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Article

Potencial productivo de conos y semillas de dos especies del género *Pinus*

Productive potential of cones and seeds of two species of the *Pinus* genus

José Alexis Martínez Rivas[1], Francisco Cruz Cobos[1]*, José Gonzalo Gurrola Amaya[1], Juan Abel Nájera Luna[1]

Resumen

La necesidad de disponer de semillas forestales de calidad y en cantidad suficiente es importante para mitigar y revertir los procesos de deforestación y de cambio de uso de suelo que ocurren a nivel local, nacional y mundial; por tanto, el objetivo del presente estudio fue evaluar el potencial productivo de conos y semillas de dos especies de pino en la región de El Salto, Pueblo Nuevo, Durango, México. Se muestrearon 63 ejemplares de *Pinus cooperi* y 53 de *Pinus durangensis*; de cada árbol se recolectaron, en promedio, cinco conos y se contabilizó el total existente en toda la copa; se determinó la longitud, diámetro y el potencial biológico de cada cono, y se clasificaron las semillas como plagadas, abortadas y viables, mediante pruebas de rayos X. Los resultados mostraron que solo 17 % de las pertenecientes a *P. cooperi* y 21 % de *P. durangensis* fueron viables; 34 % y 27 % correspondieron a la categoría de abortadas; mientras que, 49 % y 52 %, respectivamente presentaron plagas. No se obtuvieron diferencias estadísticas para las variables de los conos y semillas en *P. durangensis* ($\alpha \leq 0.05\%$); sin embargo, para *P. cooperi* sí se registraron en la longitud del cono, potencial biológico y semillas desarrolladas.

Palabras clave: Análisis de semillas, eficiencia reproductiva, *Pinus cooperi* C. E. Blanco, *Pinus durangensis* Martínez, potencial biológico, producción de semillas.

Abstract

It is important to have forest seeds in sufficient quality and quantity in order to alleviate and reverse the processes of deforestation and land use change that occur at local, national and global levels; therefore, the objective of the present study was to evaluate the productive potential of cones and seeds in two pine species of the *El Salto* region in *Pueblo Nuevo*, *Durango*, Mexico. A total of 63 specimens of *Pinus cooperi* and 53 of *Pinus durangensis* were sampled; an average of five cones were collected from each individual, and the total number of the remaining cones in the whole crown of each tree was counted; the length, diameter and biological potential of each cone was determined, and the seeds were classified as infested, aborted and viable, based on X-ray tests. The results showed that only 17 % of the *P. cooperi* and 21 % of *P. durangensis* seeds in the region are viable, 34 % and 27 %, respectively, are aborted, and 49 % and 52 % are infested with pests. No statistical differences were found for the variables of the cones and seeds in *P. durangensis* ($\alpha \leq 0.05$ %); however, for *P. cooperi*, statistical differences were obtained in cone length, biological potential and developed seeds.

Keywords: Seed analysis, reproductive efficiency, *Pinus cooperi* C.E. Blanco, *Pinus durangensis* Martínez, biological potential, seed production.

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[1]Tecnológico Nacional de México-Instituto Tecnológico de El Salto, División de Estudios Profesionales e Investigación. México.
*Autor por correspondencia: cobos_cruz@yahoo.com.mx

Introduction

The number of viable seeds is an indicator of the ability of forests to remain at their original distribution sites (Alba *et al*., 2003; Vázquez *et al*., 2004). However, this seed potential varies significantly between years, populations and individuals, and may endanger the reproductive capacity of a species (Cain and Shelton, 2000; Quiroz *et al*., 2017). The variation in the number of seeds is ascribed, primarily, to environmental, biological (endogamy, pests and diseases), and other intrinsic factors of the tree (Mendizábal *et al*., 2015); this variability is rendered even more severe, in certain regions, by the selection processes utilized in forest management.

In the state of *Durango*, in recent years the *Comisión Nacional Forestal* (National Forestry Commission) has established the goal of producing 20 million pine seedlings in nurseries in order to meet the reforestation needs in areas affected by pests and forest fires, as well as of incorporating new areas into the forest production, for reforestation programs aiming at environmental compensation, and of meeting the demands of the providers of technical services who seek to attend to issues related to lack of renewal resulting from failure of the natural regeneration methods or from other conditioning factors established in the management programs. All of this calls for a strong program for collecting seeds, mostly from natural stands, due to the scarcity of certified seed areas in the state (López *et al.,* 2011).

