusing on cultivation, utilization, morphological description and distribution in order to provide a clue for germplasm conservation and further research.

Materials and methods

Germplasm collection

A survey was undertaken for systematic localizations and collections of *C. pauciflorus* germplasm from natural populations in Ethiopia since December 10, 2016–February 20, 2016. A total of 155 accessions of *C. pauciflorus* germplasm was collected from East and West Hareghe, West Arsi, North and South Wallo, Sheshemene (Fig. 1A), Sidama, Awassa Zuria, Bench Maji, Dirashe and Konso, out of which 80 diverse accessions were selected for morphological characterization. Collections of seed samples from *V. galamensis* trees were made on selective strategy and the seeds were collected within a distance range of 5–10 km. Then all samples were threshed, cleaned and allotted to their own accession numbers. Soil samples were randomly taken from each site and analyzed for pH.

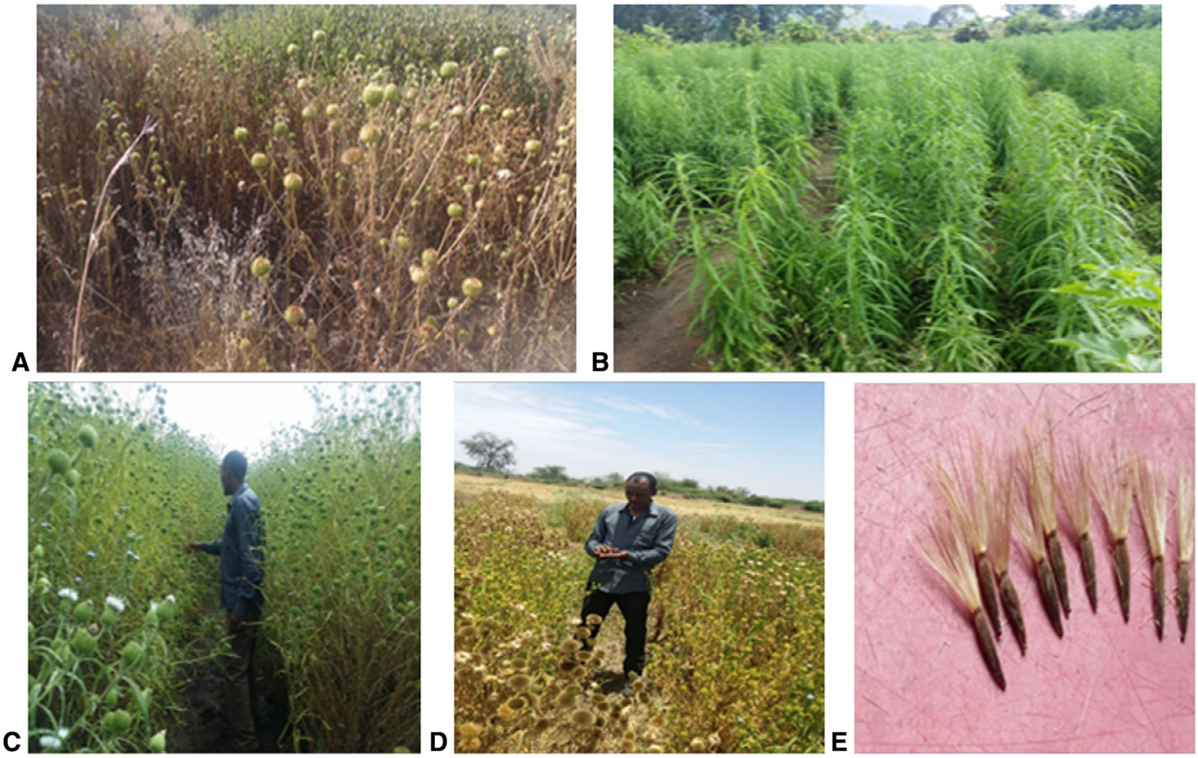

Fig. 1 Wild *Centrapalus pauciflorus* during seed sample collections from, Sheshemene botanical garden (**A**), vegetative part grown at Wondo Genet Agricultural Research Center (**B**), 50% flowering observation at Wondo Genet Agricultural Research Center (**C**), data recording during 90% maturity at Melka Werer Agricultural Research Center (**D**) and *Centrapalus pauciflorus* seeds with achene's resting at the tip (**E**)

