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Original Article

Seed and Cone Morphological Variation and Seed Germination Characteristics of Scots Pine Populations (*Pinus sylvestris* L.) in Mongolia

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Abstract

Key words: cone, seed, morphological traits, variation, seed germination, Scots pine, Mongolia

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Variation in cone size, seed number per cone, seed morphology and seed germination characteristics of *Pinus sylvetsris* L., and its relation to stand conditions was analyzed. Data were collected from *P. sylvestris* natural seed stands in four provinces of Northern Mongolia, namely, Selenge, Khuvsgul, Khentii and Tuv provinces. Cone morphological characteristics as well as their seed production were measured. Seeds were extracted from the collected cones, seed traits were measured and their germination characteristics was examined. The study results revealed that two sources, namely Yangiin ar area, Binder district, Khentii province and Ikh-Ulunt area, Bugant district, Selenge province showed the best and stable performance in all measured traits of seed quality, cone and seed morphological traits, whereas Mukhar dukhum area, Selenge province were lowest in all the measured traits among the studied seed populations. These seed sources are recommended for better productivity and vigorous seedlings in Mongolia, particularly in the research site of this study.

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Introduction

Scots pine (*Pinus sylvestris* L.) covers a climatically diverse continuous habitat, which ranges from Central and Northern Europe to Russia and Northern-Central Asia (Boratynski, 1991). Additional parts of the habitat are isolated, for instance the Pyrenees, Scotland and Northern Turkey. *Pinus sylvestris* is a very important tree species in several countries due to its wood quality for commercial purposes. Within its extensive natural geographic range, Scots pine is the most widely distributed member of the family *Pinaceae* in the world, and exhibits considerable genetic, morphological and ecophysiological variations. The longitudinal range of Scots pine covers over 14,000 km and extends from 8°W in Spain to 141°E in Siberia. The latitudinal range of Scots pine covers over 3,700 km and extends from 37°N in Turkey to 70°N in Norway, Sweden, and Finland (Critchfield, 1966). Diversity in desirable traits entailed first seed movements in Europe as early as 18th century. This was also the case for the first provenance experiments established in France in 19th century. Since that time the ecotypical or clinal variation within this species in a number of traits has been well known base on results of from many provenance tests (Wright & Bull, 1963; Steinbeck, 1966; Wright *et al*., 1966; Giertych, 1979; Giertych & Oleksyn, 1992; Stephan & Liesebach, 1996; Shutyaev & Giertych, 1997, 2000; Oleksyn *et al*., 1992 b, 1998, 2000, 2001; Chmura, 2000 a, b). Although performance and adaptation of *P. sylvestris* provenances has been well studied in the northern or continuous range, not much information exists in the non-continuous or southern range, where more complex mechanisms of evolution affect the differentiation of the species.

The vertical dimension of its habitat is extraordinarily large. *Pinus sylvestris* is a significant carrier species of various ecosystems from low elevations up to the mountainous regions and in some cases also in the sub-alpine vegetation zones. A great variety with respect to morphological traits, especially habitats and growth, is evident throughout the habitat of *P. sylvestris*.

Pinus sylvestris is the one of the most important economic timber species even their distribution is very limited in Mongolia compared with *Larix sibirica*, and *P. sylvestris* stand covers approximately 4.9% of total forest cover of Mongolia (MNET, 2017), and distributes in sub-taiga elevation zone. Southern borderline of *P. sylvestris* distribution crosses the Mongolian border and main massive are distributed in Khentii mountain ranges and goes along the ridge of Khantai-Buren-Buteeliin mountains in the northwest and goes to water catchments area of Orkhon-Selenge, then turns to the south in Onon-Balj-Barkhiin river basins in the South Khentii. From the South Khentii it turns to northeast along Bayan-Uul-Ereen Davaa area. The southernmost distribution of *P. sylvestis* found in the Orkhon-Tuul river basins, and southern and southeastern edge of the Bogd Khan Mountain Strictly Protected Area (Map of Forest Distribution of Mongolia, 1981).

Genetic variation within and between populations is essential to exploit their improvement potential and is considered to be a substantial determinant of adaptive abilities of populations; also, it is best indicated for the knowledge of extent of variation available within the species (Subramanium *et al*., 1992). The significance of provenances and seed source variation studies in tree improvement is well recognized (Callaham, 1964; Wright, 1976; Suri, 1984).

Seed source variation with respect to cone, seed and seedling characteristics is well documented for a number of tree species (Yeatman, 1966; Khalil, 1974; Venator, 1974; Birot, 1978; Salazar, 1986; Isik, 1986; Bethune & Longdon, 1986; Dvorak et al., 1996; Singh et al., 1996; Thapliyal & Dhiman, 1997; Roy *et al*., 2004; Mukherjee, 2005).

Cone and seed characteristics have been shown to vary among species, provenance and genotypes in pines and are well documented by Langdon (1958), Anderson (1965), Khalil 1974), Sorenson and Miles (1978), Singh *et al.* (1996), Thapliyal and Dhiman (1997).

Cone size (length and width) and seed size (length, width and weight) have been used for intra-specific taxonomic distinction between populations of *Pinus gregii* (Donahue & Upton, 1996), while parameters like seed weight and length are useful for classifying provenances into high and lowland groups in *Pinus caribea* (Salazar, 1986). Environmental factors in combination with genetic and physiological ones play important role in determining a forest tree's potential for seed quality, by determining its flowering threshold intensity and periodicity of flowering and fertility of seed. Thus, characters of seed quality appear under strong genetic control. Depending on the species, seed germination varies according to latitude, elevation, soil moisture, soil nutrient, temperature, type and density of plant cover, and degree of habitat disturbance of the site where the seeds are matured.

Genetic variation is the fundamental component of adaptation and stability of the forest ecosystems. This is particularly important when the long-term stability of forest ecosystems is increasingly threatened by environmental stress and mismanagement. Thus, a genetic characterization of natural forest resources is an essential step for a better understanding of genetic resources for the implementation of *in situ* and *ex situ* conservation activities.