If it is acknowledged that the success of natural regeneration depends primarily on the number of viable seeds, it is essential to implement constant monitoring in order to determine its modifications and take these into account in forest management programs. However, little is known about the potential viability of seeds of trees from natural stands under management to ensure the establishment of a new forest mass, particularly when regeneration cuttings are applied, or from seed trees; or for estimating the number of seeds required to meet the seedling production goals. Therefore, the objective of the present work was to assess the relationship between tree mensuration variables and the production potential of the cones, as well as the quantity and quality of *Pinus durangensis* Martínez and *Pinus cooperi* C. E. Blanco seeds in the *El Salto* region, in *Pueblo Nuevo, Durango*. These two species are the most abundant and have the most commercial interest, as they account for 80 % of the timber production in the area (Cruz, 2007).

Materials and Methods

Study area and climate

This study was carried out in the El Salto region, in Pueblo Nuevo, Durango, in geographical areas where *P. durangensis* and *P. cooperi* occur; the selected trees were located within three areas: 1) *El Brillante* and *La Victoria ejidos* and Adjoining Areas (*La Victoria* area); 2) *La Campana* and *San Esteban ejidos* and Adjoining Areas (*San Esteban* area), and 3) *La Ciudad (La Ciudad* area) (Figure 1).

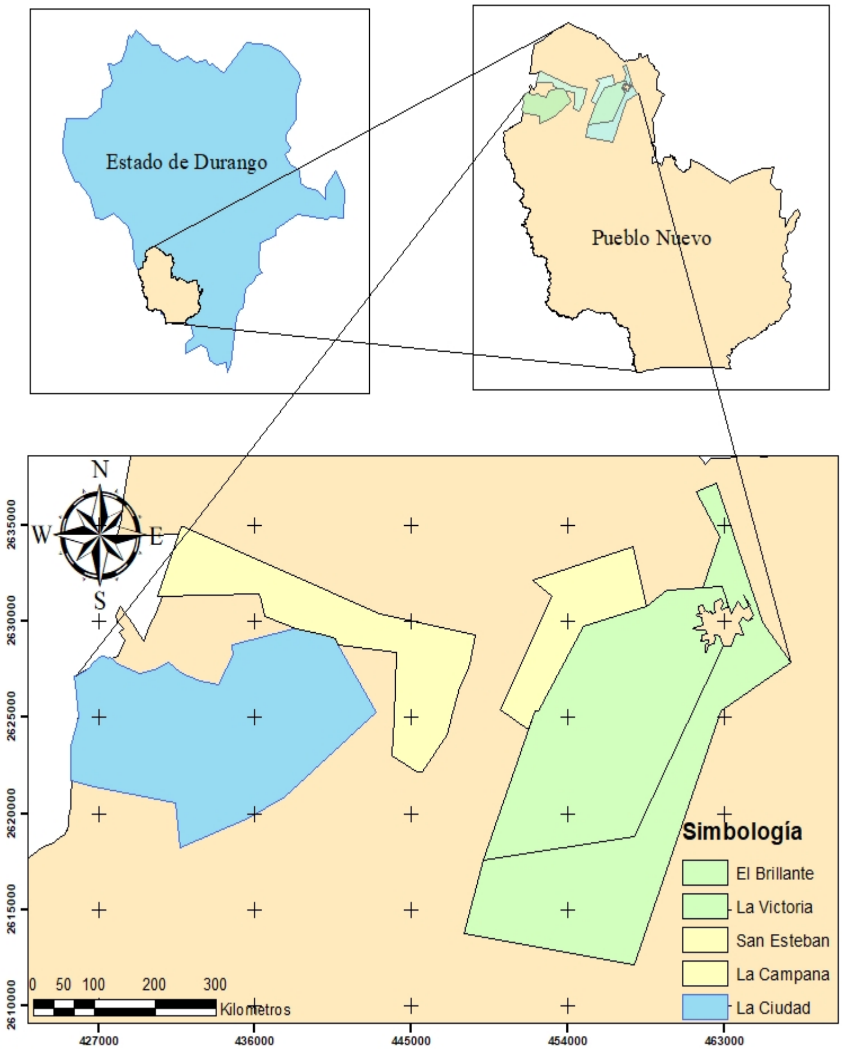


Figure 1. Location of the study area.

