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Using an "Index of Merit" to Evaluate Winterhardy Pea Lines

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Abstract

Winter feed pea (*Pisum sativum* ssp. arvense) might serve as a partial or complete replacement for fallow in the winter wheat-summer fallow (WW-SF) system with potential to integrate cereal and livestock production in the Central Great Plains (CGP). The objective of this study was to evaluate advanced winter pea lines bred in the Wyoming environment in comparison with existing winter feed pea cultivars that were bred elsewhere. Six elite lines, one a blend of two lines, and three check cultivars were compared for overall merit, based on yield for forage and seed, and in two different production systems, dryland and irrigated, and at two locations (Lingle WY and Laramie WY) during the 2010-2011 and 2011-2012 growing seasons. Indices of merit, calculated in two ways: a mean-adjusted index and a standardized index, were used to simultaneously evaluate lines/cultivars for forage and seed yield. Based on the results from both indices, five Wyoming-bred elite lines (one a blend of two lines) ranked in the top five lines of 10 lines/cultivars tested. Importantly, three Wyoming-bred lines (Wyo#11, Wyo#11 +Wyo#13, and Wyo#13) all ranked significantly higher for overall merit than any existing winter feed pea cultivar tested in this study: 'Common', 'Specter' and 'Windham'. Because four measures of merit in the both indices are positively correlated no serious compromises or "trade-offs" are manifested among these four traits. This research shows that winter pea has potential value for forage and seed yield, mostly depending on growing season precipitation in the CGP.

Keywords: index of merit, selection, winter pea, breeding, yield, dryland farming

1. Introduction

Plant breeders usually consider selecting multiple traits in their crop improvement programs. New cultivars of a crop should perform similar to or better than existing cultivars to be acceptable by growers. Breeders may use one of the three methods of tandem selection, independent culling, and index selection to simultaneously select several traits (Hazel & Lush, 1943; Luby & Shaw, 2008; Acquaah, 2012).

An "index of merit" is essentially a "selection index", as originally defined by Smith (1936) which has been used widely by breeders, and which can take many forms (Simmonds & Smartt, 1999; Sleper & Poehlman, 2006; Acquaah, 2012). Hazel and Lush (1943) showed that selection for a total score or index of net desirability is much more effective than selection for one trait at a time.

Brown and Caligari (2008) state that "in almost all studies carried out it has been shown that index selection is more effective in identifying genotypes that are 'superior' for many different traits" in contrast to alternative methods such as tandem selection or independent culling. Acquaah (2012) notes that it is often the case that using the concept of "selection on total merit, the breeder would make certain compromises, selecting individuals [or in this study lines/cultivars] that may not have been selected if the choice was based on a single trait." Acquaah (2012) goes on to say that "An index by itself is meaningless, unless it is used in comparing several individuals [or in this study lines/cultivars] on a relative basis." A classic selection index takes the form

$$I = b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_n x_n \quad (1)$$

Where, x_1, x_2, x_3, to x_n are the phenotypic performance for each line/cultivar for *n* traits of interest, and where b_1, b_2, b_3, to b_n are relative weights attached to the respective traits. Weights are often the respective relative economic importance of each trait. Acquaah (2012) refers to this as a "basic index" which is an additive index that may be used in cultivar assessment in registration trials. Brown and Caligara (2008) note that multiplicative selection indices are also possible, but they provide no examples of the use of such indices in plant breeding.

Jost et al. (2012) evaluated the effectiveness of selection indices (classic, base, parameters and weight free, based on desired gains, multiplicative, and rank sum) for the identification of inbred common bean lines with higher grain yield, desirable morphological and phenological traits, and better nutritional quality traits. They concluded that the classical, base and multiplicative indices provided superior genetic progress in the selection of inbred common bean lines. In this study, we consider only additive selection indices, which can be directly analyzed without transformation as linear additive models (LAM) of merit for yield via analysis of variance (ANOVA).

Sometimes, when different traits are measured with different units, or when the variance for different traits varies among lines/cultivars (i.e., heteroskedasticity), a selection index may be based on standardized measures of components of merit (Acquaah, 2012). Sleper and Poehlman (2006), in their discussion of "selection index", emphasize that the procedure often necessitates making "personal judgments" on the value to assign to each trait.