Sample collection site description and experimental layout

80 accessions of *C. pauciflorus* were grown at two sites, Melk Werer Agricultural Research Center (MWARC) and Wondo Genet Agricultural Research Center (WGARC) for morphological analysis (Fig. 1). Melka Werer Agricultural Research Center elevation is 750 m a.s.l. with a latitude of 9°16′N and a longitude of 40°9′E. It has an annual maximum temperature ranging from 26.7 to 40.8 °C and receives an average annual rainfall of 590 mm, which is erratic and uneven in distribution. The site is dominated by Vertisols and flui-soil textures. The Wondo Genet Agricultural Research Center has an altitude of 1765 m a.s.l., a latitude of 7°19′N and a longitude of 38°7′E with an annual average rainfall of 1376 mm. Its annual maximum temperature ranges from 11.5 to 26.2 °C. The soil is fine sandy loam in texture with a pH of 6.40. Experimental design of each site was laid out in alpha-lattice design (8 × 10) with two replications. Each plot consisted of two rows of 2.5 m size with spacing of 0.6 m between plants and 0.6 m between rows (Shimelis et al. 2011). To study various quantitative parameters, five individual plants in the middle were tagged in each plot to avoid bordering effect and, monitored until maturity. The analysis of variance (combined ANOVA) of two locations was computed using GraphPad prism 7 (GraphPad Software, Inc. California, San Diego 2018) and PROC GLM procedure of SAS software.

Result and Discussion

Cultivation history

In cultivation, *C. pauciflorus* requires a rainy season that provides sufficient moisture and well-drained soil with pH 5.0–8.5 to permit the main flower heads to develop. A long rainy season could be promoting the development of secondary flower heads, which result in poor uniformity of maturations and the risk of seed shattering (Baye et al. 2001). Agricultural research was conducted during the mid-1950s by the USDA Agricultural Research Service and identified new sources of industrial raw materials with unique fatty-acid composition, *Vernonia anthelmintica* (L.) Willd. that could satisfy the needs at the time (Perdue et al. 1986). However, lack of seed retention and other agronomic constraints contributed to the abandonment of research efforts to cultivate and commercialize this species (Thompson et al. 1994a). Gunstone (1954) first discovered naturally occurring vernolic acid in the seed oil of *V. anthelmintica*, which is native to India and Pakistan. Perdue et al. (1986) interested in domestication and cultivation of *C. pauciflorus* var. *ethiopica* M. Gilbert, due to its good natural seed retention and promising new crop for semiarid tropical areas (Thompson et al. 1994b).

In the previous study, Thompson et al. (1994c) evaluated *C. pauciflorus* accessions for agronomic and chemical parameters and reported that significant differences existed for seed yield, oil content and vernolic acid. Baye et al. (2001) conducted field experiments at three sites using *C. pauciflorus* accessions that were collected from its grown area in Ethiopia, and reported that great variations were observed among the studied materials. With respect to oil content and fatty acid composition, Bhardwaj et al. (2007) conducted field experiments at the Randolph Farm of the Virginia State University and reported that significant differences were found between fatty a cid concentrations of *C. pauciflorus*. Baye and Becker (2005b) evaluated the chemical parameters of *C. pauciflorus* germplasm and showed the existence of wide genetic variability for seed yield, oil content and vernolic acid.

More recently, Shimelis et al. (2008) and Shimelis and Hugo (2011) conducted field work in the Limpopo province of South Africa and reported that significant differences were found among *C. pauciflorus* var. *ethiopica* lines for agronomical traits as well as for seed oil and fatty acid content (Mebrahtu et al. 2009). In this study most of the morphological characters of 80 accessions showed highly significant differences, except days to seed emergence (Table 1), that is consistent with previous reports (Mulualem 2013; Mishra et al. 2015). These genetic variabilities reveal that the existence of variations in the materials used, and have a good chance of improvement through selection. During sample collection, observed that *C. pauciflorus* was not cultivated in any of the collecting sites.

