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SEED YIELD AND YIELD COMPONENTS OF VETCH SPECIES AND THEIR ACCESSIONS UNDER NITOSOL AND VERTISOL CONDITIONS IN THE CENTRAL HIGHLANDS OF ETHIOPIA

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ABSTRACT

Vetch species and their accessions were evaluated for seed yield and yield components at Holetta (nitosol) and Ginchi (vertisol) conditions in the central highlands of Ethiopia. The experiment was conducted in randomized complete block design with three replications. The seed yield and its related performance were highly influenced by environment and hence comparatively higher seed yield and its related performance were recorded at Ginchi than Holetta. The highest grain filling period (72.4) and number of pods per plant (85.3) and the lowest pod length per plant (2.7 cm) was recorded for Vicia villosa at Holetta. The highest grain sink filling rate (16.4 kg ha-1 day-1) and seed yield (0.8 t ha-1) and the lowest grain filling period (46.9) was recorded for Vicia sativa at Holetta. Vicia narbonensis had the highest pod length per plant (5.4 cm) and thousand seed weight (222.8 g) and the lowest grain sink filling rate (7.2 kg ha-1 day-1), number of pods per plant (7.6) and seed yield (0.4 t ha-1) at Holetta. The lowest thousand seed weight (44.1 g) was recorded for Vicia dasycarpa at Holetta. On the other hand, the highest number of pods per plant (159.1) and the lowest grain sink filling rate (26.0 kg ha-1 day-1) was recorded for Vicia dasycarpa at Ginchi. The lowest pod length per plant (2.8 cm) and thousand seed weight (42.5 g) was recorded for Vicia villosa at Ginchi. The highest grain filling period (79.8) and the lowest seed yield (2.0 t ha-1) was recorded for Vicia sativa and Vicia atropurpurea at Ginchi respectively. Vicia narbonensis had the highest grain sink filling rate (41.0 kg ha-1 day-1), pod length per plant (5.5 cm), seed yield (2.9 t ha-1) and thousand seed weight (242.2 g) and the lowest grain filling period (70.0) and number of pods per plant (30.6) at Ginchi. The seed yield was positively correlated with grain sink filling rate, pod length per plant, number of seeds per pod and thousand seed weight. Generally, vetch species and their accessions varied in seed yield and yield components potential under nitosol and vertisol conditions in the central highlands of Ethiopia.

INTRODUCTION

Feed shortage is among the few most critical problems of livestock production in Ethiopia. As feed becomes critically scarce in the different agro-ecologies and farming systems, livestock keepers are now a day's perceived the importance of using improved forages as feasible option of availing feed for their animals (Getnet, 2012). The introduction and development of selected forage species into the farming system is to help solve the severe forage deficit that the country is presently facing (Alemayehu and Getnet, 2012). The success of forage development depends upon the establishment of a local seed production system that can ensure the supply of adequate quantity of good quality forage seed. Use of improved forage crops is increasing from time to time due to shrinkage of grazing areas as a result, demand for quality forage seed is increasing (Karta, 2012; Muluneh *et al.*, 2012). However, reliable source of quality seed or vegetative materials of recommended species for different agro-ecologies of the country at affordable price remained a problem due to lack of organized system for seed production and distribution in the country (Muluneh *et al.*, 2012). According to Getnet (2012), availability of seed and planting materials accompanied by subsistence production systems hindered forage development in most parts of Ethiopia (Getnet, 2012). Seed production in forage crops is a complex process that involves the relationship between a large number of biotic and abiotic stress factors. Maximum seed yields can only be achieved when all of the contributing factors are at their

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respective optimum. Thus, an increase in the seed yield may be achieved through a carful choice of agricultural practices (Martiniello, 2008; Zhang *et al.,* 2008). Many of the temperate and tropical pasture and forage crops that have been tested and grown in Ethiopia have no problem of flowering and seed setting. This provides a good opportunity for the country to establish local seed production in the existing farming system. However, forage seed production requires knowledge and skills on seed crop establishment, management, seed harvesting and post-harvest handling to ensure seed quality (Getnet, 2012; Karta, 2012). Determination of proper harvesting stage for forage seeds is more complex compared to food crops due to unsynchronized seed maturity and seed shattering problems caused mainly by indeterminate growth of some forage crops (Getnet *et al.,* 2012). Some of the problems associated with forage seed production are low seed yield performance, unsynchronized seed maturity, seed shattering and difficulty in threshing that consequently result in high cost of production (Getnet *et al.,* 2012). Most annual forage crops produce higher seed yields and are easier to process and mange compared to most small seeded perennials (Getnet *et al.,* 2012). Moreover, seed production technologies and pasture establishment techniques are easier in annuals than in perennials. Vetch is an annual forage legume widely adapted to the highlands of Ethiopia (IAR, 1986). Experimental results have showed that vetch gave higher seed yield when planted at the rate of 20-30 kg/ha and row spacing of 30 cm. Vetch is weak stemmed and requires a supporting structure which holds them erect making vigorous growth to attain maximum seed production. It has also been confirmed that it is possible to increase the seed yield of this species by providing some supporting structures (Lulseged, 1985). Generally, supporting structure allowed better aeration and more light penetration resulting in better growth and multiple harvesting was more possible than either broadcasting or row planting (Gezahagn *et al.,* 2012). Generally, previous evaluations of vetch were done mainly on environmental adaptation and biomass yield but there is no wide assessment with respect to seed yield and its yield components of vetch species and their accessions was done in the country. Therefore, the objective of this study was to evaluate seed yield performance of vetch species and their accessions under nitosol and vertisol conditions in the central highlands of Ethiopia.