Simmonds and Smartt (1999) note that detailed economic analysis is seldom performed and that plant breeders often use an "intuitive selection index" over the course of a breeding program. These authors also discuss how "Index equations may be constructed on a purely economic basis or on a genetical one or on both". They note that a "genetic selection index" often starts from the assumption that characters are equally important and need no economic weighting (or, in other words, are weighted equally). That is the approach taken in this study.

The "intuitive selection index" of Simmonds and Smartt (1999) is related to the "concept of general worth" discussed by Acquaah (2012), where "a number of traits, which considered together, define the overall desirability of the cultivar" and where "yield of the economic product is almost universally the top priority." In this study, we focus on yield of forage and seed, and in dryland and irrigated systems.

Although all four yield traits, forage dryland (FD), forage irrigated (FI), seed dryland (SD), and seed irrigated (SI), were expressed in the same units, i.e., kg ha^{-1}, these can be considered distinctly different measures of merit (and specifically, yield) involving forage vs. seed, and dryland vs. irrigated, even if the underlying genetic basis for these traits is largely the same. Also, forage and seed yields were measured at different times, i.e., early summer for forage and mid-summer (at maturity) for seed.

Index selection may be used to test top ranking varieties in multiple environments before and after registration in order to assess their value for cultivation and use (Przystalski et al., 2008). The objective of this study was to identify the best lines/cultivars for dual use (forage vs. seed) in different production systems (dryland vs. irrigated, and where irrigated test may indicate potential maximal production in good years on dryland, when moisture is not limiting).

2. Materials and Methods

Diverse *arvense* genotypes were hybridized in the greenhouse, and natural and artificial selection began in an F_2 spaced-plant nursery. Selection continued among single plants within superior segregating families, and finally among bulked progenies of advanced lines, integrating elements of both pedigree selection and the bulk breeding method. As breeding populations were advanced from the F_2 through F_9 generations, the number of lines retained was reduced, as seed of elite, advanced lines was increased.

In the 2010-2011, and 2011-2012 winter annual growing seasons, seven Wyoming advanced breeding lines which were selected in the dryland WW-SF environment were evaluated together with three U.S. winter pea cultivars ('Common', 'Specter', and 'Windham', all from the Pacific Northwest) in Lingle (42°15′N, 104°20′W, elevation 1272 m), and Laramie, WY (41°18′N, 105°35′W, elevation 2184 m), under dryland and irrigated conditions in RCBD experiments. "Index of merit", related to "selection indices," was used to simultaneously evaluate the lines/cultivars for several traits including forage and seed yield.

The index of merit was calculated in two different ways; a "mean-adjusted index of merit" and "a standardized index of merit". In both cases, the indices of merit were based on relative measures of forage dryland (FD), forage irrigated (FI), seed dryland (SD), and seed irrigated (SI)), for the 10 lines/cultivars, and take this form,

$$I = .25x_{\mathrm{FD}} + .25x_{\mathrm{FI}} + .25x_{\mathrm{SD}} + .25x_{\mathrm{SI}} \quad (2)$$

Where, the four measures of relative yield were weighted equally and the relative phenotypic values were calculated from data summarized in Table 1, where means are for 10 lines/cultivars for each of the four traits.

For the "mean-adjusted index of merit," for each line/cultivar, and for each trait i, x_i is a relative deviation from the mean for all 10 lines/cultivars, and presented as a percentage. Thus for a given line/cultivar, for each trait the phenotypic value takes this form,

$$x_i = [(\text{value for trait for line} - \text{mean for all lines})/\text{mean for all lines}] \times 100\% \quad (3)$$

Calculated this way, the individual x_i values are positive and negative percent deviations from the overall mean for each trait, and the mean of x_i values is zero.

For the "standardized index of merit", for each line/cultivar, and for each trait i, x_i is a standardized deviation from the mean for all 10 lines/cultivars. Here the phenotypic value takes this form,

$$x_i = \text{(value for trait for line – mean for all lines)/standard deviation for all lines} \quad (4)$$

Calculated this way, the individual x_i values are positive and negative dimensionless deviations from the overall mean for each trait, and the mean of x_i values is 0, with a variance of 1, and is related to the Z-distribution in statistics, with deviations, x_i, normally distributed and where $\bar{x} = 0$ and $\sigma_x^2 = 1$ (Snedacor & Cochran, 1967; Acquaah, 2012).