Its climate is temperate (C), a subgroup of semi-warm (A)C(w_1) and semi-warm subhumid climates with summer rains, a percentage of winter rainfalls ranging between 5 and 10.2 %, a mean annual precipitation of 800 to 1 200 mm, and a mean annual temperature of 20 to 22 °C (Inegi, 2010). The vegetation is made up of species of the genera *Pinus* and *Quercus*, as well as of other taxa associated with conifers and broadleaves, of the genera *Arbutus, Juniperus, Pseudotsuga, Abies*, and *Picea* (Inegi, 2005).

Selection of trees

A total of 63 *P. cooperi* specimens and 53 *P. durangensis* individuals with cones in mixed and irregular stands under forest management were selected. The normal diameter of each selected tree was measured at 1.3 m from the ground level, using a Haglöf Mantax 59722 caliper; its total height was measured with a Suunto Pm5 Spc clinometer, and the crown diameter was measured, with approximation in the centimeter range, using a TRUPER TP50ME tape. An average of five cones were collected from each individual, and the total number of cones in the crown was counted. This activity was performed during the maturity periods established by García and González (1998); the collections corresponded to the 2015-2017 reproduction cycle, and they were carried out during the months of October to December, 2017.

Assessment of the production potential

The length (*Cl*) and diameter (*Cd*) of 740 cones were determined; subsequently, the cones were placed in a brown paper bag for drying in a Yamato DNE-91 oven at 40 °C during 72 hours, in order to facilitate the opening of the scales and the release of the seeds. The seed potential (*Sp*), or production potential, was estimated according to the methodology of Bramlett *et al*. (1977), as the number of fertile scales multiplied by two. The biological potential (*Bp*) was obtained from the total scale count multiplied by two. For the developed seed (*Ds*), the cone destruction method was followed, and the seeds having completed their development stage were counted. The seeds were analyzed using X-ray tests, with replications with batches of 100 seeds selected at random, adding up to a total of

14 batches of *P. durangensis* and 19 batches of *P. cooperi*. Those seeds that interrupted the development of the embryo were classified as aborted, and those that exhibited insects at any stage of their reproduction within the seed were classified as infested; they were kept until the adult insects emerged and were fully identified; the seeds were classified as viable when they were not infested or aborted and had the ability to generate a new individual.

Assessed variables and data analysis

The recorded variables were the total number of cones in the crown, the cone diameter, the cone length, the developed seed, the biological potential and the developed seed potential; the variance analysis was based on the following model:

$$Y_{ijk} = \mu + S_I + A(S)_{IJ} + e_{ijk}$$

Where:

Y_{ijk} = Response variable

μ = General mean

S_I = Effect for the i^{th} area factor

$A(S)_{IJ}$ = Effect of the j^{th} level of the tree factor within the area

e_{ijk} = Experimental error

In the case of variables with significance, Tukey mean comparison tests were carried out for equal variances and unbalanced data (0.05 %), using the *InfoStat* 2018 statistical package. In addition, a Pearson's correlation analysis was applied in order to observe the level of association between the dasometric variables and the reproduction indicators.

Results and Discussion

Production potential

No variable of *P. durangensis* cones or seeds registered statistical differences between the assessed areas (Table 1), unlike *P. cooperi*, in which differences in cone length, developed seeds and developed seeds' potential were detected (Table 2).

Table 1. Variance analysis of *Pinus durangensis* Martínez by area.

