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Evaluation of Dry Peas (*Pisum sativum* L.) Varieties for Seedling Vigor Indices in Eastern Montana

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ABSTRACT

Genetic and environmental factors lead to a variation in yield and protein content of dry pea (*Pisum sativum* L.) seeds. The quality of seed, particularly seed vigor, also influences the establishment of crop and thus final grain yield. The area and production for dry peas are increasing in the Northern Great Plains but knowledge is lacking on how the pea lines/varieties differ in the seed vigor at seven leaf stage. This field and greenhouse study evaluated the eight dry pea lines/varieties for seedling vigor indices and correlated them with grain yield and protein concentrations. Significant differences were observed among the lines/varieties for nodule number plant^{-1} in greenhouse, and grain yield in field conditions. The highest number of nodules plant^{-1} was obtained with the line MT632, which were at par with lines MT457, and MT190. The highest Vigor Index I was achieved with line MT632 associated with their more shoot lengths as compared to other lines/varieties. The highest Vigor Index II was obtained by variety Majoret and line MT632. The variety DS Admiral yielded 5205 kg ha^{-1}, which was 17.4 and 33.3% higher than lines MT460 and MT190, respectively. The highest seed protein content was obtained with variety Majoret (23.4%) having highest Vigor Index II and seed yield (4940 kg ha^{-1}) at par with variety DS Admiral. The lowest seed protein was found with variety DS Admiral (20.3%). The line named MT190 showed lowest yield potential along with the lower protein contents also. Studies show a positive and significant correlation between biomass and Vigor Index I only. Plant nitrogen uptake was positively and significantly correlated with biomass and Vigor Index I in greenhouse only. The results also indicated that seed vigor indices did not reveal any significant correlations with dry peas yield and protein content, so more efforts are needed to evaluate varieties for higher yield and protein content during initial stages of growth in order to maximize their acreage and productivity.

Introduction

To increase profitability and sustainability of agriculture, the crop diversification plays an important role (Hatfield and Karlen 1994). Earlier studies (Chen et al. 2012; Miller et al. 2002) have shown that pulse crops can play a much greater role for diversifying wheat-based cropping systems in the Northern Great Plains (NGP) and at present, pea is increasingly being rotated with wheat crop in Montana (Miller et al. 2015). Moreover, new market opportunities and processing facilities have encouraged farmers to increase the area sown to adapted legumes. For instance, in Montana, the dry pea production area is increasing and has reached to 240,000 ha in 2015, placing the state the top dry pea producer in the USA (USDA-NASS 2016). Legumes play an important role in improving the soil fertility in the rotation systems with cereal crops, by fixing the atmospheric nitrogen and thus adding to the pool of soil nitrogen and improve the yields of cereal crops (Chalk et al. 1993; Herridge et al. 1995).

Pulses also play an important role in the diet of most of the people in the world. Dry peas are the second most important food legume grown worldwide after common beans (*Phaseolus vulgar*is L.) (Tar'an et al. 2004; Wang and Daun 2004). Among legume crops, dry peas apart from soybeans and lentils provide high nutritional value resulted from a well-balanced amino acid composition of the protein and relatively low content of antinutrients (Borowska, Zadernowski, and Konopka 1996). Due to the rich source of protein, peas are also grown for hay, pasture, or silage production, either alone or mixed with cereals, in different parts of the world (Chen et al. 2004; Mckenzie and Spooner 1999).

Earlier studies (Robertson et al. 1962; Eppendorfer and Bille 1974; McLean et al. 1974; Wang and Daun 2004; Nikolopoulou et al. 2007; Wang et al. 2010) have shown that the yield and protein content of dry peas vary with environmental and genetic factors. Genotypes respond to changes in environmental conditions such as temperature, rainfall, soil type, and moisture (Falconer and Mackay 1995; Acikgoz et al. 2009).