Table 1. Four individual measures of merit for yield of winter peas for forage and seed under dryland and irrigated production systems

Lines/Cultivars	Forage DM yield (kg ha^{-1})		Seed yield (kg ha^{-1})	
	dryland	irrigated	dryland†	irrigated
Wyo #11	693.7 a ‡	2739.4 c	953.8 a	2248.8 b
Wyo#11+Wyo#13	588.1 c	2858.9 b	849.3 ab	2518.3 a
Wyo #13	561.6 c	2987.8 a	982.3 a	1853.3 d
Wyo #8	479.8 e	2501.6 d	819.2 ab	2517.8 a
Wyo #6	639.8 b	1983.3 h	764.3 abc	2049.3 c
Common	530.4 d	2146.6 f	708.3 bc	1863.6 d
Wyo #12	438.8 f	2215.1 e	538.2 d	1854.6 d
Specter	380.5 g	2257.8 e	624.0 c	1721.5 e
Windham	376.9 g	1759.7 i	780.5 abc	1621.3 f
Wyo #10	375.9 g	2095.7 g	622.0 c	1381.5 g
Mean	506.6	2354.6	764.2	1963.0

Note. †Results from only 2010-2011 growing season combined over two locations; ‡ Values followed by the same letter in a column are not significantly different (p = 0.05) based on LSD.

There is no *a priori* knowledge of how locally bred and adapted winter pea cultivars might be adopted by the CGP producers. It cannot be predicted to what extent they might be grown for forage vs. seed, or in dryland vs. irrigated production systems. Therefore, FD, FI, SD, and SI were weighted, in the indices of merit equally, $b_{FD} = b_{Fi} = b_{SD} = b_{SI} = 0.25$ (as per Acquaah, 2012, where relative economic values of different measures of phenotypes were not known, and were therefore weighted equally).

For both indices of merit, summary data for the 10 lines/cultivars, and for the four yield traits, were analyzed with one-way ANOVA, randomized complete block design (RCBD), where main effects were lines and traits (FD, FI, SD, and SI). Here, traits may also be considered blocks.

3. Results and Discussion

Means for all four traits, forage dryland (FD), forage irrigated (FI), seed dryland (SD), and seed irrigated (SI) for the 10 lines/cultivars, were summarized in Table 1. Measures of these traits were based on mean performance in randomized, replicated trials of lines/cultivars over two years and at two locations, except for SD, which was measured only in the first year because severe drought at both locations prevented seed production at both locations in the second year. For each of the four traits, 160 plots were established, 640 plots overall. Means are least-square means as determined by ANOVA.

Although all yield data in Table 1 were presented in the same units, kg ha^{-1}, the traits represent different plant products harvested at different times (forage vs. seed) and under different production systems (dryland vs. irrigated). Standard deviations for the four traits were highly correlated with means, r = .9944 (Prob = .0028, n = 4), a classic indication of heteroscedasticity, and a strong indication to adjust data relative to means ("mean-adjusted index of merit") or standard deviations ("standardized index of merit"), as suggested by Acquaah (2012).

3.1 Mean-Adjusted Index of Merit

For the "mean-adjusted index of merit", deviations from means for the four yield traits (FD, FI, SD, and SI) for the 10 lines/cultivars are presented in Table 2 in units of plus or minus 1000 kg ha^{-1}.

Table 2. Deviations from means for the four yield traits for 10 winter pea line/cultivars

Lines/Cultivars	Forage		Seed	
	Dryland	Irrigated	Dryland	Irrigated
Wyo #11	187.1	384.8	189.6	285.8
Wyo11+Wyo13	81.5	504.3	85.1	555.3
Wyo #13	55.1	633.2	218.1	109.7
Wyo #8	-26.8	147.0	55.0	554.9
Wyo #6	133.2	-371.3	0.1	86.3
Common	23.9	-208.0	-55.9	-99.4
Wyo #12	-67.7	-139.5	-226.0	-108.3
Specter	-126.0	-96.7	-140.2	-241.5
Windham	-129.7	-594.9	16.4	-341.7
Wyo #10	-130.6	-258.9	-142.2	-581.5
Mean	0.0	0.0	0.0	0.0
Std Dev.	114.5	402.2	144.6	373.0

The ANOVA for the "mean-adjusted index of merit" showed that nearly 70% of variation is due to lines/cultivars (Table 3), indicating that; overall, the primary source of the variation observed in this study is genetic. For the "mean-adjusted index of merit," relative deviations from means for the four yield traits (FD, FI, SD, and SI) for the 10 lines/cultivars were presented as an overall percentage mean deviation for each line/cultivar, together with mean separations (Figure 1).