Var	Factor	SS	DF	MS	*F*	*P*-value
Nc	Area	13 928.4	2	6 964.2	4.07	0.05
	Tree	72 381.61	25	2 895.26	1.69	0.09
	Error	44 445.42	26	1 709.44		
	Total	130 755.43	53			
Cl	Area	1.15	2	0.57	0.97	0.39
	Tree	20.48	25	0.82	1.39	0.2
	Error	15.29	26	0.59		
	Total	36.91	53			
Cd	Area	0.02	2	0.01	0.17	0.84
	Tree	2.32	25	0.09	1.57	0.13
	Error	1.54	26	0.06		
	Total	3.88	53			
Ds	Area	399.5	2	199.75	1.12	0.34
	Tree	4 936.69	25	197.47	1.11	0.4
	Error	4 638.98	26	178.42		
	Total	9 975.17	53			
Bp	Area	638.95	2	319.48	0.48	0.62
	Tree	15 483.82	25	619.35	0.93	0.57
	Error	17 280.61	26	664.64		
	Total	33 403.39	53			
Sp	Area	227.96	2	113.98	0.14	0.87
	Tree	24 930.6	25	997.22	1.18	0.34
	Error	21 887.36	26	841.82		
	Total	47 045.92	53			

Var = Variable; *Nc* = Number of cones; *Cl* = Cone length; *Cd* = Cone diameter; *Ds* = Developed seed; *Bp* = Biological potential; *Sp* = Seed potential; *SS* = Sum of squares; DF = Degrees of freedom; MS = Mean squares; *F* = Estimated *F; P*-value = Significance level at 0.05.

Table 2. Variance analysis of *Pinus cooperi* C. E. Blanco by area.

Var	Factor	SS	DF	MS	*F*	*P*-value
Nc	Area	5 135.47	2	2 567.73	2.37	0.11
	Tree	17 940.95	25	717.64	0.66	0.86
	Error	42 238.63	39	1 083.04		
	Total	65 315.04	66			
Cl	Area	13.28	2	6.64	14.33	<0.0001
	Tree	12.58	25	0.5	1.09	0.40
	Error	18.07	39	0.46		
	Total	43.93	66			
Cd	Area	0.24	2	0.12	1.74	0.19
	Tree	1.07	25	0.04	0.62	0.90
	Error	2.68	39	0.07		
	Total	3.99	66			
Ds	Area	2 265.61	2	1 132.8	4.56	0.02
	Tree	5 689.65	25	227.59	0.92	0.58
	Error	9 684.03	39	248.31		
	Total	17 639.29	66			
Bp	Area	1 073.6	2	536.8	0.51	0.61
	Tree	24 962.21	25	998.49	0.94	0.55
	Error	41 321.35	39	1 059.52		
	Total	67 357.16	66			
Sp	Area	8 219.06	2	4 109.53	4.73	0.01
	Tree	26 058.57	25	1 042.34	1.2	0.30
	Error	33 888.36	39	868.93		
	Total	68 166	66			

*All these variables were described in Table 1.

The lowest cone length average was observed in the *San Esteban* area, and the highest, in *La Ciudad* (Table 3). As in this study, Ramírez *et al*. (1999), Menchaca (2000), Alba *et al*. (2001), Vázquez *et al*. (2004), Márquez *et al*. (2007) and Contreras (2009) register differences in the length of cones in *Pinus oaxacana* Mirov; Alba *et al*. (1997), in *P. durangensis*; Ramírez *et al*. (2007), in *Pinus greggii* Engelm; Munive *et al*. (2008), in *Pinus ayacahuite* var. *veitchii* Shaw, and Nieto *et al*. (2002), in *Pinus macrolepis* Flous. This relationship is important, as large cones produce large seeds, which in turn produce more vigorous plants (Castro, 1999; Mueller *et al*., 2005; Quiroz *et al*., 2017).

Table 3. Mean comparison test for *Pinus cooperi* and *Pinus durangensis* Martínez in the *El Salto* region, in *Pueblo Nuevo*, *Durango*.