The objectives of this study were to investigate seed and cone morphological characteristics and seed germination characteristics of several northern populations of *P. sylvestris* in Mongolia, and determine their within population variations, using 17 different morphological characters of cone, seed and seed germination.

Materials and Methods

Geographic locations of the studied populations.

The locations of fourteen different populations of *P. sylvestris* in the four provinces namely, Khentii, Khuvsgul, Selenge and Tuv, Mongolia listed in Table 1. Four populations from Khentii, eighth populations from Selenge, one population from Khuvsgul and Tuv provinces were selected for this study.

Measurement of cone and seed characteristics.

Collection of cones was carried out in March, 2018. Thirty representative trees of the approximately same age from the natural stands of *P. sylvestris* were subjected to cone collection, and selected trees were located at minimum 50 m apart from one another, and thirty cones with three replications were collected from each tree (in total of 900 cones). The variation in cone, seed and seed quality characteristics were measured. Cone size (length and width), seed size (length and width), seed wing size (length, width and area) were measured with Vernier calipers; number of scales (upper, middle and lower part of cone) was counted and number of seeds per cone was determined after seeds are extracted manually (Stoehr, 2000; Johnson *et al*., 2003). Cone fresh weight was measured and then after oven-dried in 72°C for 48 h, cone dry weight was measured. Seed wing area was estimated using wing size (length multiplied by width).

Seed germination in the laboratory.

The germination capacity in a germination cabinet was considered as the standard method in this study. One hundred seeds with four replications from each seed source were soaked in distilled water for 24 hours then germinated on filter papers in Petri dishes under light condition for 21 days. Temperature was maintained at 25^0C to 26^0C. Germination was checked everyday and seeds were considered germinated when the length of root radicle was twice as large as seed size. Seed germination values, such as germination capacity (*GC*) and germination energy (*GE*), were recorded. Germination capacity is the proportion of total germinated seeds to that of sown seeds, which is expressed in percentage. Germination energy (also expressed in percentage), which is one of the commonly employed indices of germination speed (ISTA, 1999), was computed as the proportion of total germinated seeds after 7 days to that of total germinated seeds after 21 days.

Statistical analysis.

The differences in cone, seed and seed germination characteristics between different provinces and seed sources were determined by analysis of variance (ANOVA) (SAS 9.2, SAS Institute Inc., NC, USA, 2008). Duncan's multiple range test (DMRT) was used for multiple comparisons. Pearson's correlation analysis was used to examine the relationship between the different traits of cone, seed and seed germination.

Table 1. Description of populations used in this study

No	Provinces	District name	Population name	Seed region**	Lat (N)	Long (E)	Alt (m)	Mean annual temperature (^{0}C)*	Annual precipitation (mm)*
1	Khentii	Binder	Uvur-Khuurt	Ereenii nuruu	48.38	110.25	1198	0.1	399.54
2	Khentii	Binder	Yangiin ar	Ereenii nuruu	48.38	110.28	1084	0.1	399.54
3	Khentii	Dadal	Shanagan	Ereenii nuruu	48.57	111.37	1064	0.7	454.94
4	Khentii	Norovlin	Zamt	Ereenii nuruu	48.44	111.30	957	-0.3	374.0
5	Selenge	Altanbulag	Gun nuur	Bayanhan-Uul	50.15	106.38	671	0.8	371.94
6	Selenge	Altanbulag	Togos uul	Bayanhan-Uul	50.03	106.35	773	0.8	371.94
7	Selenge	Javkhlant	Yargait	Shariin gol	49.41	106.41	706	-1.5	371.94
8	Selenge	Bugant	Ikh-Ulunt	Yuroo-Khuder	49.25	107.20	882	-1.2	504.1
9	Selenge	Shaamar	Tsaram	Bayankhan-Uul	50.05	106.05	761	0.8	371.94
10	Selenge	Khuder	Tukhum	Yuroo-Khuder	49.46	107.13	893	-1.3	486.96
11	Selenge	Shariin gol	Monostoi	Shariin gol	49.11	106.39	1089	-0.4	371.94
12	Selenge	Altanbulag	Mukhar dukhum	Bayankhan-Uul	50.11	106.37	701	0.8	371.52
13	Tuv	Bayanchandmani	Urgun bulgiin am	Jargalant	50.31	101.37	1534	0.5	337.06
14	Khuvsgul	Tsagaan-Uur	Ongonii nars	Tsagaan-Uur	48.43	106.39	1144	-3.5	462.96

**Source: Long-term mean annual temperature and precipitation data obtained from Information and Research Institute of Meteorology, Hydrology and Environment, 2018.*

**Source: Jamiyansuren *et.al*. (2019).

Results and Discussion

Cone morphological characteristics.

Considerable variation in cone morphological traits was observed among provinces and populations. Cone characteristics, such as cone length (*CL*), cone width (*CW*), number of scales in upper part of cone (*SU*), number of scales in lower part of cone (*SL*), number of scales in middle part of cone (*SM*), total scale number (*TS*), total seed per cone (*TSN*), cone fresh weight (*CFW*) and cone dry weight (*CDW*) were varied significantly among provinces and populations (Table 2).

The average cone length and cone width were 41.61±0.18 mm, 21.15±0.07 mm, respectively; longer cones (42.34±0.28 mm) was observed in from Khentii province, while shorter cones (38.72±0.60) were originated from Khuvsgul province. In case of variation at the population level, Bugant, Ikh-Ulunt population had longest and widest cones (52.98±0.62 mm and 22.33±0.21 mm), while shortest and narrowest cones (37.81±0.64 mm and 18.72±0.23 mm) were originated from Khuder, Tukhum population, Selenge province (Fig. 1).

