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Developing Winterhardy Vegetable Pea for Wyoming, USA: Description of Winter Survival in Early Generation Breeding Lines

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Abstract- In Wyoming USA, vegetable production is challenging for vegetable growers, whether home gardeners or commercial producers due to a short growing season, high elevation and a relatively cool climate. A significant limitation to local vegetable production is that virtually no vegetable varieties have been bred in Wyoming for local adaptation. As a cool season annual crop, pea has potential for vegetable production in Wyoming. The objective of this study was to produce winterhardy vegetable peas that combine the characteristics of fresh, edible peas with the winterhardiness of feed peas.

Hybridizations between winterhardy feed pea (*Pisum sativum* ssp. *arvense*) and with all three types of food peas (shell, snow, and snap; *P. s.* ssp. *sativum*) were accomplished in the greenhouse in 2009. Natural selection began in F_2 and elite, surviving lines were advanced from the F_2 through F_4 generations using pedigree selection. The best hybrid-derived lines survived the 2010-11 winter, and their selected progeny performed even better over the 2011-2012 winter. Based on a chi-square test for independence comparing F_2 and F_3 survival indicates that the F_3 progeny of surviving F_2 plants was much higher than the survival of F_2 progeny of F_1 plants at the Prob < 0.001 level. Thus, we conclude that winterhardiness was heritable from F_2 to F_3 generations; even though considerable genetic segregation would still be taking place for what is apparently a complex polygenic trait.

Index Terms- winterhardy pea, vegetable, breeding

I. Introduction

A number of limiting factors makes home gardening and commercial vegetable production challenging in Wyoming. One of the limitations to vegetable production is that most areas in the state have a short growing season due to high elevation and a relatively cool climate (Panter, 2004). During the growing season, snow or frost, below freezing temperatures, low humidity, and high or steady winds in some areas can constrain vegetable production and limit the area of adaptation for many vegetables. One of the means to extend the growing season in Wyoming would be to develop locally adapted vegetable cultivars with increased cold tolerance and high yield. As a cool season annual crop, pea has potential for vegetable production in Wyoming.

There are a number of shell and edible-pod pea cultivars recommended for Wyoming in a UW extension bulletin (Panter, 2002). However, all the existing vegetable pea cultivars were bred elsewhere, and thus there appears to be a necessity for locally bred and adapted cultivars for pea production in Wyoming and the West. Benefits of locally-adapted edible pea cultivars should accrue to both growers (ranging from home gardeners to large-scale commercial productions) and consumers (who will enjoy the contribution of locally produced healthy food to the diet).

Botanically, peas are seeds and pea pods are fruits but, overall, peas are considered a vegetable crop. In the human diet, fresh peas are a valuable source of vitamin A, C, significant amounts of B vitamins, iron and phosphorus and fiber. Shell peas are higher in protein compared to snow and snap peas; however, snow and snap peas provide twice the calcium and more iron than shell peas (Kirkland and Hedstrom, 2008).

Three types of peas used as vegetables are the shell peas (or garden pea or English pea or *P. s.* ssp. *s.* var. *sativum*), the snow pea (or Chinese pea or *P. s.* ssp. *s.* var. *saccharatum*) and the snap pea or (sugar snap pea or *P. s.* ssp. *s.* var. *sativum* var. *macrocarpon*; Myers et al., 2001). Garden peas are grown for their immature green seeds which can be used fresh or for canning and freezing. Snow pea, with thin pod walls, and snap pea, with thick pod walls, are the edible-podded peas and are grown and consumed for their tender, unripe pods that lack the parchment layer inside the pod (Sneddon, 1970; De Ron, 2005). Two independent recessive alleles at two loci, ***p*** and ***v***, are responsible for reducing the fibrous membrane on the inside of the pod (Gritton, 1986). Modern edible-podded pea cultivars have genotype ***ppvv*** which is required to make the pods suitable for consumption when the pods are large and the seeds have started to form whereas shell pea cultivars usually have genotype ***PPVV*** (Deppe, 2000). An additional recessive allele ***n,*** at the ***N*** locus, increases pod thickness and all snap pea cultivars have genotype ***ppvvnn*** (Gritton, 1986; Deppe, 2000).