An interaction between seedbed environment and quality of seed also influences the establishment of crop and final yield (Khajeh-Hosseini, Powell, and Bingham 2003). Powell et al. (1984) also found that differences in vigor levels of seed lots lead to differences in crop establishment and yield, especially in grain legumes. Atak et al. (2008) found a significant difference in seed vigor of three dry pea genotypes cvs. "Rondo," "Carina," and "Jof" with each genotype producing a mixture of light (L), medium (M), and dark (D) green seed at maturity.

The major determinant of seed quality, particularly seed vigor is an environment experienced by plants during seed development (Delouche 1980). Seed vigor is an important seed quality factor, which describes the potential of seed for rapid and uniform emergence and the development of normal seedlings under a wide range of field conditions (Perry 1987). Seed vigor is an interaction of characteristics, which can be considered as an independent attributes of physiological potential such as speed of germination, seedling growth, ability to germinate above or below optimal temperatures, and other aspects of tolerance to stresses (Marcos-Filho 2015). A vigorous seed lot is one that is potentially able to perform well under not optimal environmental conditions for the species (ISTA 2014). Vigorous seeds are usually expected to recover from the stress conditions often found in the fields and can result in high crop productivity. Many factors such as seed size, seed maturity, genetic constraints, and growth conditions of the mother plant can cause the differences in seed vigor (ISTA 1995). The rapid and uniform emergence of vigorous seedlings of the desired variety is important to ensure high plant performance that finally affects uniformity of development, competition against weeds, yield, and quality of the harvested product. Dias et al. (2010) found that vigor of seed is directly related to initial crop growth and affects plant competitive ability against weeds with their inferior growth rates.

Seed vigor is the combination of characteristics that determine the potential of seed for high performance after seeding (Marcos-Filho 2015). The various techniques that are used for assessment of seed vigor in different crops are accelerated aging (Helmer, Delouche, and Lienhard 1962), cold test (Caseiro and Marcos-Filho 2000), electrical conductivity (Matthews and Bradnock 1967), tetrazolium (Bhéring et al. 1999; Bittencourt and Vieira 1999), automated computer imaging (Chiquito, Gomes-Junior, and Marcos-Filho 2012), and tests that evaluate seedling growth (Matthews and Khajeh-Hosseini 2007). The tests that are based on seedling performance includes first count of the germination, speed of germination or seedling emergence, growth of the seedling (length or dry weight), seedling vigor classification, and more recently the emergence rate of the primary root (Marcos-Filho 2015).

Seed yield and protein content vary among different legume crop varieties. Mohammed et al. (2016) found that an average grain yield among dry pea genotypes varied from 2243 to 2680 kg ha^{-1} in Montana. Ali-Khan and Youngs (1973) found significant differences in pea protein content, which varied among cultivars, locations, and years and reported that an average protein content among cultivars varied from 23.1 to 28.3%, among locations from 24.0 to 26.3%, and among years from 25.8 to 27.4%. So, the need exists for a test which would give a better indication of the growth, yield, and harvest quality of different dry pea lines/varieties that is not detected by viability tests and rank the lines/varieties according to their seed protein content and also yield potential. The basic objective of seed vigor testing is to provide a precise identification among different dry pea lines/varieties, mostly with those of similar germination percentage, with higher protein concentration and yields. The effects of garden pea seed vigor on field establishment are well studied (Bedford 1974; Perry 1967, 1969, 1970; Scott and Close 1976a). However, evaluation of different field pea varieties for early growth and seedling vigor indices and how they correlate to agronomic parameters have not been assessed. We hypothesize that variation in field pea lines/varieties would result in significant differences in early growth, seedling vigor indices, thus causing a significant differences in the seed protein content and yield. Therefore, the objectives of this study were (1) to determine the differences of field pea lines/cultivars with regard to early growth, seedling vigor indices at seven-leaf stage in greenhouse, (2) to find the relationship of these results with the field seed protein content, and yield, and (3) to find the correlation of seedling vigor indices observed in greenhouse and incubation studies with field studies.