MATHERIALS AND METHODS

Characteristics of the study sites

The experiment was conducted at Holetta Agricultural Research Center (HARC) and Ginchi sub center during the main cropping season of 2009 under rain fed condition. HARC is located at 9°00'N latitude, 38°30'E longitude at an altitude of 2400 m above sea level. It is 34 km west of Addis Ababa on the road to Ambo and is characterized with the long term (30 years) average annual rainfall of 1055.0 mm, average relative humidity of 60.6%, and average maximum and minimum air temperature of 22.2°c and 6.1°c respectively. The soil type of the area is predominantly red nitosol, which is characterized by an average organic matter content of 1.8%, total nitrogen 0.17%, pH 5.24, and available phosphorus 4.55ppm (Gemechu, 2007). Ginchi sub center is located at 75 km west of Addis Ababa in the same road to Ambo. It is situated at 9°02'N latitude and 38°12'E longitude with an elevation of 2200m above sea level (masl), and characterized with the long term (30 years) average annual rainfall of 1095.0 mm, average relative humidity of 58.2%, and average maximum and minimum air temperature of 24.6°c and 8.4°c respectively. The soil of the area is predominately black clay vertisol with organic matter content of 1.3%, total nitrogen 0.13%, pH 6.5 and available phosphorus 16.5 ppm (Getachew *et al.,* 2007). Soil samples were taken using a soil auger from each plot at two depth intervals (0-15 cm and 15-30 cm) prior to sowing and at harvest. Samples from relevant depths were combined in block basis and 3 composite samples from each soil depth interval were used to determine soil chemical and physical properties of the testing plots. After analysis, mean of the relevant soil depth at each sampling period was used to evaluate the soil physico-chemical properties. The laboratory analysis was done on samples <2 mm and analyzed for pH in 1:1 soil water ratio using pipette method (Schoffield and Taylor, 1955); determination of organic carbon by Walkly-Black wet digestion method (Black, 1965); total nitrogen by Kjeldahl method (Ranist *et al.,* 1999); available phosphorus using bray II method and cation exchange capacity (CEC) was determined from ammonium acetate saturated samples using Kjeldahl method (Ranist *et al.,* 1999). The soil texture was also determined by using Bouyocucos hydrometer method (Bouyocucos, 1951).

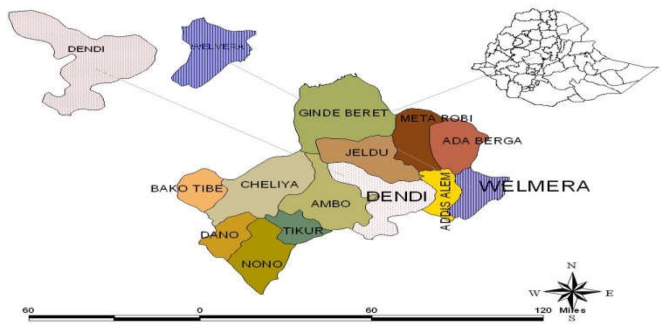

Fig. 1. Map of the experimental sites, at Holetta (Welmera) and Ginchi (Dendi) in the central highlands of Ethiopia

Experimental set-up and procedure

The study was executed using 20 accessions from five vetch species (Table1). The experiment was conducted on a Randomized Complete Block Design (RCBD) with three replications. Seeds were drilled in rows of 30 cm on a plot size of 2.4 m x 4 m= 9.6 m^2. Based on experimental design, each treatment was assigned randomly to the experimental units within a block. The treatments were sown according to their recommended seeding rates: 25 kg ha^{-1} for *Vicia villosa*, *Vicia dasycarpa* and *Vicia atropurpurea*; 30 kg ha^{-1} for *Vicia sativa* and 75 kg ha^{-1} for *Vicia narbonensis*. At sowing, 100 kg ha^{-1} diamonium phosphate (DAP) fertilizer was uniformly applied for all treatments at both locations. At Ginchi site, sowing was done on Camber-beds to improve drainage and reduce water-logging problems of vertisol. Generally, maximum cares were taken in the experimental plots to reduce the possible yield limiting factors which could affect the yield performance of vetch species and their accessions.

Data collection and analysis

Plant parameters collected were days to seed harvesting, grain filling period, grain sink filling rate, number of pods per plant, pod length per plant, number of seeds per pod, seed yield and thousand seed weight. Days to seed harvesting was counted from days to emergence to the date when plants reach for seed harvesting stage. Grain filling period (GFP) and grain sink filling rate (GSFR) were also used to determine seed yield related performance. Number of days between days for flower initiation and days to seed maturity is known as GFP, while GSFR is calculated as the ratio of grain yield to number of days from flower initiation to seed maturity and expressed as kg ha^{-1} day^{-1}. Six plants were randomly taken and uprooted at seed filling stage from two destructive sampling rows of each plot for determination of number of pods per plant. Six pods were then randomly taken to measure pod length and the number of seeds per pod was counted. The inner most two rows of each plot was maintained for seed yield determination. The plants were harvested at ground level at the optimum seed harvesting time (visual observation due to indeterminate growth nature of the crop) and total seed yield was determined from two rows after threshing and winnowing. Seed samples were taken and oven dried at 100°c for 48 hours to adjust moisture content of 10%, a recommended percentage level for legumes (Biru, 1979). Seed yield (t ha^{-1}) and thousand seed weight (g) were then calculated at 10% moisture content. Analysis of variance (ANOVA) procedures of SAS general linear model (GLM) was used to compare treatment means (SAS, 2002). Bartlett's test for homogeneity of variance was carried out to determine the validity of individual experiment. Log and square root transformations were used for data which couldn't exhibit homogeneity of variance for measured agro-morphological traits according to Gomez and Gomez (1984). Accordingly, data on grain filling period, grain sink filling rate, seed yield and thousand seed weight were log transformed but square root transformation was used for number of pods per plant and untransformed means were presented according to Gomez and Gomez (1984). Duncan Multiple Range Test (DMRT) at 5% significance was used for comparison of means. The Pearson correlation analysis procedure of the SAS statistical package was also applied to measure the strength of linear dependence between two measured quantitative traits. The data was analyzed using the following model. $Y_{ijk} = \mu + T_i + L_j + (TL)_{ij} + B_{k(j)} + e_{ijk}$ Where, Y_{ijk}= measured response of treatment i in block k of location j, μ= grand mean, T_i= effect of treatment i, L_j= effect of location j, TL= treatment and location interaction, $B_{k(j)}$= effect of block k in location j, e_{ijk}= random error effect of treatment i in block k of location j.