The short-term goal of this study was to develop breeding lines of locally-adapted, fresh edible peas (as immature seeds or pods) and edible dry peas (as a pulse crop) in one or more classes of winterhardy edible pea. Specifically, our primary objective was to produce cultivars that can be seeded in late summer/early autumn such that an established stand will overwinter and reawaken in the spring to produce fresh, local vegetable produce, perhaps earlier in spring than any other product of the home garden or commercial production field. Cold hardiness of such cultivars may also prove useful for very early spring seeding.

II. MATERIALS AND METHODS

Pea lines utilized in this study mostly involved crosses between the two subspecies, with the goal of genetically recombining edible pea traits from ssp. *sativum* with winterhardiness from ssp. *arvense*. Characteristics of twelve parental cultivars (three winterhardy feed pea and nine food pea cultivars) are summarized in Table 1. Hybridizations were accomplished in the greenhouse in Laramie (41° 18' N, 105° 35' W, elevation 2184 m) during spring-summer of 2009 and 17 cross combinations were obtained (Table 2). Common-2, Common-3, 45×C9, 47×C8, etc. are various selections within 'Common' and hybrids from *arvense* × *arvense* crosses in the early stages of the winter feed pea breeding program for Wyoming adaptation and winterhardiness, some of which gave rise to (or are related to) the Wyoming-bred winterhardy feed pea lines.

Based on parentage of crosses in this study, Table 3 shows all of the winterhardy, edible types of peas expected to segregate from hybridizations and with subsequent genetic recombination and selection in the Wyoming environment. All of the outcomes listed in Table 3 are possible because of the diverse pea germplasm used in multiple hybridizations.

The F_1 hybrids of 14 *sativum* × *arvense* cross combinations and 3 *arvense* ×*arvense* were grown in the greenhouse to produce F_2 seed during the fall and winter of 2009. A large number of seeds of each F_2 population (ranging from 40 to 100), and twenty seeds of each parental line/cultivar, were planted 30.5 cm apart in rows spaced 46 cm apart in early September, 2010 in Laramie. Surviving F_2 plants were single-plant threshed at maturity to produce F_2-derived F_3 families in the summer of 2011. Soil type in the experimental area at Laramie is classified as sandy loam. Watering was done by hand. No fertilizer was applied.

F_3 seeds of each line (from 50 to 100) were planted 10 cm apart in rows spaced 46 cm apart in late September at the same location and were single-plant threshed at maturity to produce F_3-derived F_4 families in summer of 2012. Again, twenty seeds of each *sativum* and *arvense* parental line were seeded in Fall 2011.

III. RESULTS AND DISCUSSION

In Fall 2010, a total of 1223 F_2 plants from 17 different cross combinations were established in Laramie, Wyoming. Three of the crosses were between winter feed peas (*arvense* × *arvense*), while the rest, 14 crosses, were derived from the crosses between spring vegetable peas and winter feed peas (*sativum* × *arvense*). Out of 1049 F_2 segregates from *sativum* × *arvense* crosses, 19 plants survived (1.8%) the 2010-2011 winter. Thus, natural selection for winter survival was very intense.

In contrast, survival among F_2 segregates from *arvense* × *arvense* crosses was higher, 77 out of 174 plants (44.3%), confirming that crosses between more winterhardy parents will produce more winterhardy progeny (Liesenfeld et al., 1986). None of the vegetable type parental cultivars survived. The percent survivals for three winterhardy parents, 'Common', 'Specter' and 'Windham' were 35%, 65% and 70%, respectively.

The very low survival of *sativum* × *arvense* F_2 progenies (1.8%) suggests that winterhardiness is a complex, polygenic trait, with only a small percentage of F_2 plants segregating for a combination of alleles at numerous genetic loci that condition winterhardiness. Moreover, we might speculate that winterhardiness is a mostly a recessive trait in pea.

In Laramie, the winter of 2010-2011 was severe and pea plants were subjected to long lasting freezing temperatures, wind, and inadequate snow protection which might have caused the considerable attrition due to winterkill, especially in the F_2 progeny of *arvense* × *sativum* crosses. The minimum temperature was -39°C on February 2, 2011**.** Moreover, there was no cereal stubble or furrow to protect seedlings from freezing temperatures and desiccating winds.