Materials and methods

A field experiment was conducted at the Eastern Agricultural Research Center (EARC), Montana State University in Sidney, Montana (47° 40′ N, 104°08′ W; 670 m elevation). The soil at the experiment site is a deep, well drained, nearly level Savage clay loam (fine, smectitic, frigid Vertic Argiustolls) formed in alluvium parent material (www.ftw.nrcs.usda.gov) with the following characteristics: 3.8% organic matter; pH of 8.0; 125.9 kg ha^{-1} nitrate-nitrogen; 24.3 mg kg^{-1} Olsen phosphorus; 43.7 mg kg^{-1} sulfate sulfur; and 440 mg kg^{-1} potassium. Weather parameters, including cumulative precipitation and average temperature during growing season, are shown in Table 1. Crops were irrigated with sprinkler irrigation and total amount of 381 mm of water was applied throughout the crop season with irrigation system. No fertilizers were applied prior to crop seeding. Treatments included were eight lines/varieties of field peas, named as Delta, DS Admiral, Majoret, Cruiser, MT632, MT460, MT457, and MT190 and conducted on a randomized complete block design with four replications. The plot size was 5.6 m^2 and the spacing between the rows was kept at 0.30 m. Seeds were sown on April 21, 2016 at a rate of 86 seeds m^{-2} and drilled at a depth of 0.05 m. Commercial peat powder rhizobia inoculant named BioSinc (Timac Agro, PA, USA) was applied to seed prior to planting. Seeds were pretreated with fludioxinyl and mefenoxam fungicide (Apron Maxx® RTA, Syngenta, Greensboro, NC) at a rate of 3.25 mL a.i. kg seed^{-1} and thiamethoxam insecticide (Cruiser MAXX®, Syngenta, Basel, Switzerland) at a rate of 1.0 mL a.i. kg seed^{-1} to control soil-borne diseases and pea leaf weevil infestation, respectively, before seed treatment with rhizobium inoculant. After physiological maturity, the plots were harvested on July 29, 2016 using a small plot combine. Seeds were weighed for each plot after harvest for yield determination. The grain yield was adjusted to 13% moisture content prior to statistical analysis. The grain protein concentration was also estimated simultaneously using Infratec™ 1241 grain analyzer (FOSS Analytical AB, Sweden).

A small sample of seed that was used for the field study was collected from each variety/genotype for a greenhouse study. The greenhouse study was conducted at EARC Research and Education Greenhouse of Montana State University. The experimental pots (21.5 cm diameter and 22 cm high) were filled with about 6 kg of sieved soil (2 mm sieve) collected from top 15 cm soil depth of the same field for the above-mentioned field study and experiment was conducted on a randomized complete block design with six replications, making total of 48 experimental units. Seeds were sown in August 2016 as 10 seeds/pot planted to a depth of about 3 cm. Commercial peat powder rhizobia inoculant and

Table 1. Cumulative monthly air temperature and average monthly rainfall along with their long-term average during the dry peas growing season.

Month	Temperature (°F)		Rainfall (cm)	
	Monthly average	Long-term average	Monthly average	Long-term average
May	55.9	56.1	5.23	5.51
June	63.5	64.5	3.56	7.01
July	67.6	70.0	6.91	5.33
August	67.5	68.7	1.96	3.73
September	66.6	57.8	6.78	3.23

seed treatment are the same as field study. The pots were watered uniformly to ensure good germination and establishment. All experimental pots received equal amount of water throughout the experimental time period to ensure only variety to be the variable factor. The greenhouse conditions were set at 16 h light/8 h dark period, temperature 21°C/18°C (day/night), and relative humidity 50 ± 5% throughout the experimental period.

Ten days after seeding, plants in each pot were counted to determine the seedling emergence and then at seven leaf stage, the plants were harvested to do early growth measurement and seedling vigor indices. Each plant in a single pot was uprooted carefully and washed to measure the number of nodules plant^{-1}, shoot height, root height, and biomass of root and shoot after drying them at 65°C for 4 days. The total fresh weight of nodules was also measured for all established plants/pot. The dried above and below-ground biomass samples were ground to pass through a 1-mm mesh screen and then analyzed for total N (Dumas method using LECO TruSpec CN, Henderson, NV) (Sweeney 1989). The N uptake (g/pot) was calculated by (multiplying the N concentration with the dry matter)/100.