The average of total scale number was 51.64±0.32, which is varied between 39 to 68 per cone, and highest number of scales (varied between 15-29 scales) were observed in middle part of the cone, while lowest number of scales

Table 2. ANOVA for cone morphological characteristics of studied populations of *P. sylvestris* (n=900)

Variables	DF	CL, mm	CW, mm	Number of scales			Total scale number	Number of seeds per cone	CFW, g	CDW, g
				Upper	Lower	Middle				
Provinces	3	14.93***	24.24***	268.01***	98.05***	61.70***	192.39***	7.08***	45.21***	42.08***
Populations	13	52.61***	29.89***	387.64***	53.98***	69.42***	177.80***	14.57***	42.65***	46.33***

*Note: ns - not significant, * - significantly different at 0.05, ** - significantly different at 0.01, *** - significantly different at 0.001*

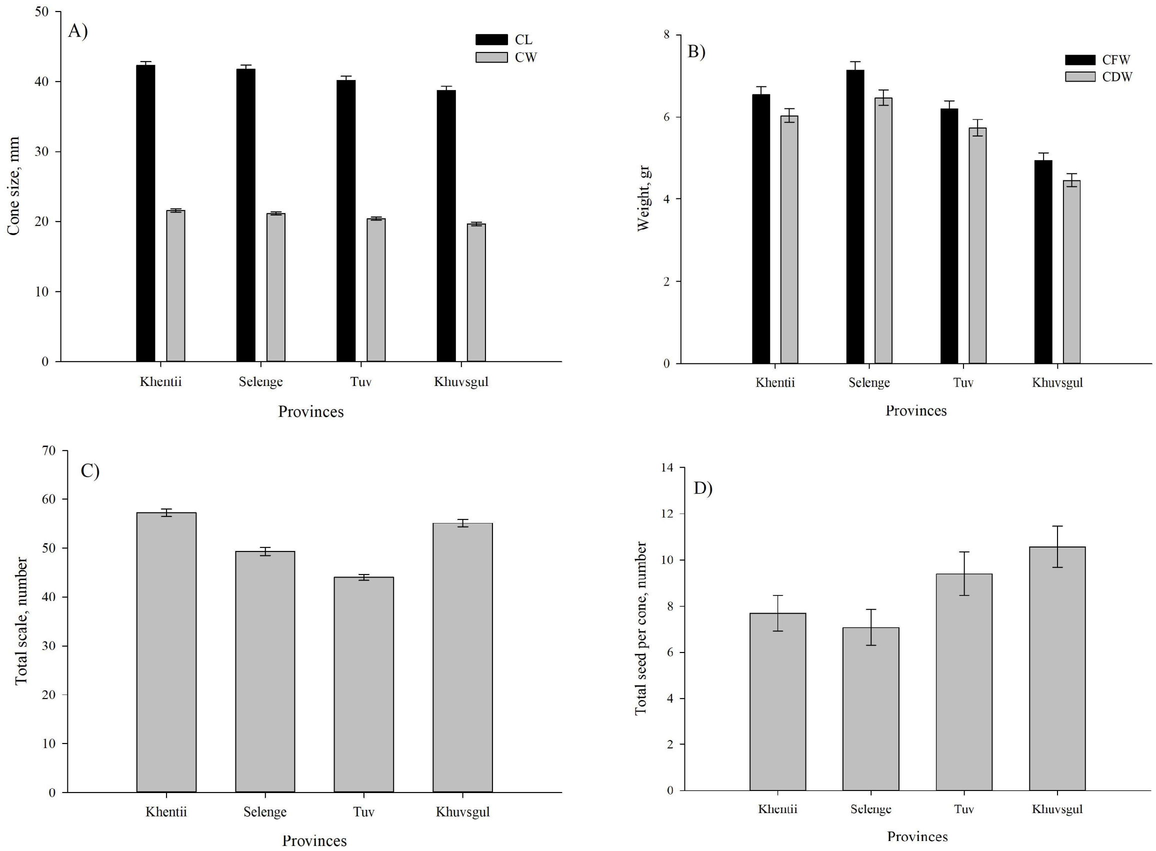

Figure 1. Cone morphological variation of *P. sylvestris* in different provinces, A) mean value of cone length and width, mm; B) mean value of cone fresh and dry weight, gr; C) mean value of total scale number, and D) mean value of total seed number per cone (mean±SE).

Table 3. Variations of studied cone traits for *P. sylvestris* from different provinces (n=900).

Provinces	CL, mm	CW, mm	Number of scales			Total scale number	Number of seeds per cone	CFW, g	CDW, g	Ranking
			Upper	Lower	Middle					
Khentii	42.34a	21.62a	12.35a	21.43a	23.49a	57.26a	7.68bc	6.54b	6.03b	I
Selenge	41.79a	21.19a	10.12b	19.19b	20.02b	49.33c	7.08c	7.13a	6.46a	II
Tuv	40.15b	20.38b	8.20d	16.67c	19.18b	44.04d	9.4ab	6.19b	5.73b	IV
Khuvsgul	38.72c	19.66c	10.48c	21.93a	22.72a	55.13b	10.56a	4.94c	4.46c	III

Note: Means with different letters are significantly different according to Duncan's multiple range test at 5% level.

(varied between 7-18 scales) were counted in upper part of the cones. At the population level, Bugant, Ikh-Ulunt population had highest number of scales (68.19±0.87), and lowest (39.58±1.27) was measured in population of Altanbulag, Mukhar dukhum areas, both from the Selenge province (Fig. 2).

The average of number of seeds per cone was 7.67±0.24, ranged between 7-11 among provinces, and higher number of seeds was extracted from Khuvsgul (10.6±0.9) and lowest was from Selenge province (7.08±0.31), respectively. While, at the population level, Binder, Uvur-Khuurt population from Khentii province had higher number of seeds per cone (11.29±0.88), while fewer seeds were observed in population of Javkhlant, Yargait (1.80±0.38) (Fig. 3).