Overall means for "mean-adjusted index of merit" of line/cultivars ranged from 23.16% (line Wyo #11, rank 1) down to -21.25% (line Wyo #10, rank 10; Figure 1). All check cultivars of winter pea ('Common', 'Specter', and 'Windham') ranked in the bottom five of ten lines/cultivars. Five Wyoming-bred elite lines (one a blend of two lines) ranked in the top five lines of 10 lines/cultivars tested. Importantly, three Wyoming-bred lines (Wyo #11, Wyo #11 + #13, and Wyo #13) all ranked significantly higher ($p = 0.05$) for overall merit than any existing winter feed pea cultivar tested in this study: 'Common', 'Specter' and 'Windham'. Five of the seven Wyoming bred and selected lines out-performed both of the Palouse-bred cultivars ('Specter' and 'Windham').

Table 3. Sums of squares (SS), mean squares (MS) and percent contribution to total sums of squares (%TSS) of analysis of variance for indices of merit

Source	Mean-adjusted index of merit					Standardized Index of Merit				
	df	SS	MS	Pr > F	%TSS	df	SS	MS	Pr > F	%TSS
Line	9	9532	1059	< .0001	69.58	9	25.22	2.80	< .0001	70.07
Error	30	4167	139		30.42	30	10.77	0.40		29.93
Total	39	13699				39	35.99			

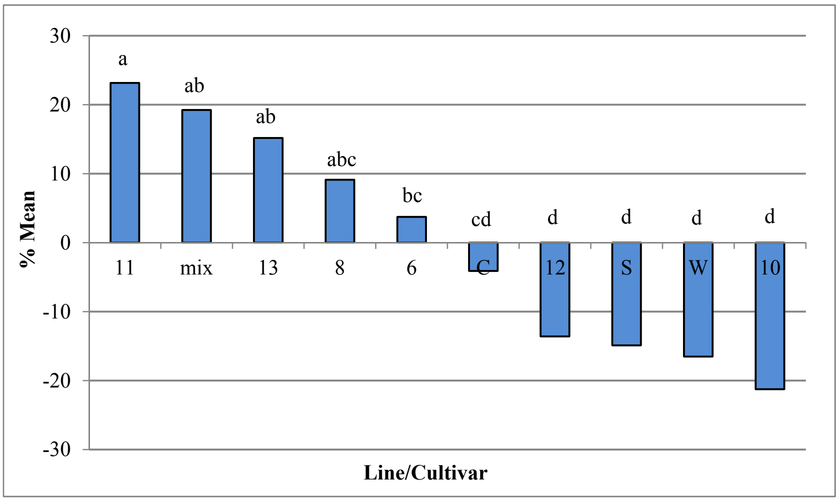

Figure 1. Mean-Adjusted Index of Merit for Wyoming-bred winter pea lines (numbered and "mix") in comparison with check cultivars 'Common' (C), 'Specter' (S), and 'Windham' (W)

Note. Lines with same letters are not significantly different at p = 0.05 based on LSD test.

3.2 Standardized Adjusted Index of Merit

For the "standardized index of merit," deviations from means for the four yield traits (FD, FI, SD, and SI) for the 10 lines/cultivars were the same as for the "mean-adjusted index of merit" as presented in Table 2 in units of plus or minus 1000 kg ha^{-1}.

As in "mean-adjusted index of merit," ANOVA for the "standardized index of merit" showed that 70% of variation is due to lines/cultivars (Table 3), indicating that, overall, the primary source of variation in these studies is genetic. For the "standardized index of merit," relative deviations from means for the four yield traits (FD, FI, SD, and SI) for the 10 lines/cultivars are presented graphically in Figure 2 together with mean separations.