In addition to the greenhouse study, the same set of seeds was also tested in an incubator for vigor. In the incubator, 15 seeds/variety or line in replication of four were kept moist on germination trays for 8 days at 30°C to measure the seedling vigor characteristics, i.e., length (cm) of the seedling (radicle and plumule), and dry weights (g) of seedling (radicle and plumule) after drying at 65°C. Ten seedlings were randomly taken to measure these characteristics.

Seedling vigor indices for greenhouse and incubation studies were calculated using following formula (1, 2) (Abdul-Baki and Anderson 1973) as

$$\text{Vigor Index I} = \text{Germination\%} \times \text{seedling length} \tag{1}$$

$$\text{Vigor Index II} = \text{Germination\%} \times \text{seedling dry weight} \tag{2}$$

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using Proc Mixed of SAS (SAS 2001). Means were separated using Fisher's LSD test at $p < 0.05$ after ANOVA gave significant F-values. Pearson correlation coefficients between pairs were determined using same data values.

Results and discussion

Field study

Yield of different lines/varieties varies from 3905–5205 kg ha^{-1} with a mean value of 4745 kg ha^{-1}. A significant difference was observed among different lines/varieties based upon grain yield (Table 2). The variety DS Admiral yielded significantly higher (5205 kg ha^{-1}) as compared to lines MT460 and MT190 ($p = 0.0286$). The yield of DS Admiral was 17.4 and 33.3% higher as compared to these two lines, i.e., MT460 and MT190, respectively. Similarly, Mohammed et al. (2016) reported that dry pea varieties Montech 4152 followed by SW Midas and DS Admiral showed combination of better yield performance and stability in a diverse range of environments in temperate semi-arid climates. They found that the highest mean yield (5627 kg ha^{-1}) was recorded for variety DS Admiral at Creston, Montana and the lowest mean yield (978 kg ha^{-1}) was recorded for Cruiser at Bozeman, Montana.

In contrast to yield, seed protein content (grain nitrogen content multiplied by a factor of 6.25) for various pea lines/varieties varies from 20.3 to 23.4%, but they were not significantly different ($p = 0.3450$, Table 2), with a mean value of 21.9%. The highest seed protein content was obtained with variety Majoret, while lowest was achieved with highest yielding variety DS Admiral. The results also showed that variety Majoret has higher yield potential (4940 kg ha^{-1}) similar to DS Admiral, along with highest protein content (23.4%). Atta et al. (2004a) reported that protein content varies significantly between nodes of different genotypes, indicating genetic variability for this variation in protein content, which could be attributed to the difference between genotypes in the ability to maintain nitrogen fixation

Table 2. Evaluation of different field pea varieties/lines for early growth and vigor indices in greenhouse and field conditions.

Line/Variety	Nodule no./ plant	Nodule fresh wt.(g)	Above-ground Biomass/plant (g)	Below-ground biomass/plant (g)	Root length (cm)	Shoot length (cm)	Total biomass/ pot (g)	Total N uptake/pot (g/pot)	Vigor index I	Vigor index II	Yield (kg/ha)	Protein content (%)
MT632	13.53	0.149	1.30	0.65	18.58	26.04	18.6	0.730	4322	188.4	4602	22.8
MT460	8.11	0.139	1.40	0.80	20.76	19.21	17.8	0.675	3442	185.2	4433	22.1
MT457	10.74	0.098	1.34	0.67	18.67	23.48	18.1	0.689	3842	183.2	5010	21.7
Delta	7.85	0.080	1.36	0.68	18.32	20.69	17.5	0.700	3354	174.0	4879	23.1
DS Admiral	7.77	0.094	1.36	0.84	17.79	20.08	17.2	0.655	3244	183.5	5205	20.3
Majoret	6.23	0.051	1.36	0.89	17.79	21.08	17.3	0.711	3290	189.1	4940	23.4
Cruiser	8.60	0.152	1.45	0.84	21.14	19.66	17.1	0.631	3321	180.7	4728	21.2
MT190	12.88	0.138	1.48	0.69	21.34	22.51	18.1	0.768	3627	178.4	3905	20.5
Mean	9.46	0.112	1.38	0.76	19.30	21.59	17.7	0.692	3555	182.8	4745	21.9
p Value	**0.0201**	0.235	0.8443	0.2940	0.2583	0.2758	0.1716	0.2532	0.1842	0.6691	**0.0286**	0.3450
LSD	4.54	NS	NS	NS	NS	NS	NS	NS	NS	NS	684	NS