Cultivar selection criteria

Analyses of associating traits such as correlation coefficients and path coefficient analysis were conducted to determine the association between seed yield and other yield related components. These information are important to identify the indirect selection criteria for increasing seed yield. The associations between thirteen (13) agro-morphological traits were shown below (Table 1). The result included both Spearman's and Pearson correlation coefficient, but the interpretation was done using Spearman's correlation coefficient. In this study, the quantitative traits, days to emergence and branch length relatively had a poor association with all the quantitative traits. The result of correlation also showed that days to 50% heading was positively correlated with plant height (r = 0.76), days to 50% flowering (r = 0.85), number of heads per plant (r = 0.65), number of seeds per head (r = 0.69) and seed yield per hectare (0.50), but negatively and poorly correlated with branch length (− 0.07). Contrary to the present finding, previous studies by Shimelis et al. (2008) suggested that negative correlations occur between plant height and head per plant, head per plant and seed yield. Likewise, the number of heads per plant were positively associated with days to 50% flowering (r = 0.66), number of seeds per head (r = 0.64), seed yield per plant (r = 0.66) and seed yield per hectare (r = 72), indicating the importance of these traits for seed yield improvement in *V. galamensis*. These results were similar to the findings of Shimelis et al. (2008) in *V. galamensis*; Ezeaku et al. (2015) in pearl millet and Gurmu et al. (2018) in sweet potato.

Path coefficient analysis

Association of traits determined by correlation coefficient analysis may not provide an exact picture of the relative importance of direct and indirect influence of each of yield components on seed yield. The result of path coefficient analysis revealed that the number of heads per plant exhibited the highest positive direct effects (0.715), this trait also had a high positive correlation (r = 0.72) with seed yield per hectare

Table 1 Spearman's (above diagonal) and Pearson (below diagonal) correlation coefficient of the 13 quantitative traits of *Centrapalus pauciflorus*

	DE	DFH	PH	DFF	NB	BL	DNM	NHP	SPH	SYP	SWP	TSW	SYH
DE		0.04	0.03	0.011	0.03	0.04	0.04	0.06	0.05	0.03	0.03	0.04	0.03
DFH	0.03		0.76**	0.85**	0.13	− 0.07	0.47**	0.65**	0.69**	0.69**	0.52**	0.22**	0.50**
PH	0.03	0.86**		0.76**	0.13	0.15	0.42**	0.67**	0.68**	0.68**	0.54**	0.21**	0.54**
DFF	0.01	0.93**	0.84**		0.09	− 0.03	0.43**	0.66**	0.65**	0.71**	0.50**	0.25**	0.49**
NB	0.05	0.17	0.17**	0.16		− 0.03	0.23**	0.23*	0.06	0.11	0.12*	0.05	0.11
BL	0.03	− 0.09	0.04	− 0.06	− 0.08		− 0.07	0.07	0.07	0.04	0.09	0.04	0.09
DNM	0.06	0.57**	0.52**	0.53**	0.28*	− 0.12		0.36*	0.39**	0.39**	0.28**	0.23**	0.26**
NHP	0.02	0.74**	0.72**	0.71**	0.24*	0.01	0.38*		0.64**	0.66**	0.48**	0.20*	0.72*
SPH	0.05	0.73**	0.69**	0.68**	0.07	0.02	0.43**	0.65**		0.66**	0.51**	0.14*	0.50**
SYP	0.03	0.73**	0.69**	0.71**	0.13	− 0.09	0.40**	0.66**	0.63**		0.48**	0.15*	0.47**
SWP	0.04	0.53**	0.54**	0.49**	0.14	0.05	0.31*	0.74**	0.48**	0.42**		0.13*	0.97**
SYH	0.06	0.51**	0.53**	0.47**	0.12	0.04	0.29*	0.45**	0.47**	0.41**	0.46**		0.11
TSW	0.04	0.17	0.16	0.18	0.04	0.03	0.21*	0.13	0.08	0.09	0.18	0.11	