The average cone fresh and dry weight were 6.74±0.06 g and 6.14±0.06 g, respectively, for studied provinces and populations, and heaviest cone was measured in Selenge province, 7.13±0.08 g and 6.46±0.07 g in their fresh and dry weight, respectively. Meanwhile, lighter cones were observed from populations of Tsagaan-Uur, Ongonii nars 4.94±0.17 g and 4.45±0.16 g in their fresh and dry weight, respectively (Table 6). At the population level, heavier cones were originated from Bugant, Ikh-Ulunt and lighter cones were observed in the population of Tsagaan-Uur, Ongonii nars population, Khuvsgul province, respectively.

The overall ranking results on cone morphological parameters among provinces and populations shows that seeds collected from Khentii province at the regional level, and Bugant, Ikh-Ulunt population from Selenge province had outstanding characteristics in all measured cone traits. Meanwhile, lower results in all measured parameters was observed in Tuv province at both regional and population levels (Table 6).

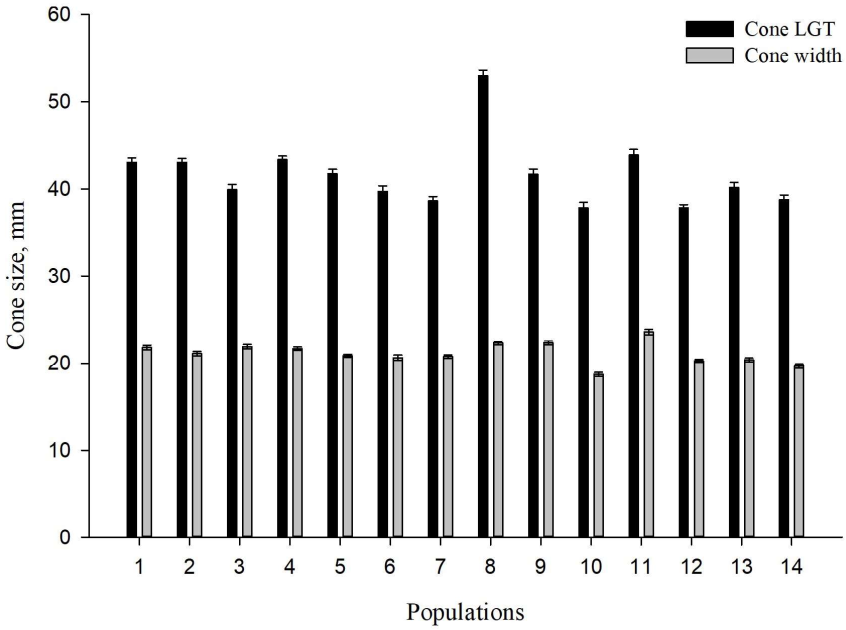

Figure 2. Within population variation in cone size (mean±SE).
For name of populations, refer to Table 1.

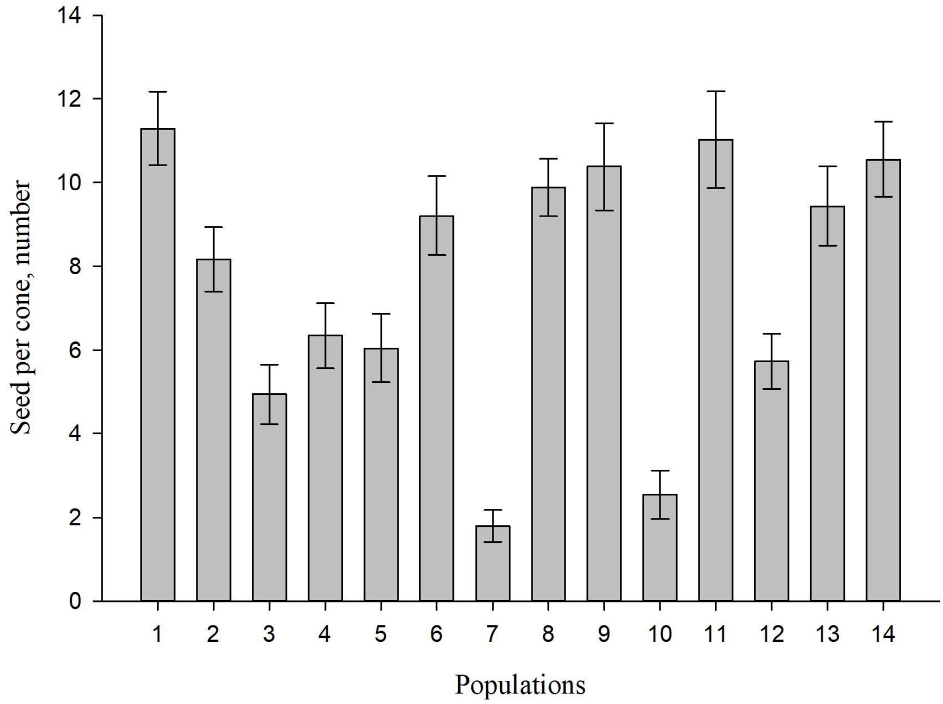

Figure 3. Within population variation in number of seeds per cone (mean±SE).
For name of populations, refer to Table 1.

Simple correlation analysis on cone morphological traits revealed that, total scale number (*r*=0.709; *p=0.004*), cone weight (fresh weight *r*=0.882; *p=0.004*; dry weight *r*=0.899; *p=0.0001*), seed wing length (*r*=0.663; *p=0.0096*) and seed wing area (*r*=0.662; *p=0.009*) were positively correlated with cone length at the population level.

Seed morphological characteristics.

