Components of phenotypic variance of seed traits and germination characteristics of 20 ponderosa pine half-sib families

Componentes de varianza fenotípica de características de semilla y germinación de 20 familias de medios hermanos de pino ponderosa

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Abstract

A study was conducted to estimate phenotypic variance components of seed traits and seed vigor of 20 ponderosa pine seed lots. A high intraspecific within-group variation in seed germination and seedling growth has been observed in both half-sib and full-sib families of conifers. Some seed traits may influence seed lot quality and seedling survival. Wind-pollinated cones were collected from 20 ponderosa pine maternal trees, 10 cones per tree, in a stand located in Fort Defiance, Arizona. Air-dried seeds were sown under laboratory conditions, by using a completely randomized design to estimate components of phenotypic variance for seed weight (SW), seed coat weight (SCW), seed imbibition (IMB), five germination characteristics, and three Weibull parameters (*a*, *b* and *c*). About 80% of size classes had a seed weight (SW) e» 41 mg and e» 97% final germination. The within-plot (within-family) variance component for SW (64.5%) and IMB (70.4%) was higher than among-family variation (35.3 and 24.8%, respectively). The among-family component varied from 35.1% (Weibull parameter *a*) to 62.3% (Peak Value). Results suggest a significant maternal contribution and a high within-family genetic influence on seed quality and germination characteristics. Finally, heavier seeds (SW e» 60 mg), whose time of germination (TOG) occurred at day 3, increased 38.3% of their seed weight due to water absorption before reaching 50% germination; on the other hand, seeds whose SW was e» 45 mg and TOG = 7, showed 102.2% increase in SW before reaching 50% germination.

Keywords: germination timing, peak value, Weibull parameters, within-family variation.

Resumen

Se realizó un estudio para estimar componentes de varianza de características y vigor de 20 lotes de semilla de pino ponderosa. En familias de hermanos completos y medios hermanos la varianza dentro de grupos es elevada para la germinación y crecimiento de plántulas de coníferas. Algunas características de semilla pueden influir en la calidad del lote y la supervivencia de plántulas. Diez conos de polinización abierta fueron colectados de cada uno de 20 árboles madre, en una población localizada en Fort Defiance, Arizona. Semillas secadas al aire fueron sembradas en el laboratorio, en un diseño completamente aleatorizado, para estimar las componentes de varianza fenotípica de: peso (SW) y cubierta de la semilla (SCW); imbibición de la semilla (IMB), cinco características germinativas y tres parámetros de Weibull (*a, b* y *c*). Un 80% de la semilla tuvo peso e» 41 mg y germinación e» 97%. La varianza dentro de progenie/dentro de familia para las características SW (64.5%) e IMB (70.4%) fue mayor que la varianza entre familias (35.3 y 24.8%, respectivamente). La varianza entre familias varió de 35.1% (parámetro *a* de Weibull) a 62.3% (Peak Value). Los resultados sugieren contribución materna y componente genética alta dentro de familias que influyen en la calidad y características germinativas de la semilla. Semillas con SW e» 60 mg y TOG=3, incrementaron 38.3% de su peso por agua absorbida para alcanzar 50% de germinación. Las semillas cuyo SW fue e» 45 mg and TOG = 7, mostraron un incremento de 102.2% en SW antes de completar 50% de germinación.

Palabras clave: tiempo para germinación, valor pico, parámetros Weibull, variación dentro de familias.

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Introduction

Conifers are considered one of the most variable plant groups for many morphological and physiological characteristics of seeds and seedlings. A high intraspecific within-group variation in seed germination and seedling growth has been observed in both half-sib and full-sib families, and this variability increases with age (Maze and Banerjee, 1989; Matziris, 1998; Parker et al., 2006).

Some authors indicate that variation in seed weight and seedling phenology is due to four major factors: (1) genotype of seeds (Bramlett *et al*., 1983; Sorensen and Campbell, 1985; Davidson *et al*., 1996; Barnett, 1997); (2) maternal effects (Perry, 1976; Perry and Hafley, 1981; (3) environmental conditions such as chilling duration, incubation temperatures, and soil moisture (McLemore, 1966; Gossling, 1988; Bai *et al*., 2004; Pasquini and Defossé, 2012); and (4) cultural practices such as fertilization, irrigation, and pest control (More and Kidd, 1982; Gummerson, 1989; Heidmann and Haase, 1989; Benjamin 1990; St. Clair and Adams, 1993).