DE = days to emergence, DFH = Days to 50% heading, PH = Plant height, DFF = Days to 50% flowering, NB = Number of branches, BL = Branch length, DNM = Days to 90% maturity, NHP = Number of heads per plant, NSP = Number of seeds per plant, SYP = Seed yield per plant, SYH = Seed yield per hectare, TSW = 1000-seed weight

**, * Significant at $P < 0.01$ and $P < 0.05$, respectively

Table 2 Estimates of direct (bold face) and indirect effect (off diagonal) of eight traits on seed yield per hectare in 80 *Centrapalus pauciflorus* accessions

	DFH	DFF	NB	DNM	NHP	SPH	SYP	TSW	SYP
DFH	**0.083**	− 0.045	0.001	− 0.531	− 0.528	− 0.627	− 0.171	0.033	0.504
DFF	− 0.268	**− 0.372**	0.019	− 0.316	− 0.534	− 0.152	− 0.735	− 0.165	0.536
NB	− 0.103	0.241	**0.417**	− 0.343	− 0.389	0.226	0.003	0.033	0.486
DNM	− 0.454	0.094	− 0.251	**− 0.553**	0.091	− 0.274	− 0.149	− 0.213	0.092
NHP	− 0.322	− 0.429	− 0.361	0.171	**0.715**	− 0.653	− 0.676	− 0.095	0.864
SPH	− 0.014	0.209	0.210	− 0.084	− 0.548	**0.354**	− 0.457	0.089	0.471
SYP	− 0.485	− 0.652	0.056	0.015	− 0.494	− 0.511	**0.326**	0.080	0.503
TSW	− 0.045	− 0.249	0.031	− 0.147	− 0.095	0.099	0.114	**− 0.030**	− 0.470

DFH = Days to 50% heading, DFF = days to 50% flowering, BN = number of branches, DNM = days to 90% maturity, NHP = number of heads per plant, NSP = number of seeds per plant, SYP = seed yield per plant, SYH = seed yield per hectare, TSW = 1000-seed weight

(Table 2). In addition, number of branches (0.417), number of seeds per head (0.354) and seed yield per plant (0.326) have a high positive direct effect on seed yield per hectare (Table 2). This indicated that any improvement in those traits could increase seed yield per hectare. Furthermore, days to 50% flowering (− 0.372), days to 90% maturity (− 0.553) and 1000-seed weight (− 0.030) had a negative direct effect on seed yield (Table 2). Similar reports were made in different crops (Ezeaku et al. 2015; Gurmu et al. 2018). Number of heads per plant had an indirect negative effect on seed yield per hectare through days to 50% heading (− 0.528) and days to 50% flowering (− 0.534). Furthermore, the number of seeds per head had a positive direct effect on seed yield through number of branches (0.226) and 1000-seed weight (0.099). This finding was in agreement with the path coefficient analysis studies carried out by Shimelis et al. (2011) in *V. galamensis* and Gurmu et al. (2018) in sweet potato.

Utilization

The seed of *C. pauciflorus* contains high amounts of new and novel vernonia oil, which has a great application in the chemical, pharmaceutical and agro-processing industries (Baye and Becker 2005a; Baye and Becker 2004a, b). Perdue et al. (1986) reported that vernonia oil can be used in the paint industry for coatings to make hardness, elongation, and deformation which is resistant to alkali, acid and solvent (Perdue et al. 1986). The author also reported that the coated materials showed good flexibility, resistance to chipping and excellent adhesion (Thompson et al. 1994a, b). The utilization research also showed that it is also widely used as a plasticizer of polyvinyl chloride (PVC) and as a structural component of polymers. The vernonia seed oil used in industries is environmentally friendly, less expensive and less viscous compared to other artificial epoxy oils. Artificially epoxidized oil, however, is expensive and contains volatile organic solvents with high emission to the environment during processing and use (Shimelis and Gwat 2013). Moreover, some of the other products that are being developed from vernonia oil are degradable lubricants and lubricant additives, epoxy resins, adhesives, insecticides and insect repellants, crop-oil concentrates, and the formulation of carriers for slow-release pesticides (Baye and Becker 2004a, b; Bhardwaj et al. 2007).