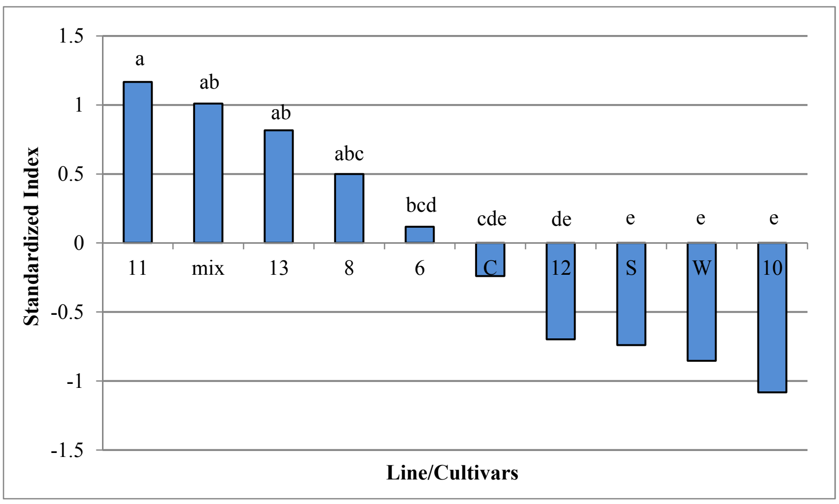

Figure 2. Standardized Index of Merit for Wyoming-bred winter pea lines (numbered and "mix") in comparison with check cultivars 'Common' (C), 'Specter' (S), and 'Windham' (W)

Note. Lines with same letters are not significantly different at p = 0.05 based on LSD test.

Here the means separation is slightly more refined than for the "mean-adjusted index of merit", with five, rather than four group means. Ranks remain the same. Again, all check cultivars of winter pea ('Common', 'Specter', and 'Windham') ranked in the bottom five of ten. Here, four Wyoming-bred lines (Wyo #11, Wyo Mix of #11 and #13, Wyo #13, and Wyo #8) ranked significantly higher for overall merit than any existing winter feed pea cultivar tested in this study: 'Common', 'Specter' and 'Windham'.

In both "indices of merit", the two Wyoming lines that ranked in the bottom five of ten, Wyo #12 and Wyo #10, were those that were retained in the breeding program for the reason that they exhibited unique morphological traits (Wyo #12: no tendrils and green cotyledons; Wyo #10: clear seed coat). These were retained and tested in the interest of maintaining phenotypic diversity throughout the breeding program.

Regarding Wyo #11, Wyo #13, and the blend, Wyo #11+Wyo#13, we tested the blend because, in the course of breeding these lines, it became obvious early on that Wyo #11 and Wyo #13 were potentially superior lines (unpublished breeders' notes). Wyo #11 and Wyo #13 have different parentage and are morphologically distinct (wild-type and afilia leaf types, respectively). It has long been known that a mix of genetically superior lines may "overyield," (Harper, 1977), and as recently reviewed by authors who advocate "in-field" diversity in agroecosystems (Vandermeer, 2011; Connor et al., 2011; Denison, 2012). We did not observe over-yielding of the blend of Wyo #11 and Wyo #13. Rather, the blend yielded approximately midway between Wyo #11 and Wyo #13. (Table 1; Figures 1 and 2). Perhaps the merit of the blend may simply be considered further evidence for the superiority of elite breeding lines Wyo #11 and Wyo #13.

Correlations among the four traits, FD, FI, SD, and SI, based upon the both "mean-adjusted index of merit" and "standardized index of merit" were identical and presented in Table 4. Correlations ranged from r = .5132 to r = .6782, with all six pair-wise correlations significant at p = .05 or nearly so.

Table 4. Correlations among traits: Mean–adjusted index of merit, Standardized index of merit

	Mean-adjusted index of merit			Standardized index of merit		
	Irrigated Forage (FI)	Dryland Seed (SD)	Irrigated Seed (SI)	Irrigated Forage (FI)	Dryland Seed (SD)	Irrigated Seed (SI)
Dryland Forage (FD)	.5360 p = .0551	.6782 p = .0156	.6372 p = .0238	.5360 p = .0551	.6782 p = .0156	.6372 p = .0238
Irrigated Forage (FI)		.6607 p = .0188	.5799 p = .0394		.6607 p = .0188	.5799 p = .0394
Dryland Seed (SD)			.5132 p = .0646			.5132 p = .0646

Note. FD = Forage dryland, FI = Forage irrigated, SD = Seed dryland, SI = Seed irrigated.