Seedling quality and the success of seedling establishment are strongly correlated with germination and emergence of seeds planted in the nursery (Silen and Osterhaus, 1979; Mexal and Fisher, 1987; Davidson *et al*., 1996). It is apparent from documented literature that seed mass, a maternally-determined characteristic, seems to be correlated with total germination and time of germination (Roach and Wulf, 1987). In ponderosa pine, genetic variation in seed morphology appears to be associated with climatic gradients (mostly precipitation, temperature and soil moisture); high estimates of within-population variation seem to be associated to adaptive mechanisms to environmental changes (Parker *et al*., 2006). In addition, evidence suggests that selective forces (temperature, soil moisture, birds) are responsible for the origin of ecotypes possessing unique variation in seed morphology (Ager and Settler, 1983).

Little information exists about the genesis of variation of germination characteristics and seeds traits in *Pinus ponderosa* (Weber and Sorensen, 1992; Matziris, 1998; Parker *et al*., 2006), which have influence on quality of seed lots and seedling survival.

This study was conducted a) to estimate phenotypic variance components of seed traits and germination parameters of seed lots; b) to compare seed vigor and germination characteristics of 20 half-sib families and c) to analyze correlations of seed size with germination and other seed traits.

Materials and methods

Study site and cone collection. The genetic material was supplied by the Department of *Navajo Forestry Reforestation and Disease Control*. Two hundred wind-pollinated cones were collected from twenty maternal trees, randomly selected from a stand of ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.). Trees of the ponderosa pine stand are located on the Defiance Plateau (35° 40' N, 111° 49' W, at an elevation between 2200 and 2500 meters (ASL), on Fort Defiance, Arizona, USA. Mature cones were collected in fall (October) and dried at room temperature (20 °C ± 2 °C) for one month. Seeds were then dewinged, cleaned, placed them in polyethylene bags and stored five months in a refrigerator at 4 °C until sown (Long and Jones, 1996; Parker *et al*., 2006; Pasquini and Defossé, 2012). Seed traits of collected cones and some morphological characteristics were recorded for selected maternal trees (Table 1). In this study, a seed lot is the progeny derived from each maternal tree, each of which will be also named subsequently as half-sib family.

Seed traits measurements. A bulked seed lot of 400 seeds was formed by combining cleaned seed from 20 half-sib families (20 seeds randomly selected from each half-sib family); then, seeds were weighed and categorized into five size weight classes: a) < 31; b) 31-40; c) 41-50; d) 51-60, and e) > 60 mg. Seed weights (SW) were used to build an histogram of frequencies (Figure 1). Seed coats of germinants were removed, dried at 100 °C for 24 hours, weighed and recorded (SCW). Values of seed imbibition (IMB), expressed as amount of daily absorbed water (mg), were calculated with the formula (Durzan, 1983; Woodstock, 1988; Terskikh *et al*., 2005): IMB= $[(SW_2-SW_1)/SW_1]$, where SW_2=Seed weight at time 2 and SW_1=Seed weight at initial time. For each individual seed, daily measurements of seed fresh weight changes were registered.

Experimental design and treatments. Twenty half-sib families, which represent 20 treatments, were compared in a completely randomized design (give a reference for this experimental design, e.g., Steel and Torrie, 1980), with two replicates. The experimental unit (EU) and sampling unit (SU) for all germination parameters were represented by a Petri dish with 10 seeds. The SU for seed weight traits and seed imbibition, on the other hand, was represented by a single seed.

Table 1. Elevation (masl) and traits of mother trees from which 20 half-sib families were collected from Navajo Forest located on Defiance Plateau (Fort Defiance, Arizona. USA).