The potential use of vernonia oil as a petroleum substitute is important since the demand for petroleum each year for the production of plastics and industrial petrochemicals is very high (Mebrahtu et al. 2009). In addition, the crop is the source of crude protein (44 g), crude fiber (11 g), ash (19 g) and carbohydrate (7 g). The plant also contains the major mineral elements such as calcium, potassium, magnesium and phosphorus (Baye et al. 2001). Many oils including vernolic acid are currently converted through extensive oleochemical processing to value added products (such as lubricants, polymer additives or surfactants) (Shimelis and Hugo 2011; Shimelis and Gwat 2013). These products are based on fatty acids, their methyl esters or fatty alcohols as intermediates (Baye and Becker 2004a, b; Shimelis et al. 2008). Epoxidized oil from the plant also has unique medical applications when applied to human or animal skin to treat skin diseases and wound, in folk medicine to treat chest pain in Tanzania, and stomach pain in Kenya, are among other uses (Baye 2002).

Shimelis and Gwat (2013) stated that the demand in the petrochemical 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 in the country would be useful for economic development. The author also stated that crop is adapted to the harsh agro-ecological conditions, and high yielding. However, improved cultivars that are non-shattering, and mature uniformly should be adopted more widely by plant breeders.

Morphological description

Centrapalus pauciflorus is herbaceous, usually annual, sometimes a short lived perennial crop. Its seed may show some dormancy for a few months after maturation and subsequent germination in average takes about 10 days (Table 3). Plants form a single unbranched stem ending in an inflorescence, branching starts after the formation of the main inflorescence and occurs only at the higher nodes that may also form flower heads. The shoot can grow up to 5 m in height with single flower to multiple flower heads. Regarding of plant height considerable variations were observed among 80 accessions of *C. pauciflorus* grown at both research centers, ranged from 159.5 to 228.0 with an average of 119.90 at Wondo Genet Agricultural Research Center, while from 89.50 to 143.50 with an average of 193.60 at Melka Werer Agricultural Research Center (Table 3). Moreover, wide variations were measured in the total number of heads per plant, the highest number of heads per plant (239.20) was recorded for accessions that were grown at Wondo Genet Agricultural Research Center, and (188.40) for those grown at Melka Werer Agricultural Research Center (Table 3). As a result, ripening of the heads of a plant was not uniform and shattering of mature fruiting heads was observed. Similar findings were reported by Baye and Becker (2004a, b).

The inflorescence consisting of a terminal flower head with lateral flower heads from the uppermost axis (Perdue et al. 1986; Gilbert 1986). Moreover, highly significant variations were measured for number of 50% flowering and number of 90% maturity between locations ranging from 96.0–111.5 and 165.5–198.5 at Wondo Genet Agricultural Research Center and 85.0–93.5 and 151.0–177.0 at Melka Werer Agricultural Research Center, respectively. Leaves are arranged in an alternate format and are sessile and membranous. The apex is more or less acuminate and cuneate at the base. The margins irregularly dentate to sharply serrate to serrulate and upper surfaces range from asperous to sparsely long-pilose with the lower surfaces sparsely to quite densely long-pilose, sometimes the hairs dimorphic with small appressed hairs as well as the normal long erect hairs (Gilbert 1986). Capitula vary greatly, from slightly longer than broad to markedly broader than long. Fruit of *Vernonia* is non-fleshy and indehiscent. The mean performance of seed yield per hectare was 383.49 kg ha^{-1} that grown at Melka Werer Agricultural Research Center while 562.16 kg ha^{-1}, that grown at Wondo Genet Agricultural Research Center (Table 3), the heaviest seed yield was recorded by accessions grown at Wondo Genet Agricultural Research Center, since the climatic condition is attractive and promotes prolonged vegetative and reproductive growth of *V. galamensis* (Fig. 2). Dispersal is commonly by wind, using hairy pappus (Perdue et al. 1986).