Similarly, with cone morphological characteris-

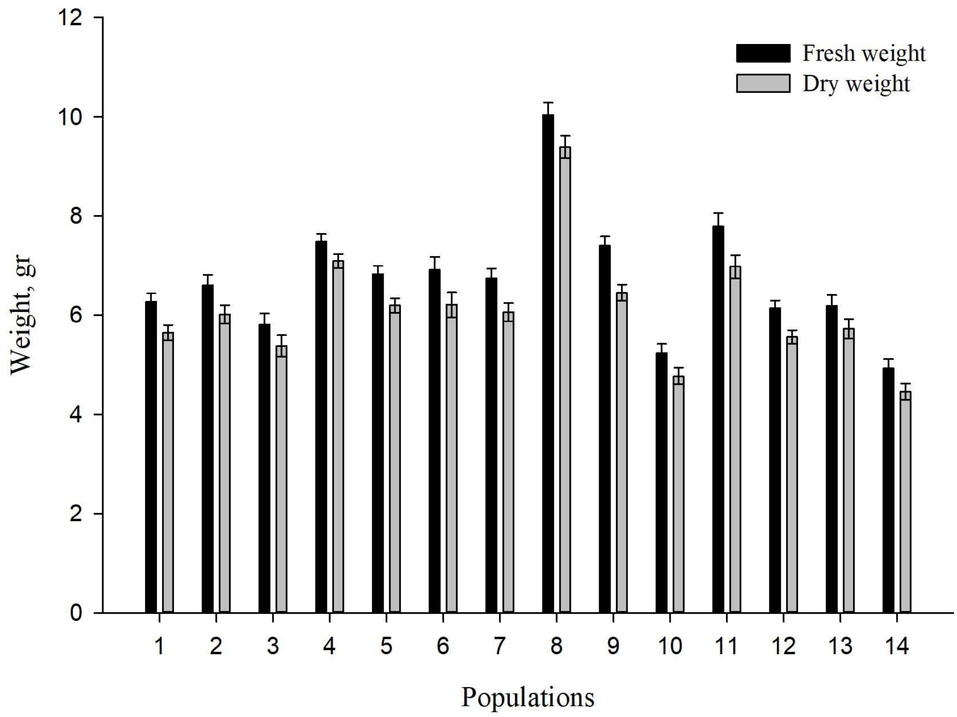

Figure 4. Variation in cone weight in different populations of *P. sylvesrtris* (mean±SE).
For name of populations, refer to Table 1.

tics, statistically significant variation was observed in seed morphological traits, such as seed length (*SL*), seed width (*SW*), seed wing length (*SWL*), seed wing width (*SWW*), and seed wing area (*SWA*) among provinces and populations (Table 4).

The average seed length and width were 4.54±0.04 mm and 2.86±0.19 mm, respectively, and longer seeds (4.61±0.02 mm) were observed in from Khentii province, while shorter seeds (3.98±0.04 mm) from Khuvsgul province. In case of variation at the population level, Dadal, Shanagan population had longer seeds (5.01±0.51 mm), and population of Javkhlant, Yargait had wider seeds (2.91±0.04 mm), while shorter and narrow cones (3.98±0.04 mm and 2.34±0.02 mm, respectively) were originated from Tsagaan-Uur, Ongonii nars population, Khuvsgul province.

The average of seed wing length and seed wing width was 14.42±0.11 mm and 5.44±0.02 mm, respectively, which ranged between 11-15 mm and 4-6 mm among provinces, and long seed wing was measured in Khentii and Selenge provinces (14.56±0.11 mm), while shorter seed wing was observed in Khuvsgul province (11.96±0.2 mm). At the population level, Dadal, Shanagan population from Khentii province had longer seed wings (5.01±0.27 mm), while shorter one was observed in Tsagaan-Uur, Ongonii nars population, Khuvsgul province (3.98±0.05 mm). In case of seed wing width, population of Javkhlant, Yargait had higher (2.91±0.05mm) value, whereas Tsagaan-Uur, Ongonii nars population, Khuvsgul had lowest (2.34±0.02 mm) value of measurements (Fig. 6).

The overall ranking results using seed morphological parameters among provinces and populations showed that seeds collected from Selenge province at the regional level and Bugant, Ikh-Ulunt population from Selenge province had outstanding characteristics in all measured traits. Meanwhile, lower results in all measured parameters was observed in Khuvsgul province at both regional and population levels (Table 7).

Seed germination characteristics.

Table 4. ANOVA for seed morphological characteristics of studied populations of *P. sylvestris* (n=900).

Source	DF	*SL*, mm	*SW*, mm	*SWL*, mm	*SWW*, mm	*SWA*,
Provinces	3	5.86**	0.72ns	18.22***	87.38***	44.24***
Populations	13	3.16***	1.15ns	22.22***	23.94***	27.42***

*ns- not significant, * - significantly different at 0.05, ** - significantly different at 0.01, *** - significantly different at 0.001*

Table 5. Means of seed morphological characteristics of *P. sylvestris*.

Provinces	SL, mm	SW, mm	SWL, mm	SWW, mm	SWA,	Ranking
Khentii	4.57a	2.58b	14.56a	5.38b	79.06a	II
Selenge	4.61a	2.76a	14.57a	5.64a	82.51a	I
Tuv	4.43a	2.56b	15.18a	4.86c	73.99b	III
Khuvsgul	3.98b	2.34c	11.96b	4.62d	55.97c	IV

Note: Means with different letters are significantly different according to Duncan's multiple range test at 5% level.

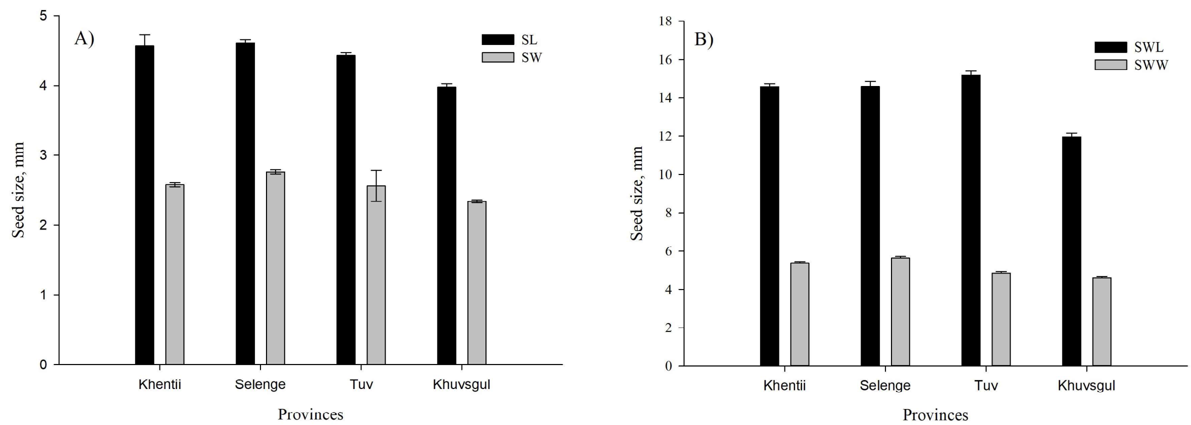

Figure 5. Seed morphological variation within provinces A) seed length and width, B) seed wing length and width (Mean±SE).