Family Number	Elevation (m)	Height (m)	DBH (cm)	Seeds per cone	Seed moisture (%)	SWt (mg)	Type
1	2361	18.0	58	86	7.3	39	Black Jack
2	2361	17.1	50	65	7.3	40	Black Jack
3	2403	18.0	57	123	7.5	41	Black Jack
4	2361	24.4	72	82	7.8	45	Yellow Pine
5	2410	17.1	48	76	7.5	39	Yellow Pine
6	2434	17.7	55	51	7.5	52	Yellow Pine
7	2434	18.0	52	60	7.6	29	Yellow Pine
8	2403	19.8	51	112	7.3	46	Black Jack
9	2403	20.4	36	82	7.0	33	Black Jack
10	2403	17.4	30	33	7.9	46	Black Jack
11	2269	21.3	36	78	7.9	56	Yellow Pine
12	2318	22.3	63	66	7.9	47	Black Jack
13	2227	13.7	48	87	7.8	52	Black Jack
14	2257	14.3	25	103	7.6	54	Black Jack
15	2257	14.3	41	73	7.9	43	Black Jack
16	2257	18.0	50	32	7.6	38	Black Jack
17	2403	13.7	33	98	7.9	34	Black Jack
18	2403	21.0	41	114	8.1	30	Black Jack
19	2379	18.3	38	47	7.7	60	Black Jack
20	2379	10.7	30	39	7.8	41	Black Jack
Mean	**2359**	**17.8**	**46**	**75**	**7.6**	**43**	-

Germination test. This study was conducted under laboratory conditions (20 ºC ± 2 ºC) at the Department of XXX, New Mexico State University, to estimate variance components of several seed quality traits of 20 half-sib families. Two replicates of ten seeds of each half-sib family were sown on Petri dishes containing three layers of filter paper (Whatman No. 2). After sowing the seeds, 10 ml of deionized water were applied in each Petri dish, and 5 ml were added every other day to replace the water lost by evaporation.

Germination parameters. The criterion to define *seed germination* was when radicle protrusion occurred (if possible, give a reference) and extended about 5 mm. In this study, several criteria were included to measure germinative characteristics of seed lots. *Germination capacity* (GC), which is also named *final* or *total germination*, was measured as *germination percentage* at the end of the test (G) and transformed into *Arc Sine* $\sqrt{(G^* \, 0.01)}$. *Time of germination* (TOG), which is usually named *germination timing*, was described as the number of days to reach 50% germination. *Germination speed* (GS), it is the reciprocal of time of germination (1/TOG). *Peak value* (PV), it is the highest quotient when dividing the maximum cumulative germination percentage by number of days to reach this percentage. *Germination value* (GV), it is the result of multiplying PV*MDG data, where MDG=*Mean daily germination* = number of seeds germinating per day (Czabator, 1962; Larson, 1963; Ranal and Garcia de Santana, 2006). Weibull parameters, other seed characteristics associated with germinative capacity of seeds, were estimated for all half-sib families. The parameter «*a*», for instance, indicates the point in which germination begins. Parameter «*b*», on the other hand, is the scale factor. Finally, «*c*» defines the shape of the curve (Rink *et al*., 1979; Bahler *et al*., 1989).

Statistical analysis and variance components. The model of analysis of variance (ANOVA) for estimating components of phenotypic variance of seed traits is shown in Table 2. Sources of variation (Source), degrees of freedom (DF), and the expected mean squares (EMS) were calculated for a completely randomized design (Kuehl, 1994). The family component of variance (σ_f^2), which it is usually named in experimental design terminology as *between groups or treatments*, is a random sample derived from a ponderosa pine population; the error term (σ_e^2), it is also known as within group component, which represents the variation among experimental units (EU), while the component of variance within-plot (σ_w^2) is the variation among individuals within each EU (Steel and Torrie, 1960). Since at each EU were sown seeds selected from a given family, the within-plot component of variance is also named within-family variation. The numbers of families, replications, and individuals/plot (progeny size/family) were, respectively, *20* (*f*), *2* (*r*) and *10* (*p*). Phenotypic variance is = $\sigma_p^2 = \sigma_w^2 + \sigma_e^2 + \sigma_f^2$.

Table 2. ANOVA model and expected means squares (EMS).

Source of variation	DF	EMS[1]
Family	f - 1	$\sigma_w^2 + p\,\sigma_e^2 + pr\,\sigma_f^2$
Error	f (r-1)	$\sigma_w^2 + p\,\sigma_e^2$
Within-Plot	fr (p-1)	σ_w^2

[1]/ σ_w^2, σ_e^2, σ_f^2 are the within-plot, error, and family components of variance, respectively.
Phenotypic variance = $\sigma_p^2 = \sigma_w^2 + \sigma_e^2 + \sigma_f^2$. *f=20* families; *r=2* replicates, and *p=10* individuals/family.