Bold values represent significant values at $p < 0.05$.

during the onset of seed filling. In addition, changes in seed nitrogen concentrations were mainly caused by variations in the seed nitrogen accumulation rates and also dependent on availability of nitrogen within the plant, transfer of nitrogen from the vegetative components of the plant (Pate et al. 1977; Cox, Qualset, and Rains 1985a; Lhuillier-Sondélé et al. 1999b; Salon et al. 2001; Atta et al. 2004b). Yoneyama and Ishizuka (1982) found that during seed filling period, symbiotically fixed nitrogen is preferentially transferred to growing seeds while mineral N (nitrogen) is equally distributed between seeds and mature vegetative organs. It has also been shown that total N varies within plants and with location and year (Ali-Khan and Youngs 1973), with maturity (Pandey and Gritton 1975). Grain nitrogen or grain protein concentrations are dependent not only on grain nitrogen content but also on grain carbohydrate content (Cataldo et al. 1975b). High protein concentrations in seeds were found not to be related to higher protein accumulations, but rather to low carbohydrate levels in seeds (Singhal, Srivastava, and Mehta 1989); water deficit and high temperature are also associated with low seed yield and elevated protein content in peas (Stoddard and Marshall 1990).

Greenhouse studies

The field pea varieties/lines showed a significant difference in number of nodules plant^{-1} (p = 0.0201) (Table 2). The highest number of nodules plant^{-1} was obtained with the line MT632 (14), which were at par with lines MT457 (11) and MT190 (13). No significant differences were observed among different pea lines/varieties for nodule fresh weight. The mean fresh weight of nodules was 0.105 g. Similarly to the nodule fresh weight, no significant differences were observed for above and below ground biomass plant^{-1}, root, and shoot heights among different pea lines/varieties. An average above and below ground biomass weights were 1.38, and 0.76 g, respectively. An average root and shoot length of all lines/varieties were found to be 19.3, and 21.6 cm, respectively.

Similarly to the above and below ground biomass plant^{-1}, no significant differences were observed in total dried biomass pot^{-1} (P = 0.1716), with mean biomass of 17.7 g pot^{-1}. Total plant N uptake pot^{-1} did not differ significantly among different dry pea lines/varieties, the lines MT632 and MT190 show the highest N uptake (0.730, and 0.768 g pot^{-1}, respectively) resulted from the more biomass accumulation with longer root and shoot heights. Vigor Indices I and II also did not show any significant difference (Table 2). However, the highest Vigor Index I was achieved with line MT632 accompanied with more shoot length (26.0 cm) as compared to other lines/varieties. The highest Vigor Index II was obtained with variety Majoret and line MT632, which were resulted from their high germination rates, and biomass respectively. This shows that other than plant heights and biomass, seedling emergence has huge impacts on vigor indices. Taweekul et al. (1998) found a marked difference in seedling emergence among seed lots of two field pea cultivars Beacon and Whero resulted in 54–60% less total dry matter and a 57–68% seed yield reduction. Earlier research (Egli and Burris 1971; Egli and TeKrony 1979; Hampton and Scott 1982) also reported reductions in seed yield from planting of low vigor seed resulted from lower plant populations. Moreover, the varieties with higher seed vigor indices resulted from more seedling emergence; biomass production can provide a better competition to weeds and can improve the grain yield. Dias et al. (2011) found that plants developed from high and intermediate seed vigor gave the best results against weeds competition by reducing weed dry mass accumulation and gave higher yields.