These may be considered genetic correlations (Crow, 1986; Falconer & Mackay, 1996) because what plants within lines/cultivars have in common is their genes and difference among the diverse lines/cultivars is genetic. The lines/cultivars tested here are highly homozygous (F_9 generation for the Wyoming-bred lines) and are mostly homogeneous for the same alleles at most loci (via identity-by-descent), tracing back to single plant F_3 parentage in the case of the Wyoming-bred lines. Wyo #11 + Wyo #13 is a uniform blend of two lines where plants are highly homozygous, but there is heterogeneity due to the mix. The Palouse-bred cultivars ('Specter' and 'Windham') are highly homozygous and homogeneous based on their breeding history (McPhee & Muehlbauer, 2007; McPhee et al., 2007). 'Common' would also be highly homozygous but no F-generation can be specified because it does not trace back to a hybridization. Rather, 'Common' is an old land-race of Austrian winter pea, and can be considered a mix of inbred purelines.

Importantly, seed of every line/cultivar tested at Lingle and Laramie in 2010-2010 and 2011-2012 was from seed increased at Lingle in 2009-2010, except for seed of 'Specter' and 'Windham' which was fresh commercial seed supplied by Washington State Agricultural Experiment Station in Fall 2010. Use of uniformly produced fresh seed minimizes any differences among lines/cultivars due to age or quality of seed. Thus, performance differences among lines should be mostly due to genetics.

It was concluded that because the four measures of merit (forage dryland, FD; forage irrigated, FI; seed dryland, SD; and seed irrigated, SI) in the both "mean-adjusted index of merit" and "standardized index of merit" are positively correlated, and that no serious compromises or "trade-offs" were manifested among these four traits. It can be also noted that because selection over segregating generations after hybridizations was all conducted in dryland and mostly for seed production (SD), that correlations of SD with FD, FI, SI may be considered to be results of correlated response to selection for adaptation and overall yield potential (Simmonds & Smartt, 1999; Acquaah, 2012). In addition, production of forage and seed under irrigation may provide a measure production on dryland in very good years when moisture conditions are good (significant and timely precipitation) and water is not limiting.

3.3 Heritability of Merit

In quantitative genetics and breeding, variances are additive, such that

$$V_P = V_G + V_E + V_{G\times E} \quad (5)$$

Where, V_P is the phenotypic variance; V_G is the genotypic variance; V_E is the environmental variance; and $V_{G\times E}$ is the genotype by environment interaction variance. From the ANOVAs for merit, Table 3, we must conclude that approximately 70% of the variance among lines/cultivars for merit observed in this study is genetically based. The percent of total sums of squares for lines/cultivars, or V_{LINES}, is 69.58% in the ANOVA for the "means-adjusted index of merit" and 70.08% in the ANOVA for the "standardized index of merit" (Table 3). Either way, 70% of phenotypic (merit) variance, V_P, is genetic variance, V_G. For the remainder of this discussion we shall consider $V_G/V_P = 70\%$.

As discussed above, the advanced elite lines from the Wyoming feed pea breeding program, as well as the check cultivars, can be expected to be highly homozygous at all genetic loci, and for the same alleles at most loci (with the exception of 'Common' which is a "landrace" or "mixed line" consisting of different homozygous genotypes).

Plant breeders (e.g., Fehr, 1987; Sleper & Poehlman, 2006; Simmonds & Smartt, 1999; Brown & Caligari, 2008; Acquaah, 2012) and quantitative geneticists (e.g., Crow, 1986; Falconer & MacKay, 1996) define Broad Sense Heritability, H_B as

$$H_B = V_G/V_P \quad (6)$$

Where, V_G is the genotypic variance, and V_P is the phenotypic variance. In words, Broad Sense Heritability, H_B, is that proportion of phenotypic variance that is genetic, and where H_B ranges from 0 to 1 (or 0% to 100%). In this study, plants within lines/cultivars are highly "correlated" (genetically) due to the inbreeding process that gave rise to lines/cultivars (And, of course, we suppose Mendelian inheritance!).