RESULTS AND DISCUSSION

Weather and soils physico-chemical properties of the experimental sites

The 10 years average annual rainfall and average maximum and minimum daily air temperatures, relative humidity, and evaporation values at the experimental site of Holetta were 962.7 mm, 22.6 °C, 6.0 °C, 53.5 % and 7.3 mm respectively. The respective values for Ginchi were 1032.0 mm, 24.4 °C, 8.8 °C, 58.5 %, and 5.4 mm. During the cropping season, total rainfall, mean maximum and minimum daily air temperatures, relative humidity, and evaporation values were 728.8 and 870.6 mm; 23.2 and 24.5 °C; 7.1 and 9.1 °C; 59.4 and 55.0 %; 3.8 and 4.6 mm for Holetta and Ginchi testing site respectively. During the main rainy season, especially in the month of June substantial shortage of rainfall was recorded for both sites as compared with the long term observations, which resulted in delayed sowing. Compared to the long term average, the rainfall was lower during the growing season, but the minimum and maximum air temperatures were relatively higher in both testing sites. In general, mean of all recorded weather elements except relative humidity values were relatively lower at Holetta as compared with Ginchi during the experimental year, 2009. Total monthly rainfall and average maximum and minimum daily air temperatures during the experimental period at the trial sites of Holetta and Ginchi are shown in Figures 2a and 2b. Soil fertility depends on a range of factors, including water, nutrients, aeration, soil structure and beneficial micro-organisms. Soil physico-chemical properties of the two experimental sites are presented in Table 2. At Holetta the soil type is red colored nitosol due to the presence of iron in different forms, while black vertisol is the characteristics of Ginchi sub center. The soil is clay in texture at both locations. Soil texture, or the relative amounts of sand, silt, and clay plays a very important role in plant nutrition due to its effect on the ability to retain both water and nutrients (Marshner, 1995). The total nitrogen and organic carbon contents of the soils were comparatively higher at Holetta, while pH, available phosphorus and cation exchange capacity (CEC) were relatively higher at Ginchi, and the same result was also reported by Muluneh (2006). Total nitrogen content at Ginchi was reduced by leaching, runoff and water logging (dinitrification) processes. Under anaerobic condition, the micro-organism decompose high amount of organic matter (OM) to get the required amount of energy, but its accumulation is high under aerobic, acidic and cold environment because of low decomposition rate due to low activity of micro-organism (Marshner, 1995). Soil pH affects the availability of the nutrients in the soil. Lower pH generally causes lower CEC, and P-fixation is affected by amount of Fe/Al oxides, clay mineral types, soil pH, organic matter and moisture content of the soil (Mengel and Kirkby, 1987). The total nitrogen, organic carbon, available phosphorus and pH of the soil slightly increased after harvesting of the crops. The total nitrogen, organic carbon, available phosphorus, and CEC decreased, while pH increased with increasing soil depth.

Location and interaction effects

The two locations displayed significant ($P<0.05$) differences for measured agro-morphological traits for tested vetch species and their accessions (Table 3). However, thousand seed weight did not show marked differences ($P>0.05$) between locations for both species and accessions level analysis. Vetch species and their accessions showed significant ($P<0.05$ or $P<0.05$) differences for all measured agro-morphological traits. Generally, vetch species and their accessions had superior performances for all measured traits at Ginchi. Species by location interaction and accessions by location interaction effect also revealed significant differences ($P<0.01$ or $P < 0.05$) for all measured traits except pod length and number of seeds per pod for both species and accession level analysis.

Table 1. Twenty accessions of five vetch species used as treatments for the experiment

No	Species	Accessions	No	Species	Accessions
1	*Vicia sativa*	64266	11	*Vicia villosa*	2434
2	*Vicia sativa*	61904	12	*Vicia villosa*	2446
3	*Vicia sativa*	61744	13	*Vicia narbonensis*	2384
4	*Vicia sativa*	61509	14	*Vicia narbonensis*	2387
5	*Vicia sativa*	61039	15	*Vicia narbonensis*	2376
6	*Vicia sativa*	61212	16	*Vicia narbonensis*	2392
7	*Vicia villosa*	2565	17	*Vicia narbonensis*	2380
8	*Vicia villosa*	2450	18	*Vicia dasycarpa*	Namoi
9	*Vicia villosa*	2424	19	*Vicia dasycarpa*	Lana
10	*Vicia villosa*	2438	20	*Vicia atropurpurea*	Atropurpurea

Table 2. Physico-chemical properties of soils of the experimental sites before planting and at harvesting of vetch species and their accessions at different soil depth (cm)

Parameters	Before planting				At harvesting			
	Holetta		Ginchi		Holetta		Ginchi	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
pH (1:1 H_2o)	5.43	5.61	6.20	6.23	5.49	5.59	6.23	6.25
Total OC (%)	2.37	2.23	1.31	1.26	2.41	2.06	1.37	1.35
Total N (%)	0.21	0.20	0.09	0.08	0.22	0.20	0.09	0.08
Avalable P (ppm)	5.40	4.67	11.60	9.60	7.13	5.60	13.73	13.70
CEC (meg/100g)	26.07	25.53	49.94	43.45	25.82	25.17	49.62	49.55
Sand (%)	13.33	13.75	15.83	15.83	15.83	15.83	17.08	15.00
Silt (%)	26.25	24.58	15.42	15.42	26.25	24.17	14.17	17.08
Clay (%)	60.42	63.33	68.75	68.75	57.92	60.00	68.75	67.92
Textural class	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay

Table 3. Mean performance of measured quantitative traits of different vetch species (a) and their accessions (b) At Holetta and Ginchi

Traits	Mean square			Locations		Mean	CV (%)
	L	S/A	L x S/A	Holetta	Ginchi		
A) Vetch species							
DSH	**	**	**	129.62^{b}	152.00^{a}	140.81	4.04
GFP	**	**	**	56.21^{b}	76.11^{a}	66.16	10.11
GSFR	**	*	**	47.88^{b}	159.05^{a}	103.47	9.36
NPP	**	**	**	58.15^{b}	97.42^{a}	77.79	12.81
PL	**	**	ns	3.75^{b}	3.93^{a}	3.84	5.75
NSP	**	**	ns	4.78^{b}	5.21^{a}	5.00	8.36
SY	**	**	**	0.62^{b}	2.39^{a}	1.51	8.86
TSW	ns	**	**	81.71^{a}	86.31^{a}	84.01	24.63
B) Vetch accessions							
DSH	**	**	**	128.98^{b}	150.07^{a}	139.53	3.64
GFP	**	**	**	57.85^{b}	76.57^{a}	67.21	2.58
GSFR	**	**	*	49.73^{b}	169.60^{a}	109.67	9.05
NPP	**	**	*	49.71^{b}	85.14^{a}	67.43	12.81
PL	**	**	ns	4.13^{b}	4.24^{a}	4.19	4.16
NSP	**	**	ns	5.08^{b}	5.46^{a}	5.27	8.18
SY	**	**	*	0.64^{b}	2.52^{a}	1.58	8.48
TSW	ns	**	**	91.09^{a}	96.47^{a}	93.78	2.21

Within row means with different superscripts differ significantly ($P<0.05$); L= location; S/A= Species or accession; L x S/A= location by species or location by accession interaction; DSH= days to seed harvest; GFP= grain filling period; GSFR= grain sink filling rate; NPP= number of pods per plant; PL= pod length; NSP= number of seeds per pod; SY= seed yield; TSW= thousand seed weight.