Results and discussion

Characteristics of mother trees and seeds of half-sib families. Recorded data for selected maternal trees (Table 1) confirm the existence of morphological variation among half-sib families, as it has been mentioned by other authors (Maze and Banerjee, 1989; Barnett, 1997; Matziris, 1998); for instance, height of trees varied from 10.7 (family 20) to 24.4 m (family 4); diameter at breast height (DBH), on the other hand, showed a range between 25 (family 14) and 63 cm (family 12). Number of seeds per cone, among families, varied from 32 (family 16) to 123 (family 3). Average seed weight showed a range from 29 to 60 mg, respectively, for family 7 and family 19. Seed moisture content (dry weight basis), averaged 7.6%, a minimum of 7.0% (family 9) and a maximum of 8.1% (family 18). Since most means were close to the average seed moisture content, this suggests similar seed maturity conditions, as it was expected because all cones were harvested on the same day of October. Similar results were documented in other pine species (Durzan, 1983; Terskikh *et al.*, 2005; Pasquini and Defossé, 2012).

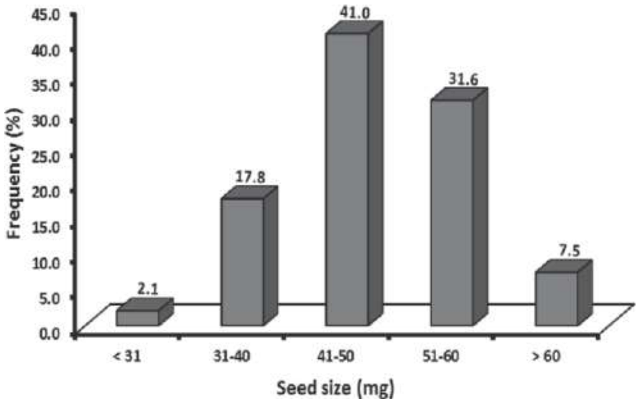

Figure 1. Frecuency distribution of seed size of a 400-seeds balanced bulk of 20 half-sib families.

Seed weight sizes and germination capacity. The histogram of frequencies for seed weight shows a normally distributed curve (Figure 1); the value of the mode corresponds to seed size 41-50 mg, since it is the class of the highest frequency (41%). The heavier seed weight (> 60 mg) represents 7.5% of the seeds, while the lighter (< 31 mg) only 2.1%. About 80% of seeds weighed ≥ 41 mg and showed 96.9% germination (Figure 2); lighter seeds, on the other hand, had only 10.9% germination because 89.1% were empty seeds; these results, however, contrast studies conducted in others tree species, under controlled environmental conditions, have observed that seed mass effects on germination and early seedling growth depend on resource availability (Parker *et al*., 2006; Mtambalika *et al*., 2014); however, results of this study agree with some researchers who have stated that embryo abortion is the main cause of empty seeds (Matziris, 1998).

IMB, SW and TOG relationships. Four curves of seed imbibition (IMB), selected from the balanced bulk of half-sib families (Figure 3), show seed weight increases and their relationships with time of germination 50% (TOG) and initial seed weight (SW). As it was mentioned before, lighter seeds (seed weight < 31 mg) showed a low percent of germination, because they had a higher percent of empty seeds; moreover, ungerminated small seeds increased their weight from 26 to 35 mg (increment = 57.7%). This could be related to damage on seed coat produced by pathogens (fungi and bacteria), seed coat layers structure, insects, high temperature, wind and other environmental factors (Timonin, 1964; Tillman-Sutela and Kaupin, 1995). On the other hand, seeds whose TOG occurred 3, 5 and 7 days after sowing, showed at day 3, respectively, SW increments of 38.3, 29.4 and 40%. Studies in *Pinus monticola* (Dougl. Ex D. Don) seeds have been reported weight increases of 30% one day after sowing, and it has been indicated that seeds should reach a desirable seed moisture content before germination begins (Terskikh *et al.*, 2005). Barnett (1997) indicated that in *Pinus taeda* (L.) seeds must reach a moisture content of 36% to split the seed coat and to initiate germination, while longleaf pine (*Pinus palustris* Mill.) seeds require around 55% moisture content (seed dry weight basis) before starting germination.