Table 6. Means of cone morphological traits in *P. sylvetsris* populations (n=900).

No	Provinces	Populations	CL, mm	CW, mm	Number of scales, number			Total scale number	Number of seeds per cone	CFW, g	CDW, g	Ranking
					Upper	Lower	Middle					
1	Khentii	Binder, Uvur-Khuurt	43.04(0.50)cb	21.80(0.27)b	10.90(0.18)cde	22.64(0.41)a	24.16(0.40)b	57.70(0.82)b	11.29(0.88)a	6.27(0.18)efgh	5.65(0.16)ef	III
2	Khentii	Binder,Yangiin ar	43.03(0.48)cb	21.12(0.24)cd	16.66(0.27)b	22.21(0.44)ab	28.29(0.39)a	67.16(0.91)a	8.17(0.77)bc	6.61(0.20)defg	6.02(0.18)cde	IV
3	Khentii	Dadal, Shanagan	39.91(0.59)d	21.90(0.26)b	11.00(0.15)cd	20.72(0.33)cd	20.84(0.43)de	52.57(0.81)d	4.94(0.71)d	5.01(0.23)i	5.39(0.21)f	VIII
4	Khentii	Norovlin, Zamt	43.36(0.39)cb	21.68(0.18)cb	10.86(0.12)cde	20.14(0.18)de	20.68(0.24)de	51.68(0.43)d	6.34(0.77)cd	7.49(0.16)b	7.10(0.14)b	V
5	Selenge	Altanbulag, Gun nuur	41.77(0.49)c	20.87(0.17)de	7.77(0.26)hi	16.90(0.54)g	18.09(0.40)hi	42.76(0.87)f	6.04(0.82)cd	6.83(0.16)de	6.19(0.14)cd	X
6	Selenge	Altanbulag, Togos uul	39.72(0.64)d	20.64(0.30)de	11.29(0.27)c	22.02(0.33)ab	18.90(0.42)gh	52.21(0.84)d	9.21(0.94)ab	6.92(0.27)cd	6.21(0.25)cd	VII
7	Selenge	Javkhlant, Yargait	38.61(0.52)de	20.77(0.20)de	7.57(0.10)i	17.17(0.23)g	17.49(0.25)i	42.22(0.46)f	1.80(0.38)e	6.74(0.20)def	6.06(0.18)cde	XII
8	Selenge	Bugant, Ikh-Ulunt	52.98(0.63)a	22.33(0.21)b	17.59(0.37)a	21.61(0.32)bc	28.99(0.47)a	68.19(0.87)a	9.89(0.68)ab	10.04(0.24)a	9.39(0.23)a	I
9	Selenge	Shaamar,Tsaram	41.71(0.58)c	22.33(0.23)b	10.07(0.14)f	19.39(0.31)e	19.58(0.31)efg	49.03(0.63)e	10.38(1.04)ab	7.40(0.20)bc	6.46(0.17)c	VI
10	Selenge	Khuder, Tukhum	37.81(0.64)e	18.72(0.22)g	8.96(0.14)g	18.44(0.27)f	20.29(0.41)def	47.69(0.64)e	2.54(0.58)e	5.24(0.19)i	4.78(0.17)g	XIII
11	Selenge	Shariin gol, Monostoi	43.85(0.69)b	23.57(0.29)a	10.63(0.23)de	21.30(0.44)bc	21.02(0.45)d	52.96(0.88)d	11.02(1.16)a	7.80(0.27)b	6.98(0.23)b	II
12	Selenge	Altanbulag, Mukhar dukhum	37.82(0.36)e	20.28(0.17)ef	7.07(0.11)j	16.70(0.20)g	15.81(1.23)j	39.58(1.27)g	5.73(0.66)cd	6.14(0.15)gh	5.57(0.13)ef	XIV
13	Tuv	Bayanchandmani, Urgun bulgiin am	40.15(0.60)d	20.38(0.22)e	8.20(0.12)h	16.67(0.23)g	19.18(0.37)fhg	44.04(0.59)f	9.43(0.94)ab	6.19(0.21)fgh	5.73(0.20)def	XI
14	Khuvsgul	Tsagaan-Uur, Ongonii nars	38.72(0.60)de	19.66(0.25)f	10.48(0.22)ef	21.93(0.41)ab	22.72(0.39)c	55.13(0.79)c	10.56(0.90)ab	4.94(0.18)i	4.46(0.18)g	IX
Overall mean±SE			41.61±0.18	21.15±0.07	10.64±0.1	19.85±0.11	21.15±0.17	51.64±0.32	7.67±0.24	6.74±0.06	6.14±0.06	

Note: Values are the mean and the standard error of the mean in parenthesis; means with different letters are significantly different according to Duncan's multiple range test at 5% level.