Distribution

Centrapalus pauciflorus subsp. *galamensis* var. *ethiopica* M. Gilbert was first identified by Perdue in 1964 in December, Eastern Ethiopia along the Harar-Jijiga road at 1700 m a.s.l. (Shimelis and Hugo 2011). Later, South and Southeastern Ethiopia were described as a natural habitat of this plant (Baye and Becker 2005b; Shimelis and Gwat 2013). From collection site observations, *C. pauciflorus* naturally grows in hilly, farmlands, forest, depression, riverbanks and parklands. The plant was also available on the roadside, growing wild along with acacia trees in Eastern Ethiopia. Subspecies *galamensis* grows naturally in marginal areas with less than 600 mm rainfall and at an elevation ranging from 700 to 2400 m a.s.l. in the southern and southeastern parts of Ethiopia (Gilbert 1986).

Table 3 Estimates of mean, ranges, mean square, error, least significant difference (LSD) and critical variation (CV) for 13 quantitative traits of *Centrapalus pauciflorus*

Characters	Locations	Mean ± SE	Range		Mean square	Error	LSD	CV (%)
			Max	Min				
Days to seed emergence	MWARC	10.74 ± 0.09	12.5	9.00	1.24	1.09	2.08	9.72
	WGARC	10.8 ± 0.086	13	9.50	0.99*	0.62	1.57	7.37
Days to 50% heading	MWARC	68.13 ± 0.26	73	63.50	9.39**	4.03	3.99	2.01
	WGARC	83.71 ± 0.26	91	81.50	6.2	5.84	4.81	2.87
Days to 50% flowering	MWARC	89.89 ± 1.31	93.5	85.00	4.11**	0.75	1.72	0.86
	WGARC	109.9 ± 1.73	111.5	96.00	14.61**	1.38	2.34	1.14
Plant height (cm)	MWARC	119.90 ± 0.25	143.5	89.50	229.94**	51.58	14.29	5.99
	WGARC	193.60 ± 0.38	228	159.50	440.8	436	41.56	10.78
Number of branches	MWARC	33.41 ± 0.97	52.35	17.80	106.28**	30.75	11.04	16.59
	WGARC	36.85 ± 0.96	59.5	19.50	88.13	149.4	24.33	33.18
Branch length (cm)	MWARC	56.26 ± 0.76	71.9	46.00	74.41**	12.19	6.95	6.21
	WGARC	55.81 ± 0.78	76	43.00	88.60*	49.52	14.01	12.61
Days to 90% maturity	MWARC	163.65 ± 0.86	177	151.00	120.87**	7.83	5.57	1.71
	WGARC	179.60 ± 0.75	198.5	165.50	60.09	65.22	16.08	4.49
Number of head/plant	MWARC	118.73 ± 2.94	188.40	84.90	1025.94**	192.70	27.63	11.69
	WGARC	189.1 ± 2.23	239.20	132.40	195.48*	118.60	21.68	5.76
Number of seed/head	MWARC	122.00 ± 1.80	163.5	93.08	432.29*	271.30	32.78	13.5
	WGARC	162.8 ± 1.19	189.00	141.20	201.11	125.00	22.25	6.87
Seed yield/plant (g)	MWARC	12.04 ± 0.22	16.84	8.70	7.15*	4.32	4.14	17.26
	WGARC	19.22 ± 0.33	25.65	14.85	16.74	3.75	3.85	10.07
Seed weight/plot (g)	MWARC	113.74 ± 39.5	246.8	23.60	1019.71**	15.63	78.69	34.76
	WGARC	169.51 ± 44.3	1104.00	137.20	1635.78*	19.61	88.14	26.12
1000-seed weight (g)	MWARC	3.00 ± 0.02	3.55	2.65	0.058**	0.07	0.51	8.54
	WGARC	3.08 ± 0.02	3.45	2.42	0.095*	0.02	0.24	3.93
Seed yield (kg ha^{-1})	MWARC	385.49 ± 9.42	580.3	163.80	10,723.23**	153.59	24.67	32.15
	WGARC	562.16 ± 11.54	1104	406.00	16,588.91**	254.44	31.75	28.38