Among the *sativum* × *arvense* crosses, the largest number of survivors (7) was obtained from the cross made with the *sativum* parent 'Oregon Sugar Pod II' (snow pea) and *arvense* parent 'Common' (Table 2). 'Oregon Sugar Pod II', a snow pea with short vines and excellent flavor, is known to be cold hardy and overwinters in maritime Oregon (Deppe, 2000).

In Fall of 2011, 500 F_3 plants from *sativum* × *arvense* crosses were established and populations were still segregating for winter survival. The number of survivors in Spring 2012 was 116, or 23.2%, much larger than the 1.8% of F_2 plants that survived the previous winter. Of the 116 survivors, 39 were white flowered. Again, none of the vegetable type parental cultivars survived.

A chi-square test for independence (a contingency test) comparing F_2 and F_3 survival indicates that the 23.2% of F_3 progeny of surviving F_2 plants (as evaluated in 2011-2012) was much higher than the 1.8% survival of F_2 progeny of F_1 plants (as evaluated in 2010-2011) with chi-square = 186.56, 2df, and significant at the Prob < 0.001 level (Prob = 1.38 x 10^{-40}). This indicates that winterhardiness was heritable from F_2 to F_3 generations, even though significant genetic segregation would still be taking place for this quantitative trait.

Table I. List of parental pea cultivars and their characteristics

Cultivars	Characteristics*
Early Alaska (Shell Pea)	Round seeds. Green cotyledon. Cold and wet tolerant. Standard early canning pea. 1 to 2 pods per node. White flowers.
Maestro (Shell Pea)	Round seeds. Early, widely-adapted and vigorous. Sweet and tender, tolerant to powdery mildew, pea enation mosaic virus, bean yellow mosaic virus. White flowers.
Spring (Shell Pea)	Round seeds. Freezer, extra early, vigorous, determinate, sweet flavored pea, very productive. White flowers. Resistant to Fusarium wilt.
Dwarf Gray Sugar (Snow Pea)	Round seeds, yellow cotyledon. Purple flowers with edible leaves and stems. This is the standard flat podded pea for oriental cooking.
Oregon Sugar Pod II (Snow Pea)	Round seeds, short vine and green cotyledon. Pods are broad and very tender in very early stage. Excellent quality and flavor. Commercial freezing. White flowers. Resistant to powdery mildew. Two pods per node. Overwinter in maritime Oregon.
Snowbird (Snow Pea)	Round seeds, yellow cotyledon. Very early, dwarf-erect, sweet pods. White flowers. Highly double podded with 3" pods.
Sugar Ann (Snap Pea)	Wrinkled seeds, yellow and green cotyledons. Short vines, small, medium green, very sweet pods. Early maturity, stringy. Freeze well. White flowers.
Sugar Daddy (Snap Pea)	Wrinkled seeds, yellow and green cotyledons. Medium vine; medium size, dark green and stringless pods. Full season maturity. Resistant to powdery mildew, tolerant to Bean leafroll virus (BLRV). White flowers.
Sugar Snap (Snap Pea)	Wrinkled seeds, yellow and green cotyledons, tall vine, medium stringy pods, excellent flavor, late maturity. Two pods per node. Susceptible to powdery mildew. White flowers. Overwinter in maritime Oregon.
Common (Landrace, Feed pea)	Round and mottled seeds. Austrian winter pea, winter hardy, purple flower, normal leaf type, seed are mottled, tall growth habit. Yellow cotyledons.
Specter (Feed pea)	Winter feed pea, winter hardy, tall growth habit, *af* for semi-leafless tendrilled leaf. Seeds are round with yellow cotyledons. Pods are straight, blunt-ended, and medium green
Windham (Feed pea)	Winter feed pea, winter hardy, semi-dwarf, *af* for tendrilled leaf. Seeds are round with yellow cotyledons. Pods are straight, blunt-ended, and medium green

*(Gritton and Myers, 1996; Wehner; 2002; McPhee and Muehlbauer, 2007; McPhee et al., 2007; Deppe, 2000).

During the 2011-2012 growing season, the minimum temperature was observed in December (-33.9 °C). Because the 2011-2012 winter was similarly severe as the previous winter, 2010-2011, and with even less snow cover, we believe that we can attribute much of the increased winter survival rate in 2011-2012 (23.2% for the F_3 generation) over the 2010-2011 (1.8% survival for the F_3 generation) to genetics and natural selection for winterhardiness. It might also be speculated that the earlier planting in 2010-2011 might be partly responsible excessive winterkill compared to 2011-2012 growing season, an environmental effect. Murray and Swensen (1991) noted that early-planted pea is usually poorly acclimated when frost occurs. However, survival of parental *sativum* lines was 0% in both 2010-2011 and 2011-2012 winters, providing no evidence that later planting, by itself, could have been responsible for higher survival of the F_3 generation relative to the F_2 generation.