We conclude that the Broad Sense Heritability, H_B, for merit among the 10 lines/cultivars in this study is 70%. This is actually a rather high heritability for a complex trait, such as plant yield (Falconer & MacKay, 1996). Plant yield is generally considered a continuously varying, polygenic trait that is sensitive to environment, and where genotype by environment interactions are likely (Fehr, 1987; Sleper & Poehlman, 2006; Simmonds & Smartt, 1999; Brown & Caligari, 2008; Acquaah, 2012).

The 30% of variance in ANOVA for merit, as measured by FD, FI, SD, and SI, and using both indices (Table 3) that is not included in the lines/cultivars variance (V_{LINE}) is all error variance (V_{error}). This could include randomly accumulated "noise" contributed by "microenvironmental" factors (e.g., soil heterogeneity among plots) and "macroenvironmental" factors (due to years, locations, dryland vs. irrigation, and forage vs. seed), and genotype by environment interactions and various higher order interactions of genotypes with environment (Brown & Caligari, 2009). However, overall macroenvironmental components of merit (yield), due to production system (dryland vs. irrigated) or product (forage vs. seed), are not main environmental effects here because FD, FI, SD, and SI were all mean-adjusted or standardized and, respectively, make no contribution to phenotypic variance in ANOVA for merit (Table 3).

All of the various V_E and $V_{G\times E}$ components that can contribute to the 30% "error variance", V_{error} in Tables 3 cannot be separated out, one from another. Nevertheless, 30% is the maximal possible contribution of genotype by environment interaction, $V_{G\times E}$, to phenotypic variation, V_P, that is possible in our indices of merit. $V_{G\times E}$, due to interaction of genotypes (lines/cultivars) with components of indices of merit (FD, FI, SD, and SI) can be, at most, 30% of phenotypic variance for merit, and is probably only a fraction of that.

We conclude that overall merit of lines/cultivars is essentially the same across the FD, FI, SD, and SI environments. Even if a substantial proportion of the 30% V_{error} in ANOVAs for merit is due to $V_{G\times E}$, V_{LINES} predominates at 70% of phenotypic variance, V_P. Thus, V_G for merit is most important here, and merit is highly heritable.

Plant breeders and geneticists often try to break down the genetic variance into various components where,

$$V_G = V_A + V_D + V_I \quad (7)$$

Where, V_G is the genetic variance; V_A is the additive genetic variance; V_D is the dominance genetic variance; and V_I is the interaction variance (epistasis).

It is not possible to break out these components here. Nevertheless, we speculate that the superiority of top Wyoming-bred lines in this study is primarily due to accumulation of favorable alleles at multiple loci with favorable epistatic interactions among loci during the breeding process that involved hybridization among diverse parents with subsequent natural and artificial selection for performance both among and within segregating populations on the CGP.

3.4 Which Index of Merit Is Most Useful?

We calculated indices of merit in two ways: first, a mean-adjusted index and, second, a standardized index. ANOVA (Tables 3) separated means of lines/cultivars as illustrated graphically in Figures 2 and 3. The four measures of merit (FD, FI, SD and SI) were highly genetically correlated for both indices (Table 4), and in fact, correlations were identical for the two indices. The standardized index was slightly more efficient in separating means with five mean groups (Figure 2) versus four mean groups for the mean-adjusted index (Figure 1). ANOVA of both indices of merit indicated that a broad-sense heritability of merit, H_B, is 70%. The standardized index might be considered superior because it is theoretically more robust (Acquaah, 2012). However, the mean-adjusted index may be more useful in communicating results to producers because results are presented as percent deviations from a mean of 0. Growers might reasonably expect elite Wyoming-bred lines to produce 20% more than existing cultivars (Figure 2). Most producers would be unfamiliar with dimensionless standardized variables, and might misinterpret Figure 2 to indicate that our top lines are twice as productive as average lines. We conclude that both indices are useful and that the choice of index to present may depend upon the audience.

4. Conclusions

We conclude that breeding in the CGP produced locally-adapted winter pea lines with good yield for both forage and seed, and under both dryland and irrigated conditions. Our elite lines, especially Wyo#11 and Wyo#13, proposed for release were well-adapted to Wyoming and yield well under different conditions. “Indices of Merit” proved to be useful for comparing lines/cultivars for multiple use in sustainable agroecosystems.

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