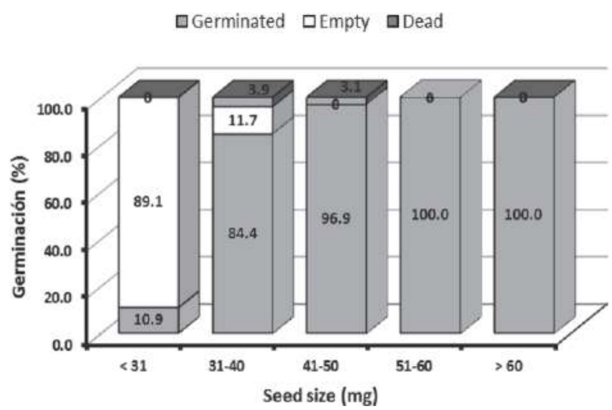

Figure 2. Seed size effect on percent germination (bulk of 20 half-sib families).

Table 3. Components of phenotypic variance (%) for seed fresh weight (SFW), seed coat fresh weight (SCFW) and seed imbibition (IMB).

Source of variation	DF	SFW	SCFW	IMB
Family	19	35.3**	50.1**	24.8**
Among-plots	20	0.2	8.0	4.8
Within- plots	360	64.5	41.8	70.4

** Highly significant (P≤0.01).

Increases in seed weights, which were recorded during the seven-day imbibition period (Figure 3), showed three imbibition stages described by other researchers (Terskikh *et al.*, 2005): 1) *Phase I* (0-1 day after sowing*)*; 2) *Phase II* (2-3 days after sowing*)*; and 3) *Saturation Phase or Phase III* (4-7 days after sowing). *Phase III* is characterized by the highest water-uptake rate and a fast increase in seed coat permeability; important changes in SW occurred in *Phase I*, since it was observed increases of 16, 12 and 13 mg, respectively, for TOG 3 (from 60 to 76 mg), TOG 5 (from 51 to 63 mg) and TOG 7 (from 45 to 58 mg). In *Phase II*, on the other hand, small SW changes were recorded from day 1 to day 2 (2-3 mg) and from day 2 to day 3 (1-4 mg). Finally, the *Saturation Phase* is characterized for another high increase and a linear trend, whose pattern continues from day 3 to day 7. It is also marked the superiority of seeds whose TOG is 3 and their average seed weight increases from 83 to 128 mg (day 3 to day 7). Patterns of imbibition curves observed in this study agree with those described by Woodstock (1988) and Terskikh *et al.* (2005).

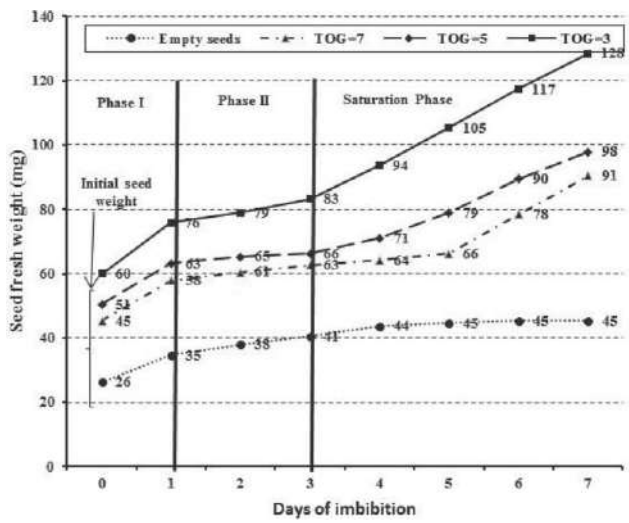

Figure 3. Imbibition of seeds associated to Time of Germination 50% (TOG).

Components of variance for seed traits. Highly significant differences (P < 0.001) were observed among families for seed weight (SW), seed coat weight (SCW), and seed imbibition (IMB); estimates of components of variance, associated to family differences (genetic variation), were 35.5, 50.1 and 24.8%, respectively, for SW, SCW and IMB (Table 3). Within-plot (Within-family) variances estimated for seed traits: SW, SCW and IMB were, respectively, 64.5, 41.8 and 70.4%; in most cases, the extent and magnitude of this component is higher than family variance; which may represent another source of genetic variation associated to differences among individuals of same family (within-family variance), resulting from cross pollination between mother tress (female parents) and male parents genetically divergent. The great amount of among and within family variation, observed for most characteristics analyzed, confirms the results found by several researchers in other species (Banerjee and Maze, 1988; Maze *et al*., 1989). The existence of a high within-family variation, equal in magnitude to within-population variance, seems to be genetic in origin (Banerjee and Maze, 1988). As in other conifers, germination parameters are clearly under maternal control because a high percentage of the phenotypic variance was determined by family variation (Bramlett *et al*., 1983; St. Clair and Adams, 1993; Sorensen and Cress, 1994). On the other hand, variation among-plots is mainly caused by environmental differences associated to experimental units.