Table II. Parentage of 17 cross combinations (♀✕♂) between advanced lines of Wyoming-selected winterhardy field pea (*P. s.* ssp. *arvense*) and food pea (*P. s.* ssp. *sativum)* cultivars, and the number of F_2 plants survived the winter during 2010-2011 growing season

Crosses	**# of F_2**	**# of F_2 plants**	**# of F_2 plants**
***sativum* ✕ *arvense* crosses**			
Early Alaska (Shell)* ✕ Common-3	100	90	3
Windham ✕ Early Alaska (Shell)	100	90	0
Maestro (Shell) ✕ (47✕C8)	50	30	0
Maestro (Shell) ✕ Common-3	49	38	1
Windham ✕ Maestro (Shell)	20	9	0
Spring (Shell) ✕ (45✕C9)	100	88	0
Dwarf Gray Sugar (Snow) ✕ (47✕C8)	100	94	0
Specter ✕ Dwarf Gray Sugar (Snow)	100	95	2
Oregon Sugar Pod II (Snow) ✕ Common-2	100	93	7
Windham ✕ Oregon Sugar Pod II (Snow)	100	86	4
Snowbird (Snow) ✕ Common-3	100	95	0
Sugar Ann (Snap) ✕ (45✕C9)	100	82	1
Sugar Daddy (Snap) ✕ (45✕C9)	100	78	0
Sugar Snap (Snap) ✕ (58✕C3)	100	87	1
***arvense* ✕ *arvense* crosses‡**			
Specter ✕ (45✕C9)	54	40	0
Specter ✕ Common-3	50	44	33
Windham ✕ Common	99	86	44

*Edible type parents are underlined. ‡The last three cross combinations are *arvense* ✕ *arvense* hybridizations involving white-flowered *arvense* cultivars, 'Specter' and 'Windham', that could produce dry edible pea segregates.

One observation from the Laramie F_3 nursery in the 2011-2012 growing season, similar to the statement from the WAES (1910) report, is that peas do actually remain green on the vine and keep producing new flowers and new pods in late summer and early fall which is most probably desired for home gardening and commercial vegetable production due to extended harvest season into the fall. Late rains, cold nights and warmer days are most probably the reason for peas to stay green longer period of time.

IV. CONCLUSIONS AND FUTURE RESEARCH

We were able to combine winterhardiness from *arvense* lines/cultivars with traits of edible *sativum* cultivars and advance the F_3 materials to the F_4 generations in the Laramie, WY growing environment. However, due to small numbers of F_4 seeds produced by some of the F_3 plants, another year of selection and seed increase would be appropriate before evaluating this advancing material in replicated trials.

We are aware of that with the intense selection for winter survival occurred in F_2 generation in this study, some of the desirable characteristics might have been eliminated from resulting F_2 populations. With plenty of F_2 remnant seeds, it would be appropriate to test these progenies in different locations at lower elevations where winter survival most likely to be higher. This could potentially increase the likelihood of getting the desired recombinant genotypes.

Table III. Types of edible peas that are expected to segregate from hybridizations between winterhardy field pea (*P. s.* ssp. *arvense*) and food pea (*P. s.* ssp. *sativum)* lines used as parents in this study

Market Class	Genotypes*	Type	Use
Garden (English, Shell)	PPRRVVNN	immature green seed	fresh, frozen, canned
Snow (Chinese)	ppRRvvNN	immature pod, thin pod walls	fresh, frozen
Snap (Sugar)	pprrvvnn	immature pod, thick pod walls	fresh, frozen
Yellow split pea	PPRRVVNN	dry seed, yellow cotyledon	pulse
Green split pea	PPRRVVNN	dry seed, green cotyledon	pulse

*R= round, r =wrinkled seeds; P and V= presence of fibrous membrane on the inside of the pod, p and v = absence of fibrous membrane on the inside of the pod; N= thin pod wall n= thick pod walls.

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