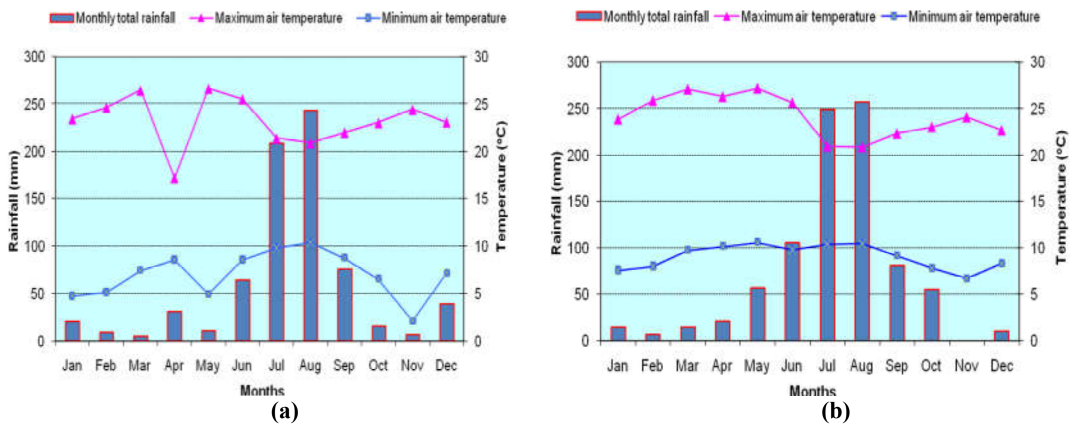

Fig. 2. Clima-diagram during the experimental period (2009) at the trial site, Holetta (a) and Ginchi (b)

These may indicate lesser sensitivity of the species of vetch and their accessions for the aforementioned traits to changes in environment. Therefore, different vetch species and their accessions selected at one location for the above both traits may repeat similar performance under other locations as well. When significant, the interaction effects were mostly a "cross-over" type; i.e. interactions were associated with rank order changes among the species and accessions of vetch. This indicated that the two locations were distinctly different for some of the characters and that better vetch species and their accessions at one location may not also be better performing at another. The Genotype x environment (G x E) interaction is important for plant breeding because it affects the genetic gain and selection of cultivars with wide adaptability (Deitos *et al.,* 2006; Souza *et al.,* 2009). G x E interaction minimizes the utility of genotypes by confounding their yield performances. According to Gemechu (2012), when genotypes perform consistently across locations, on the other hand, breeders are able to effectively evaluate germplasm with a minimum cost in a few locations for ultimate use of the resulting varieties across wider geographic areas. However, with high G x E interaction effects, genotypes selected for superior performance under one set of environmental conditions may perform poorly under different environmental conditions (Ceccarelli, 1997). Therefore, it could be implicated that selection of better performing genotypes at one location may not enable the identification of genotypes that can repeat nearly the same performances at another location.

Days to seed harvesting

Vetch species and their accessions showed significant ($P<0.05$) difference for days to seed harvesting at both testing sites (Table 4 and Table 5). *Vicia narbonensis* showed significantly earlier ($P<0.05$) than the remaining species at both locations. On the other extreme, *Vicia villosa* was significantly late ($P<0.05$) for seed harvest at Holetta but not significantly late with *Vicia dasycarpa* and *Vicia atropurpurea* at Ginchi. According to Getnet *et al.,* (2003) *Vicia narbonensis* and *Vicia sativa* are early maturing; *Vicia dasycarpa* and *Vicia atropurpurea* are intermediate and *Vicia villosa* is late maturing species recommended for utilization in the highlands of Ethiopia. Phenology (earliness and lateness) of vetch species and their accessions has a great effect on seed yield productivity. In this study, sowing has not been done at the right sowing time of vetch species due to the late onset of rainfall during the cropping season. Consequently, the grain filling period (at the early) and frost occurring months coincided for most vetch species that could be attributed to low seed yield. For seed purpose, early maturing species should be grown at Holetta, whereas early and late maturing specie recommended for Ginchi, because seed yield reduction by frost is low due to relatively warm climatic condition at Ginchi. Accordingly, *Vicia narbonensis*, *Vicia sativa* and *Vicia dasycarpa* should be grown for seed production due to earliness to escape frost months, whereas late maturing species like *Vicia villosa* and *Vicia atropurpurea* should not be advisable to grow for seed purpose at Holetta. However, all vetch species should be grown for seed purpose at Ginchi. Generally, variation in seed maturity period of the accessions of vetch over the testing sites need careful selection of the legumes to be sown in a particular soils and climatic conditions. Seed shattering is the common characteristics of vetch species. The pods on the upper part of the plant are still at grain filling period, while those of the lower pods have already reached maturity due to indeterminate growth nature of vetch species which makes seed harvesting activity quite difficult (Gezahagn, 2011). Hence, seed loss due to shattering problem is very high in the field unless a frequent follow-up is not taken especially at grain filling period. Therefore, farmers in the highlands of Ethiopia are reluctant to plant vetch on their field due to seed shattering problem, because the shattered seeds can grow during the onset of rain and becomes a weed for the succeeding crop. However, harvesting of such legumes at optimum maturity period can reduce the loss of seed as well as the weed effect on the succeeding crop. All the tested vetch species and their accessions had great variation in seed maturity. Therefore, a close monitoring should be carried out to minimize the seed shattering problem by harvesting at the right time depending on their maturity period. Generally, establishment of seed maturity calendar based on genetic and environmental factors may reduce these problems.