Components of phenotypic variance. Significant differences among half-sib families were found for all germinative characteristics (Table 4); means varied from 35.1% (parameter a) to 89.2% (parameter b). In the former case, a low percentage also indicates a low genetic contribution involved in germination onset; the higher amount of variance, associated to the scale factor «b», on the other hand, strongly suggests that differences among seedlots reflect a significant genetic influence on that parameter, regardless the small number of half-sib families compared in this study.

Table 4. Components of phenotypic variance (%) of germinative traits and Weibull´s parameters for 20 half-sib ponderosa pine families.

Source	DF	Germinative traits					Weibull´s parameters		
		ArcSin	(TOG)	PV	GV	GS	a	b	c
Family	19	48.8*	44.4*	62.3**	60.4**	44.4*	35.1*	89.2**	51**
Error	20	51.2	55.6	37.7	39.6	55.6	64.9	10.8	49

*Significant (P ≤ 0.05); ** Highly significant (P ≤ 0.01)

LSD mean comparison test. For all seed traits and germination parameters was used the *Fisher´s Least Significant Level (LSD) test,* a multiple comparison procedure, and the *significant level of 5%* (P = 0.05). Percent seed germination (G), expressed as angular transformation ArcSin √G*0.01, varied from 45 (families 7 and 16) to 90 (families 14 and 15); moreover, means of families with the highest germination capacity included in group a (Table 5), varied from 67.5 to 90, while group d, which included families of the lowest germination capacity showed averages between 45 and 67.5. Three groups of significance were found for time of germination 50% (TOG); group c, which showed the fastest germination of them (TOG = 4), included 17 families; while the slowest germination group consisted of families 19, 11 and 4, whose TOG means were, respectively, 5.5, 5 and 5 days. The Czabator´s germination value (GV) describes completeness and speed of germination process, so then it is a good criterion to compare family performance. More variation was observed in GV means (Table 5), because seven significant groups were formed; group a, for instance, included seven of better performance families with the highest GV values; on the other hand, group g included eight of lower performance families with the smallest GV values.

Time of germination for 50% (TOG) in all families took place 4-5.5 days after sowing. These results agreed with other general findings in which southern pine populations did not require pre-chilling treatment (Larson, 1963; Hoff, 1987; Gossling, 1988). Number of days required to start germination was statistically the same for all half-sib families; this result was expected because seeds were non-dormant when running the germination test; in other words, stratification treatments were not required, by any seed lot compared here, to begin germination.

Families 15, 14, and 6 had the best performance by comparing the germination capacity (Arcsine), TOG, and GV. Those germination parameters are indicators of high quality seed lots, thus, they measure germinative energy of seeds via percentage of viability, completeness and rate of germination. Peak Value means of ten families were statistically superior to population mean (17.0) and families 3, 6, 14 and 15 were statistically superior to any progeny whose mean was < 17.2. Most half-sib families (60%) had fast germination because their average GS values were superior to the population mean. In this germination test, family 14 was the fastest germinating seedlot (0.252), while family 19 performed as the slowest germinating seedlot (GS = 0.183).

Table 5. Mean comparison test[1] (LSD) for seed germination [expressed as ArcSin √(% germination)*0.01], time of germination 50% (TOG), and germination value (GV).

Family Number	ArcSin	Group	TOG (days)	Group	GV	Group
15	90.0	a	4.0	c	281	a
14	90.0	a	4.0	c	281	a
6	80.8	ab	4.0	c	283	a
12	80.8	ab	4.0	c	215	abcd
11	80.8	ab	5.0	ab	201	abcde
10	80.8	ab	4.5	bc	226	abc
1	73.4	abc	4.5	bc	166	bcdef
18	73.4	abc	4.5	bc	176	bcde
3	71.6	abc	4.0	c	253	ab
13	67.5	abcd	4.0	c	189	bcde
19	67.5	abcd	5.5	a	125	defg
2	64.2	bcd	4.0	c	145	cdefg
4	64.2	bcd	5.0	ab	151	cdefg
8	64.2	bcd	4.0	c	178	bcde
17	63.4	bcd	4.0	c	180	bcde
5	57.1	cd	4.0	c	156	cdefg
20	57.1	cd	4.5	bc	112	efg
9	53.8	cd	4.0	c	133	defg
7	45.0	d	4.0	c	78	fg
16	45.0	d	4.5	bc	70	g

[1]/Means with the same letters are not significantly different ($P \leq 0.05$).