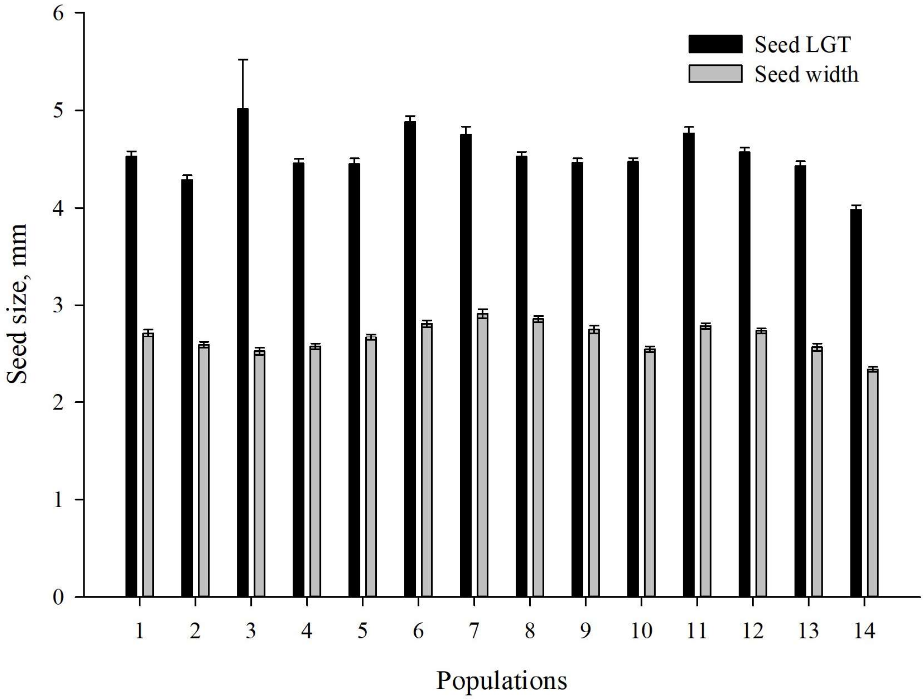

Figure 6. Within population variation in seed size (mean±SE).
For name of populations, refer to Table 1.

Seed quality testing, including germination energy (*GE*, %), germination capacity (*GC*, %), and 1000-seed weight was examined by the State Forest Seed Testing Laboratory, Ministry of Environment and Tourism, Mongolia, and the Laboratory of Forest Genetics and Ecophysiology, National University of Mongolia.

Seed testing results within provinces of *P. sylvestris* showed non-significant differences in all tested variables, meanwhile we found statistically significant differences within population (Table 8).

In most plant species, seeds vary in their degree of germinability between and within populations and individuals (Benowicz *et al*., 2000 and 2001; Gera *et al*., 2000; Mkonda *et al*., 2003). Some of this variation can be of genetic origin, but much of it is known to be influenced by the environmental factors, *i.e.* caused by the local conditions under which seeds become matured.

The overall mean germination capacity (*GE*) and germination energy (*GC*) were 68% (varied from 50% to 81%) and 69% (varied from 51% to 81%), respectively. Highest germination value was shown by population Binder, Yangiin ar (*GE*=80.8% and *GC*=81%). Whereas lowest germination value (*GE*=50.5% and *GC*=51%0) was revealed by population Dadal, Shanagan (Table 10). Bat-Erdene (2000) found that mean viability of *P. sylvestris* seed sources collected during 1992-1994 from different regions of Mongolia, varied between 89.5% and 96.2%.

In the present study, no particular correlation was found between seed weight and seed germination parameters. Previous research results on seed quality of Scots pine from same forest vegetation subregions showed that heavier seeds had good germination capacity, good performance in growth and biomass accumulation (Batkhuu *et al*., 2009). Under limited available resources, plant may allocate the available resource to the production of fewer larger seeds or many smaller ones (Harper *et al*., 1970).

The mean weight of 1000 seeds was 5.75 g (Table 10). The heaviest seed (7.1 g) was found in population Altanbulag, Togos uul, Selenge province, while the lightest one (4.6 g) was found in population Khuder, Selenge province. Udval (2014) reported that seed weight of *P. sylvestris* collected in the Selenge province was 8.0 g, and germination percentage was 92.5% which considered as category I according to the Mongolian National Standard (MNS-5994:2009). Physiologically, seeds with greater mass have more developed embryo and greater energy reserves, which produce plants with greater vigor and capacity to grow (Wrzesniewski, 1982a-c; Howe & Richter, 1982; Bonner, 1987; Righter, 1945; Dunlap & Barnett, 1983). Seed weight is

Table 7. Means of seed morphological characteristics of *P. sylvestris*.

No	Provinces	Populations	*SL*, mm	*SW*, mm	*SWL*, mm	*SWW*, mm	*SWA*	Ranking
1	Khentii	Binder, Uvur-Khuurt	4.53(0.05)bc	2.68(0.04)d	13.85(0.14)e	5.26(0.07)d	73.00(1.30)fg	XI
2	Khentii	Binder, Yangiin ar	4.29(0.05)cd	2.59(0.03)ef	15.29(0.27)bc	5.33(0.07)d	82.14(2.14)cd	IX
3	Khentii	Dadal, Shanagan	5.01(0.51)a	2.52(0.04)f	13.23(0.20)ef	5.29(0.08)d	70.29(1.60)g	XII
4	Khentii	Norovlin, Zamt	4.45(0.05)bc	2.57(0.03)f	15.87(0.14)b	5.67(0.09)bc	90.80(1.78)b	IV
5	Selenge	Altanbulag, Gun nuur	4.45(0.06)bc	2.67(0.03)f	15.33(0.13)bc	5.65(0.08)bc	86.98(1.27)bc	VI
6	Selenge	Altanbulag, Togos uul	4.88(0.06)ab	2.81(0.03)bc	12.44(0.18)fg	5.55(0.10)bc	69.12(2.18)g	VIII
7	Selenge	Javkhlant, Yargait	4.75(0.08)abc	2.91(0.05)a	14.01(0.18)e	5.68(0.08)bc	79.93(1.75)de	II
8	Selenge	Bugant, Ikh-Ulunt	4.52(0.05)bc	2.86(0.03)ab	17.84(0.14)a	5.70(0.07)b	102.16(1.76)a	I
9	Selenge	Shaamar, Tsaram	4.46(0.04)bc	2.80(0.04)bc	14.30(0.25)cde	5.93(0.10)a	85.62(2.40)bcd	III
10	Selenge	Khuder, Tukhum	4.47(0.04)bc	2.54(0.03)f	16.26(1.18)b	5.46(0.07)cd	88.63(6.14)bc	VII
11	Selenge	Shariin gol, Monostoi	4.76(0.06)abc	2.79(0.03)bc	14.21(0.19)de	5.55(0.07)bc	78.96(1.51)def	V
12	Selenge	Altanbulag, Mukhar dukhum	4.57(0.05)bc	2.74(0.03)cd	12.17(0.11)g	5.63(0.08)bc	68.72(1.27)g	X
13	Tuv	Bayanchandmani, Urgun bulgiin am	4.43(0.05)bc	2.56(0.04)f	15.18(0.22)bcd	4.86(0.08)e	73.99(1.71)efg	XIII
14	Khuvsgul	Tsagaan-Uur, Ongonii nars	3.98(0.05)d	2.34(0.02)g	11.96(0.20)g	4.62(0.07)f	55.97(1.53)h	XIV