Variable	Areas					
	LV	LC	SE	LV	LC	SE
	Pinus cooperi			*Pinus durangensis*		
Nc	21.5 a (7.44)	41.3 a (6.01)	35.4 a (6.26)	20.4 a (6.31)	42.0 a (6.44)	17.8 a (15.78)
Cl	6.4 b (0.14)	6.8 b (0.14)	5.6 a (0.17)	6.0 a (0.17)	6.3 a (0.13)	5.8 a (0.41)
Cd	2.3 a (0.05)	2.4 a (0.05)	2.2 a (0.06)	2.4 a (0.06)	2.4 a (0.04)	2.4 a (0.14)
Ds	30.0 b (3.04)	22.2 ab (3.16)	15.3 a (3.76)	19.0 a (2.8)	23.6 a (2.69)	15.4 a (6.85)
Bp	231.2 a (6.31)	231.3 a (6.57)	240.4 a (7.81)	213.0 a (5.17)	209.3 a (4.97)	222.2 a (12.67)
Sp	91.70 b (6)	73.7 ab (6.23)	64.8 a (7.42)	62.2 a (6.18)	61.4 a (5.94)	54.0 a (15.15)

LV = *La Victoria*; LC = *La Ciudad*; SE = *San Esteban*; *Nc* = Number of cones; *Cl* = Cone length; *Cd* = Cone diameter; *Ds* = Developed seed, *Bp* = Biological potential; *Sp* = Seed potential; average values with different letters are statistically different ($p \leq 0.05$); Values between parentheses = Standard error.

With regard to the seeds developed per cone, differences were found between the *San Esteban* areas and those of *La Victoria* and *La Ciudad* (Table 3); although the resulting values were low, they surpassed those registered by González *et al*. (2006) in *Pinus cembroides* (2.09) and by García *et al*. (2014) in *P. cembroides* subsp. *orizabensis* D.K. Bailey (2.09), but were lower than those registered by Parra *et al*. (2016) for *Pinus patula* Schltdl. *et* Cham. (77.57); by Owens *et al*. (2008), for *P. albicaulis* Engelm. (66); by López and Donahue (1995), for *P. greggii* Engelm. (46 a 74), and by Alba and Márquez (2006), for two harvests of *P. oaxacana* (171.76 and 225.51); Ramírez *et al*. (2007) for *P. greggii* (155) and Alba *et al*. (2001) in two *P. oaxacana* harvests (171.76 y 225.5). On the other hand, they are similar to those registered by Mápula *et al*. (2007) and by Sivacioglu and Ayan (2008) for *Pseudotsuga menziesii* (Mirb.) Franco and *Pinus sylvestris* L.

These differences in the production of developed seeds may be ascribed to endogamy issues in small populations (Gómez *et al*., 2010), or, perhaps, to the deterioration of the forest due to selective timber extraction, which consists in the removal of the trees with the highest commercial value and the maintenance of a forest mass made up of individuals whose wood is rated low-quality in the market. This may also produce an impact on the genetic structure due to dysgenic selection, with the resulting reduction of the productive amplitude of the forest (Sola *et al.*, 2015).