Incubation studies

In line with greenhouse experiment, the longest shoot length was observed with the line MT632 (3.20 cm) (p < 0.0001), and variety Cruiser had the shortest shoot length of 0.92 cm (Table 3). An average shoot length was 2.15 cm after 8 days of incubation. In contrast to greenhouse experiment, a significant difference was observed in below-ground (root) lengths (p = 0.0048) (Table 3). Line MT457 showed significantly longest root length (11.28 cm) as compared to other lines/varieties. Variety DS Admiral has shortest root length of 7.02 cm. An average root length observed in incubator was 8.93 cm. A significant difference was also observed among lines/varieties for total biomass (p < 0.0001). Highest

Table 3. Evaluation of different pea varieties/lines for vigor indices in incubator.

Line/Variety	Shoot length (cm)	Root length (cm)	Biomass/seedling (g)	Total biomass (g)	Vigor index I	Vigor index II
MT632	3.20	9.07	0.449	4.49	1202	44.03
MT460	2.31	9.20	0.483	4.83	1128	47.34
MT457	2.35	11.28	0.462	4.62	1335	45.29
Delta	1.19	9.33	0.449	4.49	1052	44.87
DS Admiral	2.45	7.02	0.494	4.81	946	49.37
Majoret	2.65	7.57	0.462	4.62	981	44.40
Cruiser	0.92	9.19	0.490	4.21	971	47.04
MT190	2.11	8.82	0.471	4.71	1093	47.13
Mean	2.15	8.93	0.470	4.63	1089	46.2
p-Value	**<0.0001**	**0.0048**	0.1086	**<0.0001**	0.0525	0.0628
LSD	0.82	1.71	NS	0.152	NS	NS

Bold values represent significant values at $p < 0.05$

biomass was observed with line MT460 (4.83 g) and highest yielding variety DS Admiral (4.81 g). In line with the greenhouse experiment, no significant differences were observed among different lines/varieties for Vigor Indices I and II.

Correlations between seed vigor indices and other parameters

A significant and positive correlation was observed among greenhouse and incubation studies for biomass weights per seedling or plant ($r = 0.46$, $p = 0.0030$) and Vigor index I ($r = 0.41$, $p = 0.0089$). However, no significant correlation for Vigor Index II was observed between greenhouse and incubation studies ($r = 0.11$, $p = 0.489$). Further, in greenhouse studies, correlation analysis was done to find relationship between different variables such as biomass, vigor indices, with yield and seed protein content obtained from field experiment (Table 4). The data showed that a positive and significant correlation ($r = 0.846$, $p < 0.0001$) was observed between total biomass and Vigor Index I. Total N uptake showed a positive and significant correlation with total biomass and Vigor Index I. As plant N uptake is the product of biomass with plant N concentration, indicating that the capacity of a plant for N accumulation was substantially influenced by dry matter. Takeda and Frey (1979) observed that the plants with greater dry matter have a greater grain yield per plant, as total plant dry matter is one of the factors determining grain yield. Results also showed that the correlation of both Vigor Indices to plant N

Table 4. Pearson correlation coefficients and p-values (in parenthesis) showing the association between selected measured parameters and level of significance for the dry pea lines/varieties for studies done in greenhouse and field studies.