Grain filling period and grain sink filling rate

The grain filling period of vetch species differed significantly ($P<0.05$) at both locations, ranging from 46.9 to 72.4 days with a mean of 56.2 days and from 70.0 to 79.8 days with a mean of 76.1 days at Holetta and Ginchi respectively (Table 4). The highest grain filling period was recorded for *Vicia villosa* at Holetta and *Vicia sativa* at Ginchi, whereas the lowest period was recorded for *Vicia sativa* and *Vicia narbonensis* at Holetta and Ginchi respectively. The grain filling period also showed significant ($P<0.05$) variation for vetch accessions (Table 5). The highest grain filling period was recorded for accession 2424 (*V. villosa*) at Holetta and accession 64266 (*V. sativa*) at Ginchi, whereas the lowest period was recorded for *Vicia narbonensis* accessions 2376 and 2387 at Holetta and Ginchi respectively. In general, most of the species started flowering early and had shorter grain filling period. However, some of the vetch species in this study showed early to start flowering, but took longer period to fill the grain. During seed filling, the established potential sink sites begin to accumulate proteins and starch reserves. This period is under genetic control and the biological processes of relocation of products from plant sink organs to seeds are influenced by environmental conditions. Among them, the water potential of leaves and seed reduced the metabolic activity of the organs and alter the process of seed filling. Vetch species showed significant ($P<0.05$) variations for grain sink filling rate, which ranged from 7.2 to 16.4 kg ha^{-1} day^{-1} with a mean of 11.4 kg ha^{-1} day^{-1} at Holetta and from 26.0 to 41.0 kg ha^{-1} day^{-1} with a mean of 31.6 kg ha^{-1} day^{-1} at Ginchi (Table 4). The rate was the highest for *Vicia sativa* (16.4 kg ha^{-1} day^{-1}) at Holetta and for *Vicia narbonensis* (41.0 kg ha^{-1} day^{-1}) at Ginchi, whereas the lowest rate was recorded for *Vicia narbonensis* (7.2 kg ha^{-1} day^{-1}) at Holetta and for *Vicia dasycarpa* (27.8 kg ha^{-1} day^{-1}) at Ginchi. Grain sink filling rate also showed significant ($P<0.05$) difference at both testing sites (Table 5). The highest and lowest rates were recorded for accession 61509 (*V. sativa*) and 2387 (*V. narbonensis*) at Holetta and accession 2380 (*V. narbonensis*) and 61039 (*V. sativa*) at Ginchi respectively. Grain sink filling rate is directly related to the seed yield.

Table 4. Least square means for days to seed harvesting (days), grain filling period (days) and grain sink filling rate (kg ha^{-1} day^{-1}) of vetch species at Holetta and Ginchi

Species	Days to seed harvesting		Grain filling period		Grain sink filling rate	
	Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi
Vicia sativa	119.7^{c}	151.3^{b}	46.9^{c}	79.8^{a}	16.4^{a}	33.9^{a}
Vicia villosa	149.9^{a}	157.9^{a}	72.4^{a}	78.6^{a}	10.2^{b}	29.1^{ab}
Vicia narbonensis	113.5^{d}	134.6^{c}	56.9^{b}	70.0^{b}	7.2^{c}	41.0^{a}
Vicia dasycarpa	129.7^{b}	156.8^{ab}	51.8^{bc}	78.8^{a}	13.6^{ab}	26.0^{b}
Vicia atropurpurea	135.3^{b}	159.3^{a}	53.0^{bc}	73.3^{ab}	9.5^{bc}	27.8^{ab}
Mean	129.6	152	56.2	76.1	11.4	31.6
CV (%)	4.08	4.05	12.85	8.00	13.17	8.86
R^2	0.90	0.73	0.68	0.35	0.29	0.19

Means followed by a common superscript letters with in a column are not significantly different from each other at P<0.05

Table 5. Average days to seed harvesting (days), grain filling period (days) and grain sink filling rate (kg ha^{-1} day^{-1}) of vetch accessions at Holetta and Ginchi

Species	Accession	Days to seed harvesting		Grain filling period		Grain sink filling rate	
		Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi
Vicia sativa	64266	119.3^{g}	156.0^{ab}	50.3^{bc}	86.3^{a}	11.0^{abc}	32.6^{bcd}
V. sativa	61904	118.7^{g}	155.3^{ab}	50.7^{bc}	85.7^{a}	19.8^{ab}	32.47^{bcd}
V. sativa	61744	121.3^{efg}	156.3^{ab}	43.7^{c}	81.0^{abcd}	13.6^{abc}	35.5^{abc}
V. sativa	61509	119.7^{g}	155.3^{ab}	43.7^{c}	81.7^{abc}	21.7^{a}	38.0^{abc}
V. sativa	61039	118.7^{g}	138.0^{c}	44.0^{c}	69.3^{ef}	14.9^{abc}	20.0^{d}
V. sativa	61212	120.3^{fg}	147.0^{b}	49.0^{bc}	74.7^{bcdef}	17.2^{ab}	44.6^{ab}
V. villosa	2565	141.0^{bc}	160.7^{a}	63.7^{ab}	83.7^{ab}	14.8^{abc}	33.0^{bcd}
V. villosa	2450	152.3^{a}	158.7^{a}	75.3^{a}	80.0^{abcd}	8.8^{bcd}	28.3^{bcd}
V. villosa	2424	153.0^{a}	160.3^{a}	76.0^{a}	78.7^{abcde}	11.7^{abc}	30.4^{bcd}
V. villosa	2438	152.0^{a}	156.3^{ab}	74.0^{a}	75.7^{abcdef}	6.2^{cd}	27.8^{bcd}
V. villosa	2434	153.7^{a}	157.7^{a}	74.7^{a}	76.7^{abcdef}	10.7^{abc}	29.9^{bcd}
V. villosa	2446	147.3^{ab}	153.7^{ab}	70.7^{a}	77.0^{abcdef}	8.8^{abcd}	25.3^{cd}
V. narbonensis	2384	114.0^{g}	134.3^{c}	60.3^{ab}	72.0^{cdef}	7.9^{bcd}	43.1^{ab}
V. narbonensis	2387	113.0^{g}	133.7^{c}	59.7^{ab}	68.0^{f}	4.6^{d}	32.2^{bcd}
V. narbonensis	2376	113.0^{g}	134.0^{c}	45.3^{c}	68.7^{ef}	6.9^{cd}	43.3^{ab}
V. narbonensis	2392	113.7^{g}	135.0^{c}	60.0^{ab}	70.3^{def}	6.2^{cd}	26.5^{bcd}
V. narbonensis	2380	114.0^{g}	135.7^{c}	59.3^{ab}	71.0^{def}	10.4^{abcd}	60.0^{a}
V. dasycarpa	Namoi	129.3^{def}	161.0^{a}	51.7^{bc}	82.3^{abc}	12.8^{abc}	27.1^{bcd}
V. dasycarpa	Lana	130.0^{de}	152.7^{ab}	52.0^{bc}	75.3^{abcdef}	14.4^{abc}	25.0^{cd}
V. atropurpurea	Atropurpurea	135.3^{cd}	159.3^{a}	53.0^{bc}	73.3^{bcdef}	9.5^{abcd}	27.8^{bcd}
Mean		129.0	150.1	57.9	76.6	11.6	33.1
CV (%)		4.15	3.27	3.39	1.6	21.59	7.60
R^2		0.93	0.87	0.75	0.64	0.57	0.57