Note: Values are the mean and the standard error of the mean in parenthesis; means with different letters are significantly different according to Duncan's multiple range test at 5% level.

also considered when assessing seed quality, because seedling growth during early stages is positively correlated with seed weight (Griffin, 1972; Mikola, 1980; Hendrix *et al*., 1991).

Conclusion

Significant geographic variations in cone and seed morphological traits, and seed germination characteristics were observed in *P. sylvestris* seed stands of Mongolia.

Table 8. ANOVA for seed characteristics of seed sources *P. sylvestris* (n=400).

Variables	df	F value	Pr>F
Weight of 1000 seeds			
Within province	3	183.60	<.0001
Within populations	13	202.53	<.0001
Germination capacity			
Within province	3	3.02	0.5641
Within populations	13	4.47	0.0148
Germination energy			
Within province	3	0.69	0.0415
Within populations	13	2.48	0.0001

Table 9. Means of seed germination characteristics of *P. sylvestris* (n=400).

Provinces	GC, %	GE, %	Ranking
Khentii	68.94a	67.86a	II
Selenge	67.88a	65.30ab	IV
Tuv	69.60a	55.20ab	III
Khuvsgul	76.80a	76.00a	I

Note: Means with different letters are significantly different according to Duncan's multiple range test at 5% level.

Cone and seed morphological traits were significantly differed within provinces and populations in all measured variables. Overall ranking of cone traits showed that Khentii province was superior among studied provinces, while, Tuv province showed lowest results in all measured variables. In case of seed morphological traits, Selenge province was superior, while, Khuvsgul province showed lowest value in all measured variables. In case of population variation in cone and seed traits, Bugant, Ikh-Ulunt population from Selenge province was superior, meanwhile, another population from Altanbulag, Mukhar dukhum showed lowest values in all measured variables of cone and seed morphology, among studied populations.

The seed quality traits of various populations of *P. sylvestris* revealed the existence of considerable geographic variation in seed quality traits (germination capacity, germination energy, weight of 1.000 seeds). The seeds originated from Khuvsgul province had good quality compared with other provinces, followed by Khentii, Tuv, and Selenge in terms of seed quality traits. But, only one population from Khuvsgul and Tuv provinces were used in this study, if we exclude these populations, seeds originated from Selenge province would have superior qualities among studied populations.

Overall ranking of seed quality traits showed, Yangiin ar population, Binder district, Khentii province had excellent performance among the studied populations, whereas Dadal, Shanagan

Table 10. Means of seed characteristics of *P. sylvestris* seed sources used for this study (n=400).

No	Provinces	Population	Seed germination energy, %	Seed germination capacity, %	1000-seed weight, gr	Seed quality category
1	Khentii	Binder, Uvur-Khuurt	74.00ab	74.75abc	5.11e	III
2	Khentii	Binder, Yangiin ar	80.75a	81.00a	5.12e	II
3	Khentii	Dadal, Shanagan	50.50de	51.00d	5.36d	NS
4	Khentii	Norovlin, Zamt	66.25abcd	69.00abcd	6.11c	III
5	Selenge	Altanbulag, Gun nuur	78.50a	79.75ab	6.91a	III
6	Selenge	Altanbulag, Togos uul	76.25a	76.50ab	6.97a	III
7	Selenge	Javkhlant, Yargait	46.40e	55.20cd	-	NS
8	Selenge	Bugant, Ikh-Ulunt	70.50abc	71.50abc	5.47d	III
9	Selenge	Shaamar, Tsaram	69.00abc	70.00abcd	6.10c	III
10	Selenge	Khuder, Tukhum	57.75bcde	59.50bcd	4.58f	NS
11	Selenge	Shariin gol, Monostoi	74.75ab	78.25ab	6.42b	III
12	Selenge	Altanbulag, Mukhar dukhum	54.00cde	55.50cd	5.08e	NS
13	Tuv	Bayanchandmani, Orgon bulgiin am	55.20cde	69.60abcd	-	NS
14	Khuvsgul	Tsagaan-Uur, Ongonii nars	76.00a	76.80ab	-	III
Overall mean			68.41	69.65	5.75	

Note: Means with different letters are significantly different according to Duncan's multiple range test at 5% level. NS-non standard or low quality seed.

population from Khentii province were lowest in their quality. According to seed quality category by Mongolian National Standard, none of populations had category I quality among studied populations, but only Binder, Yangiin ar population had category II, meanwhile other populations were categorized as III, and other populations were not qualified Mongolian standard, which means unsuitable for seedling production and reforestation.

In conclusion, seed sources Binder, Yangiin ar, Khentii and Bugant, Ikh-Ulunt, Selenge showed the best and stable performances in all measured traits of seed quality, cone and seed morphological traits, whereas source Altanbulag, Mukhar dukhum, Selenge were lowest in all the measured traits. Therefore, these seed sources with high seed quality and best performance are recommended for better productivity and vigorous seedlings in Mongolia, particularly in the research site of this study.

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