Max = maximum, Min = minimum, MWARC = Melka Worer Agricultural Research Center, WGARC = Wondo Genet Agricultural Research Center, LSD = least significant differences, CV = critical variation

**, *Significant at $P < 0.01$ and $P < 0.05$, respectively

According to Gilbert (1986) the taxonomic revision of *galamensis* is recognized to include six subspecies including *galamensis* M. Gilbert, *mutomoensis* M.Gilbert, *nairobensis* M. Gilbert, *afromontana* (R. E. Fries) M. Gilbert, *gibbosa* M. Gilbert and *lushotoensis* M. Gilbert (Perdue et al. 1986). Furthermore, subsp. *galamensis* more diverse and has four botanical varieties, namely var. *galamensis* M. Gilbert, *petitiana* M. Gilbert, *australis* M. Gilbert and *ethiopica* M. Gilbert (Thompson et al. 1994c; Baye et al. 2001). The subspecies *galamensis* and *mutomoensis* are found in areas that receives 200 mm rainfall per year. *Centrapalus pauciflorus* subsp. *afromontana* (R. E. Fries) M. Gilbert and *lushotoensis* M. Gilbert grows in the areas of higher elevations and higher rainfall (Perdue et al. 1986; Shimelis et al. 2008).

Conclusion

The genus *Centrapalus* contains more than 500 species that have two major centers of origin; South America and tropical Africa, most of which have bitter-tasting leaves, and Ethiopia is considered as the

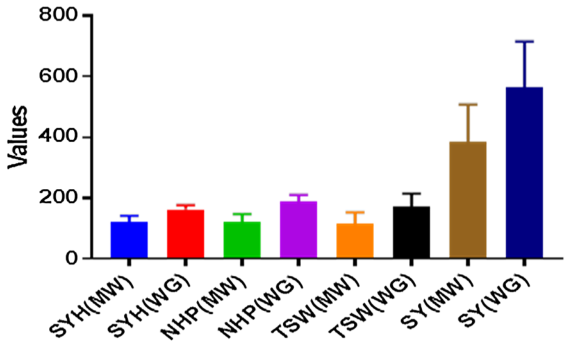

Fig. 2 Seed yield and yield components of *Centrapalus pauciflorus* accessions grown at Melka Werer Agricultural Research Center and Wondo Genet Agricultural Research Center. SYH = seed per head, number of heads per plant, TSW = 1000-seed weight, SY = seed yield per hectare, MW = Melka Werer Agricultural Research Center, WG = Wondo Genet Agricultural Research Center)

center of origin and diversity for *Centrapalus pauciflorus* of subsp. *galamensis* variety *ethiopica* M. Gilbert. *C. pauciflorus* naturally grows in marginal areas with less than 600 mm rainfall and at an elevation ranging from 700 to 2400 m a.s.l. in Eastern, Southern and Southeastern part of Ethiopia. The study revealed that there is significant genetic variability among *C. pauciflorus* accessions studied. The heaviest seed yield was recorded by accessions grown at Wondo Genet Agricultural Research Center, since the climatic condition is attractive and promotes prolonged vegetative and reproductive growth of the plant. Seed yield was positive and significantly associated with the number of heads per plant, seed yield per head and seed yield per plants, and the number of heads per plant also exhibited the highest positive direct effects on seed yield, indicating the importance of these traits for yield improvement. The result of path coefficient analysis revealed that the number of heads per plant exhibited the highest positive direct effects (0.715) with high positive correlation (r = 0.72) with seed yield per hectare. From the present study, it can be suggested that to increase the seed yield in *C. pauciflorus*, the accessions should possess a number of branches, number of heads per plant, number of seeds per head and seed yield per plant. There was non-uniform seed maturity, tall plant height, seed shattering and lack of technologies for harvesting and cleaning, and genetic improvement should be adopted for the modification of shattering, plant height and maturity.

Acknowledgement s The authors wish to thank Melka Werer Agricultural Research Center and Wondo Genet Agricultural Research Center for the creation of good working environment during the research period and Addis Ababa University for financial support.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest

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