Means followed by a common superscript letters within a column are not significantly different from each other at P<0.05

Improvement in gain sink filling rate is an important task for maximum seed yield production of any crop. According to Yifru (1998), tef grain yield improvement over thirty five years of research has been associated mostly with corresponding increase in panicle grain sink filling rate and panicle yield. Tamene (2008) also reported that sizeable improvement was made in economic growth rate and biomass production rate in faba bean breeding. Westgate (1994) for some cereals and Wang *et al.,* (2008) in tufted vetch reported that the effect of environmental stress reduced the period and duration of seed filling as a consequence, poor seed size and weight resulted. The consequences of stress on grain filling are associated with leaf senescence and with a decrease in metabolic activity of the embryo and endosperm cells which promotes the premature desiccation of seed (Egli, 1994; Lemke *et al.,* 2003).

Seed yield and its components

The number of pods per plant was counted at the optimum seed filling stage due to indeterminate growth nature. The number of pods per plant for vetch species varied significantly (P<0.05) at both locations which ranged from 7.6 to 85.3 with a mean of 58.2 at Holetta and from 30.6 to 159.1 with a mean of 97.4 at Ginchi (Table 6).

The highest number of pods per plant was counted for *Vicia villosa* at Holetta and *Vicia dasycarpa* at Ginchi, whereas the lowest was counted for *Vicia narbonensis* at both locations. Variation among the accessions was also significant (P<0.05) for number of pods per plant at both locations (Table 7). The highest number of pods per plant was counted for accession 2565 (*V. villosa*) at Holetta and Namoi (*V. dasycarpa*) at Ginchi. On the other extreme, the lowest was counted for *Vicia narbonensis* accessions 2387 and 2376 at Holetta and Ginchi respectively. In general, branching or tillering performance of the plant has a direct effect on number of pods per plant. Hence vetch species with a higher branching or tillering performance has higher number of pods per plant. The pod length of vetch species differed significantly (P<0.05) at both locations and ranged from 2.7 to 5.4 cm with a mean of 3.8 cm at Holetta and from 2.8 to 5.5 cm with a mean of 3.9 cm at Ginchi (Table 6). The result showed that *Vicia narbonensis* had comparatively the longest pod length than all the other vetch species at both locations. *Vicia villosa* had the shortest pod length at both locations. Pod length has a direct effect on number of seeds per pod and indirect effect on seed yield. Accessions of vetch also varied significantly (P<0.05) for pod length at both locations (Table 7).

Table 6. Least square means for number of pods per plant, pod length (cm), number of seeds per pod, seed yield (t ha^{-1}) and thousand seed weight (g) of vetch species at Holetta and Ginchi

Species	No. of pods/plant		Pod length		No. of seeds/pod		Seed yield		Thousand seed weight	
	Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi
Vicia sativa	32.3^{b}	45.7^{c}	5.3^{a}	5.3^{b}	7.0^{a}	7.4^{a}	0.8^{a}	2.7	49.4^{b}	54.7^{b}
V. villosa	85.3^{a}	41.2^{ab}	2.7^{b}	2.8^{c}	3.9^{c}	4.3^{c}	0.7^{a}	2.3	46.2^{b}	42.5^{b}
V. narbonensis	7.6^{c}	30.6^{d}	5.4^{a}	5.5^{a}	4.8^{b}	5.2^{b}	0.4^{b}	2.9	222.8^{a}	242.2^{a}
V. dasycarpa	85.1^{a}	159.1^{a}	2.8^{b}	3.0^{c}	4.0^{c}	4.4^{c}	0.7^{a}	2.1	44.1^{b}	43.4^{b}
V. atropurpurea	80.5^{a}	110.6^{b}	2.7^{b}	3.1^{c}	4.2^{c}	4.9^{bc}	0.5^{ab}	2.0	46.1^{b}	48.8^{b}
Mean	58.2	97.4	3.8	3.9	4.8	5.2	0.6	2.4	81.7	86.3
CV (%)	10.62	13.78	5.61	5.93	8.2	8.5	12.4	5.9	24.5	24.9
R^2	0.94	0.87	0.97	0.96	0.92	0.90	0.32	0.12	0.93	0.93

Means followed by a common superscript letters with in column are not significantly different from each other at P<0.05.

Table 7. Average number of pods per plant, pod length (cm), number of seeds per pod, seed yield (t ha^{-1}) and thousand seed weight (g) of vetch accessions at Holetta and Ginchi