The means of Weibull parameters for the seed lots are listed (Table 6). Ten means of parameter «a», one of parameter «b» and 12 of parameter «c» belong to group a and they were statistically superior to most population means. The shape parameter «c» has a strong genetic influence from maternal parent. Significant effects of family component found in this experiment, are indicative of genetic variation among half-sib families. It was initially discussed that mean parameter «c» describes among half-sib families. It was initially discussed that mean parameter «c» describes the shape of the curve. Values of «c» near 3.6 (Table 6), like those for families 1 and 13 (3.5), describe a symmetrical curve (approximately normal), which also means a more uniform germination; if «c» decreases below that value (families 2, 19 and 20), the shape of the curve will be possibly skewed (the pronounces tail to the right); shapes negatively skewed, on the other hand, are correlated with values of «c» greater than 3.6 (Families 3, 5, 6 and 7). Several authors (Bonner and Dell, 1976; Bahler *et al*., 1989) stated that an increase in parameter «a» and decrease in «b» and «c» are correlated with a decrease in seed quality. The scale factor «b» is inversely associated to increase in germination capacity and germination rate of seed lots, so a faster or more vigorous germination will be reflected in lower values of the parameter «b». Comparing the larger scale parameter of family 19 (2.8) with that of family 6 (1.0), it can be suggested that the firs progeny has a lower seed quality. In this sense, GS and GV parameters suggest the same conclusion.

Table 6. Mean comparison test[1] (LSD) of seed germination traits and Weibull's parameters for 20 half-sib ponderosa pine families.

Family Number	Peak Value (PV)		Germination speed (GS)		Weibull´s Parameters					
					a		b		c	
15	22.5	ab	0.250	a	2.2	d	1.6	b	7.0	ab
14	22.5	ab	0.250	a	2.8	abc	1.0	e	8.0	a
6	23.8	a	0.250	a	2.6	bcd	1.0	e	8.0	a
12	18.0	bc	0.250	a	3.0	ab	1.1	de	3.0	bcd
11	17.0	cd	0.200	bc	2.9	abc	1.6	b	3.0	bcd
10	19.0	abc	0.225	ab	2.8	abc	1.3	cd	6.0	abc
1	15.5	cde	0.225	ab	2.7	bc	1.5	bc	3.5	bcd
18	15.9	cde	0.225	ab	3.0	ab	1.1	de	3.0	bcd
3	22.5	ab	0.250	a	2.6	bcd	1.0	e	8.0	a
13	17.8	bcd	0.250	a	2.7	bc	1.1	de	3.5	bcd
19	11.7	e	0.183	c	2.8	abc	2.8	a	2.0	cd
2	14.2	cd	0.250	a	3.0	ab	1.1	de	1.0	d
4	15.0	cde	0.200	bc	3.2	a	1.1	de	5.0	abcd
8	17.5	bcd	0.250	a	2.5	cd	1.3	cd	5.0	abcd
17	18.0	bc	0.250	a	2.8	abc	1.1	de	5.0	abcd
5	17.5	bcd	0.250	a	2.6	bcd	1.0	e	8.0	a
20	12.5	de	0.225	ab	3.0	ab	1.2	de	1.0	d
9	16.2	cde	0.250	a	2.6	bcd	1.0	e	8.0	a
7	12.5	de	0.250	a	2.6	bcd	1.0	e	8.0	a
16	11.2	e	0.225	ab	2.7	bc	1.0	e	5.5	abc

[1]/Means with the same letters are not significantly different ($P \leq 0.05$)

Conclusions

1. There was among-family and within-family significant variation associated for all seed traits and Weibull parameters. These findings suggest that analyzed characters are under control of both genetic and environmental control.

2. Czabator´s GV and Weibull´s parameters were useful criteria to compare overall performance of seed lots. Half-sib families 6, 14, and 15 were consistently superior to the rest of seed lots for germination parameters Arcsine, TOG, PV and GV.

3. Seed weights e» 60 mg were positively correlated with high percentages of sound and viable seeds, fast germination (TOG = 3) and higher imbibition rates (IMB).

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