	Pearson correlation coefficient Prob > |r| under H0: Rho = 0						
Variables	Total biomass	Vigor I	Vigor II	Total N uptake	Protein content	Yield	Total protein
Total biomass	-	-	-	-	-	-	-
Vigor I	0.846 (**<0.0001**)	-	-	-	-	-	-
Vigor II	0.245 (0.0937)	0.190 (0.1956)	-	-	-	-	-
Total N uptake	0.374 (**0.0348**)	0.481 (**0.0053**)	−0.548 (**0.0012**)	-	-	-	-
Protein content	−0.123 (0.5338)	−0.117 (0.5517)	0.077 (0.6973)	0.058 (0.7689)	-	-	-
Yield	0.081 (0.6824)	0.232 (0.2340)	0.268 (0.1672)	−0.267 (0.1703)	−0.062 (0.7529)	-	-
Total protein	−0.030 (0.8785)	0.098 (0.6198)	0.260 (0.1810)	−0.157 (0.4253)	0.653 (**0.0002**)	0.714 (**<0.0001**)	-

Total biomass, Vigor Indices, and total N uptake were obtained from greenhouse.
Protein content, yield, and total protein were obtained from field.
Bold values represent significant values at $p < 0.05$.

Table 5. Pearson correlation coefficients and *p*-values (in parenthesis) showing the association between selected measured parameters and level of significance for the dry pea lines/varieties for studies done in incubator and field studies.

	Pearson correlation coefficient Prob > |r| under H0: Rho = 0					
Variables	Total biomass	Vigor I	Vigor II	Protein content	Yield	Total protein
Total biomass	-	-	-	-	-	-
Vigor I	0.016 (0.8973)	-	-	-	-	-
Vigor II	0.073 (0.5641)	−0.166 (0.1898)	-	-	-	-
Protein content	−0.119 (0.3808)	−0.115 (0.3991)	−0.226 (0.0944)	-	-	-
Yield	−0.077 (0.5723)	−0.103 (0.4505)	−0.082 (0.5459)	−0.062 (0.6484)	-	-
Total protein	−0.134 (0.3243)	−0.170 (0.2117)	−0.215 (0.1112)	0.653 (**<0.0001**)	0.714 (**<0.0001**)	-

Total biomass, Vigor Indices, and total N uptake were obtained from greenhouse.
Protein content, yield, and total protein were obtained from field.
Bold values represent significant values at $p < 0.05$.

uptake is significant and contrasting. Vigor Index I had a positive correlation while vigor Index II had a negative correlation with total N uptake by all plants in a pot.

A comparison of seed yield and protein content observed in field with agronomic parameters of dry pea lines/varieties observed in greenhouse and incubation studies did not reveal any significant correlations (Table 4 and 5). The correlation between grain yield and protein content was also observed to be non-significant ($r = -0.062$, $p = 0.6484$). Al-Karaki and Ereifej (1999) also observed a negative correlation between pea seed yield and seed protein concentrations and found that seeds of the variety Praire No. 11 had the highest protein concentration among other cultivars, and it produced the lowest seed yield. Ali-Khan and Youngs (1973) also found non-significant correlation between field pea seed protein content and yield and mentioned that selection for high protein should not be accompanied by deleterious effects on the other characters. Henry, Slinkard, and Hogg (1995) also demonstrated that the protein content of pea seeds decreases as seed yields increase. Total protein (product of yield and protein concentration) showed a positive significant correlation with yield ($p < 0.0001$) and protein content ($p = 0.0002$).

Conclusions

The dry pea lines/varieties differ significantly in nodule numbers and grain yield only. The variety DS Admiral, with the lowest protein content, showed the highest yield potential; however, the line MT190, with similar protein content, had the lowest yield potential. Also, variety Majoret has higher yield potential (at par with DS Admiral) along with highest protein content (23.4%), showing that yield and seed protein content varied among genotypes and did not show any correlation between yield and protein content. Correlation analysis also showed non-significant relation between yield and seed protein content. Studies showed a positive and significant correlation between biomass and Vigor Index I in greenhouse only. The results of the current study indicated that Vigor Indices obtained in greenhouse and incubation studies did not reveal any significant relationship with seed yield and protein content obtained in the field, indicating that more efforts are needed to evaluate the different lines/varieties for higher yield potential and protein content at the earlier stages of growth.

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