Species	Accession	No. of pods/ plant		Pod length		No. of seeds/pod		Seed yield		Thousand seed weight	
		Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi	Holetta	Ginchi
Vicia sativa	64266	31.6^{c}	41.4^{cd}	5.6^{a}	5.5^{ab}	6.9^{a}	7.2^{b}	0.6^{abcd}	2.8^{abcd}	54.7^{d}	61.3^{f}
V. sativa	61904	26.2^{c}	66.7^{c}	5.4^{ab}	5.2^{cd}	6.7^{a}	7.1^{a}	1.0^{a}	2.8^{abcd}	54.3^{d}	60.2^{fg}
V. sativa	61744	37.8^{c}	46.0^{cd}	5.3^{ab}	5.6^{ab}	7.1^{a}	7.1^{b}	0.6^{abcd}	2.9^{abcd}	46.0^{def}	56.5^{g}
V. sativa	61509	35.5^{c}	51.4^{cd}	5.5^{a}	5.6^{a}	6.8^{a}	7.3^{b}	0.9^{a}	3.1^{abc}	54.7^{d}	67.7^{e}
V. sativa	61039	31.4^{c}	35.0^{cd}	4.9^{c}	4.7^{e}	7.3^{a}	8.4^{a}	0.7^{abc}	1.4^{e}	37.9^{f}	26.4^{k}
V. sativa	61212	31.0^{c}	33.5^{d}	5.1^{bc}	5.0^{d}	7.2^{a}	7.0^{b}	0.8^{ab}	3.2^{ab}	48.8^{de}	56.0^{g}
V. villosa	2565	96.7^{a}	149.3^{ab}	2.6^{d}	2.8^{gh}	3.9^{de}	4.3^{ef}	0.8^{ab}	2.8^{abcd}	46.2^{def}	42.6^{i}
V. villosa	2450	70.3^{b}	127.8^{b}	2.7^{d}	2.9^{fgh}	3.8^{de}	4.2^{ef}	0.7^{abc}	2.3^{bcde}	46.5^{de}	39.1^{j}
V. villosa	2424	83.1^{ab}	156.3^{ab}	2.6^{d}	2.7^{h}	3.7^{e}	3.9^{f}	0.9^{ab}	2.4^{bcd}	47.0^{de}	41.7^{ij}
V. villosa	2438	91.5^{ab}	139.3^{ab}	2.7^{d}	2.9^{fgh}	4.1^{cde}	4.3^{ef}	0.5^{abcd}	2.1^{bcde}	46.2^{def}	42.4^{i}
V. villosa	2434	84.9^{ab}	136.2^{ab}	2.8^{d}	3.0^{fg}	4.1^{cde}	4.5^{def}	0.8^{ab}	2.3^{bcde}	46.6^{de}	44.0^{i}
V. villosa	2446	85.6^{ab}	138.2^{ab}	2.6^{d}	2.8^{gh}	3.9^{de}	4.3^{ef}	0.6^{abc}	1.9^{cde}	44.8^{def}	44.9^{i}
V. narbonensis	2384	8.7^{d}	30.3^{d}	5.3^{ab}	5.3^{bc}	5.1^{b}	5.4^{c}	0.5^{abcd}	3.1^{abcd}	199.8^{bc}	243.9^{c}
V. narbonensis	2387	4.6^{d}	31.8^{d}	5.2^{ab}	5.3^{bcd}	4.8^{bc}	5.2^{cd}	0.3^{d}	2.2^{bcde}	248.4^{ab}	201.2^{d}
V. narbonensis	2376	5.4^{d}	26.8^{d}	5.5^{a}	5.7^{a}	4.9^{bc}	5.2^{cd}	0.3^{cd}	3.0^{abcd}	258.0^{a}	301.6^{a}
V. narbonensis	2392	9.2^{d}	28.2^{d}	5.3^{ab}	5.5^{ab}	4.8^{bc}	5.2^{cd}	0.4^{bcd}	1.9^{cde}	177.3^{c}	192.9^{d}
V. narbonensis	2380	10.3^{d}	35.7^{cd}	5.4^{ab}	5.5^{ab}	4.6^{bcd}	4.9^{cde}	0.6^{abcd}	4.2^{a}	230.6^{ab}	271.7^{d}
V. dasycarpa	Namoi	82.3^{ab}	182.8^{a}	2.7^{d}	2.9^{fgh}	4.0^{de}	4.3^{ef}	0.7^{abc}	2.2^{bcde}	45.7^{def}	44.1^{i}
V. dasycarpa	Lana	87.8^{ab}	135.4^{ab}	2.8^{d}	3.1^{f}	4.0^{de}	4.5^{def}	0.8^{abc}	1.9^{de}	42.4^{ef}	42.6^{i}
V. atropurpurea	Atropurpurea	80.5^{ab}	110.6^{b}	2.7^{d}	3.1^{f}	4.2^{bcde}	4.9^{cde}	0.5^{abcd}	2.0^{bcde}	46.1^{def}	48.8^{h}
Mean		49.7	85.1	4.1	4.2	5.1	5.5	0.6	2.5	91.1	96.5
CV (%)		10.29	13.94	4.69	3.59	8.89	7.56	12.53	4.75	2.96	1.03
R^2		0.96	0.9	0.99	0.99	0.93	0.94	0.51	0.58	0.98	1.00

Means followed by a common superscript letters with in a column are not significantly different from each other at P<0.05

Table 8. Pearson's correlation coefficients between measured agro-morphological traits of vetch accessions

Parameters	DSH	GFP	GSFR	NPP	PL	NSP	TSW
GFP	0.79***						
GSFR	-0.42	-0.22					
NPP	0.91***	0.68**	-0.49*				
PL	-0.87***	-0.68**	0.57**	-0.96***			
NSP	-0.49*	-0.61**	0.31	-0.66**	0.74**		
TSW	-0.76**	-0.39	0.43	-0.66**	0.58**	-0.08	
SY	-0.16	-0.03	0.96***	-0.27	0.39	0.24	0.21

DSH= days to seed harvesting; GFP= grain filling period; GSFR= grain sink filling rate; NPP= number of pods per plant; PL= pod length per plant; NSP= number of seeds per pod; SW= thousand seed weight; SY= seed yield

Among the accessions, 64266 (*V. sativa*) at Holetta and 2376 (*V. narbonensis*) at Ginchi had the longest pod length, while the shortest pod length was recorded for accession 2424 (*V. villosa*) at both locations. It was observed that vetch accessions with erect growth habit and early maturing have higher pod length than creeping growth type with an intermediate to late maturing dates. The number of seeds per pod for vetch species varied (P<0.05) significantly at both locations, which ranged from 3.9 to 7.0 with a mean of 4.8 at Holetta and from 4.3 to 7.4 with a mean of 5.2 at Ginchi (Table 6). *Vicia sativa* had significantly higher (P<0.05) number of seeds per pod at both locations.

Number of seeds per pod is highly related with pod length and seed size and hence the number of seeds per pod for most vetch species increased with increasing pod length. Though *Vicia narbonensis* had the longest pod length, the highest number of seeds per pod was obtained from *Vicia sativa*, because the seed size of *Vicia narbonensis* is larger than *Vicia sativa*. Among the accessions, the highest number of seeds per pod was recorded for 61039 (*V. sativa*), and the lowest for accession 2424 (*V. villosa*) at both locations. The early maturing vetch species and their accessions that are normally erect had larger seed size compared to other tested vetches.

In addition to this feature it was also found that these species had higher number of seeds per pod. Generally, early maturing species had the highest seed yield due to larger seed size and longer pod length compared to the other tested species. The seed yield of vetch species differed significantly (P<0.05) at Holetta, but not at Ginchi, which ranged from 0.4 to 0.8 t ha^{-1} with a mean of 0.6 t ha^{-1} at Holetta and from 2.0 to 2.9 t ha^{-1} with a mean of 2.4 t ha^{-1} at Ginchi (Table 6). The highest seed yield was obtained from *Vicia sativa* (0.8 t ha^{-1}) at Holetta and *Vicia narbonensis* (2.9 t ha^{-1}) at Ginchi, whereas the lowest yield was obtained from *Vicia narbonensis* (0.4 t ha^{-1}) at Holetta and *Vicia atropurpurea* (2.0 t ha^{-1}) at Ginchi. Seed yield also differed significantly (P<0.05) among the accessions of vetch at both locations (Table 7). At Holetta, accession 61094 (*V. sativa*) and 2387 (*V. narbonensis*) gave the highest and lowest seed yield respectively. The highest seed yield was obtained from accession 2380 (*V. narbonensis*), whereas the lowest from accession 61039 (*V. sativa*) at Ginchi.Thousand seed weight of vetch species showed a significant (P<0.05) difference at both locations, which ranged from 44.1 to 222.8 g with a mean of 81.7 g at Holetta and from 42.5 to 242.2 g with a mean of 86.3 g at Ginchi (Table 6). The highest thousand seed weight was recorded for *Vicia narbonensis* at both locations, whereas the lowest for *Vicia dasycarpa* and *Vicia villosa* at Holetta and Ginchi respectively. Though *Vicia narbonensis* had the highest thousand seed weight, its seed yield was relatively lower due to lower establishment performance at Holetta. Unless the establishment performance is poor, species with high thousand seed weight has higher seed yield. Getnet *et al.,* (2003) and Fekede (2004) also reported that most of the oats varieties with high grain yield showed higher 1000 kernel weight. In general, vetch species (*V. narbonensis* and *V. sativa*) which have erect growth habit and early maturing had comparatively higher thousand seed weight than creeping growth habit and intermediate to late maturing vetch species. Similarly, the vetch accessions varied significantly (P<0.05) in thousand seed weight at both locations (Table 7). The highest thousand seed weight was recorded for accession 2376 (*V. narbonensis*), whereas the lowest was recorded for accession 61039 (*V. sativa*) at both locations. The difference could be due to the inherent variation in seed size complemented with the environmental and soil conditions. This agronomic trait is important for seed rate determination of vetch species. Fekede (2004) also reported that thousand seed weight has got practical significance in estimating seeding rate for each oat variety in order to ensure that equal number of seeds could be sown per unit area.

Correlations of observed traits

When one selects varieties for certain desired trait, there is a need to consider the relationships between various production traits to select varieties with most of the traits compromised (Getnet *et al.,* 2003). They also reported that this general relationships help to identify varieties that best fits to a specific purpose, with a reasonable forage yield, better quality and overall efficiency utilization. The linear correlation coefficients between quantitative traits were estimated for different accessions of vetch species. Correlations between agro-morphological traits are illustrated in Table 8. The result showed that grain filling period was significantly (P<0.01) and positively correlated with number of pods per plant (r= 0.68). It was also significantly and negatively correlated with pod length (r= -0.68; P<0.01), number of seeds per pod (r= -0.61; P<0.01), but non-significant with grain sink filling rate (r= -0.22), thousand seed weight (r= -0.39), and seed yield (r= -0.03). Grain sink filling rate showed a significant positive correlation with pod length (r= 0.57; P<0.01), seed yield (r= 0.96; P<0.001), and non-significant with number of seeds per pod (r= 0.31), and thousand seed weight (r= 0.43), but a significant inverse relation with number of pods per plant (r= -0.49; P<0.05). Generally, grain filling period inversely related with grain sink filling rate and late maturing accessions and varieties had negative effect on seed yield and its related performance but positive effect on number of pods per plant due to higher number of branches or tillers. Number of pods per plant was significantly and negatively correlated with pod length (r= -0.96; P<0.001), number of seeds per pod (r= -0.66; P<0.001), thousand seed weight (r= -0.66; P<0.01) and had non-significant negative correlation with seed yield (r= -0.27). Pod length was significantly (P<0.01) and positively correlated with number of seeds per pod (r= 0.74), and thousand seed weight (r= 0.58), but not significantly correlated with seed yield (r= 0.39). Number of seeds per pod was not significantly and positively correlated with seed yield (r= 0.24), and negatively correlated with thousand seed weight (r= -0.08).

Conclusions

The seed yield and its related performance were highly influenced by environment and hence comparatively higher seed yield and its related performance were recorded at Ginchi than Holetta. *Vicia narbonensis*, *Vicia sativa*, and *Vicia dasycarpa* should be grown at Holetta for seed production due to earliness to escape frost months, however, all vetch species should be grown for seed purpose at Ginchi. Early maturing vetch species had comparatively shorter grain filling period and higher grain sink filling rate than intermediate to late maturing species. Frost is one of the major forage seed yields reducing factor in the highlands of Ethiopia. Early maturing species had the advantage to escape the coolest period in the area. The highest number of pods per plant was obtained from *Vicia villosa* (85.3) at Holetta and *Vicia dasycarpa* (159.1) at Ginchi, whereas *Vicia narbonensis* had the lowest (7.6 and 30.6) at Holetta and Ginchi respectively. The highest pod length was obtained from *Vicia narbonensis* (5.4 and 5.5 cm), and *Vicia sativa* (7.0 and 7.4) gave the highest number of seeds per pod at Holetta and Ginchi respectively. *Vicia sativa* (0.8 t ha^{-1}) and *Vicia narbonensis* (2.9 t ha^{-1}) gave the highest seed yield at Holetta and Ginchi respectively. The highest thousand seed weight was recorded for *Vicia narbonensis* (222.8 and 242.2 g) at Holetta and Ginchi respectively, whereas the lowest for *Vicia dasycarpa* (44.1 g) and *Vicia villosa* (42.5 g) at Holetta and Ginchi respectively.

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