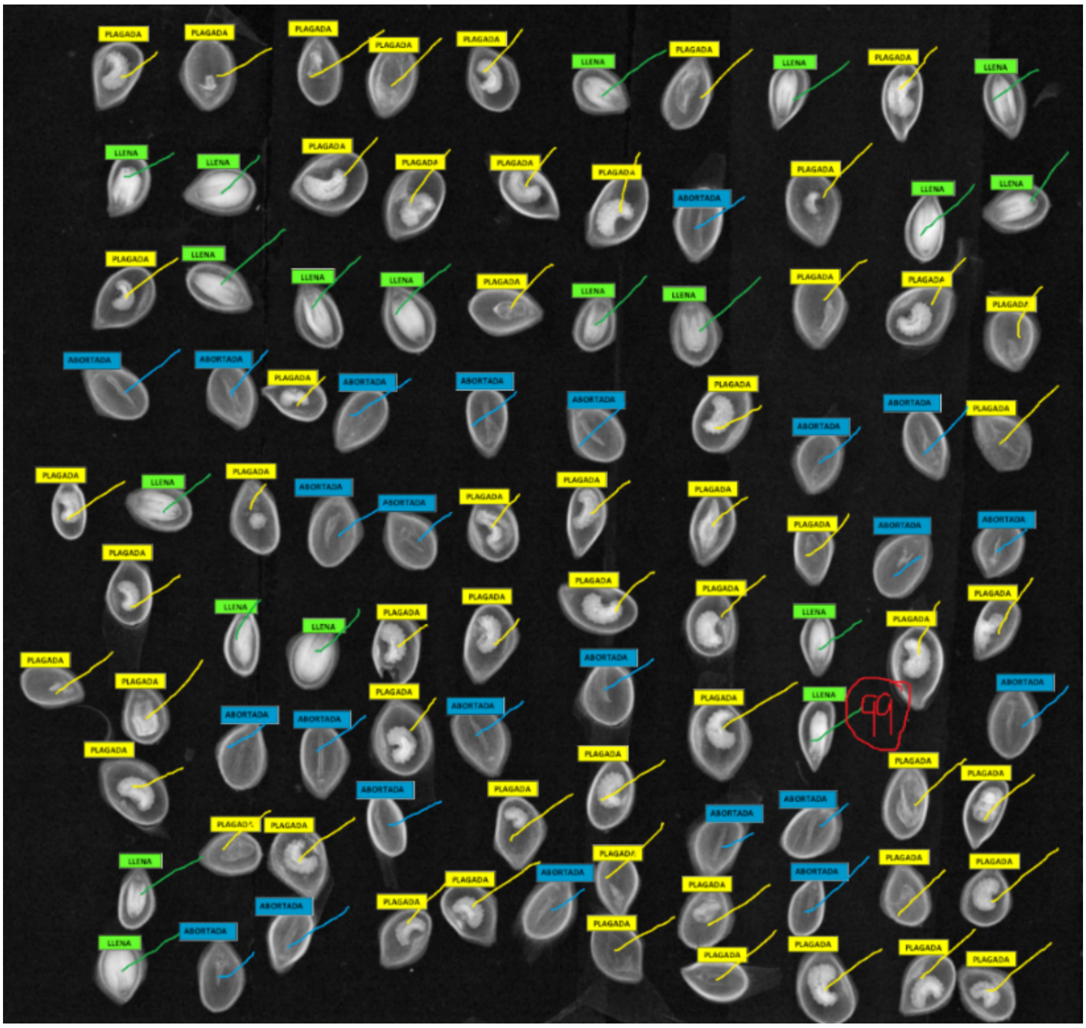
The lowest potential of developed seeds was recorded in the *San Esteban* area, and the highest, in *La Victoria* (Table 3). The values obtained in the *El Salto* region, *Durango*, surpass those documented by Sánchez *et al.* (2002) for *P. cembroides* subsp. *orizabensis*, but are lower than those cited by Alba and Márquez (2006) for *P. oaxacana* (106.1); by Ramírez *et al*. (2013) for *P. patula* (138); by Alba *et al*. (2005), in two years (2003 and 2004), for *P. greggii* (170.93 and 151.98, respectively); by Bustamante *et al*. (2012a) in *P. engelmannii* (143.7); by Alba *et al*. (2003) in three *P*. *hartwegii* Lindl. harvests (152.5, 170.93 and 151.96); by Parra *et al*. (2016) in *P. patula* (219), and by Santos *et al*. (2018), in two years (2013 and 2015), for *P. durangensis* (86.6 and 113.6, respectively), and in 86 and 109 *P. cooperi* seeds, also in the *El Salto* region, *Durango*.

X-Ray seed analysis

The results of the X-ray tests (Table 4, Figure 2) in the two species proved that the highest percentage of seeds infested with *Megastigmus albifrons* Walker (Cibrán *et al*., 1995) was observed in the *La Victoria* area (58 % and 53 %, respectively), while the least affected area was *La Ciudad* (with 41 % and 46 %, respectively). These values are increasing, and they are alarming, when compared to those cited by Bustamente *et al.* (2012b) for *P. engelmannii* (1.1 %) and by Bustamante *et al*. (2014) for *P. durangensis (*1.2%).

Table 4. Mean percentage of viable, aborted and infested seeds by species, area and region.

Area	*Pinus cooperi*			*Pinus durangensis*		
	Viable	Aborted	Infested	Viable	Aborted	Infested
La Ciudad	0.18	0.36	0.46	0.17	0.42	0.41
San Esteban	0.17	0.36	0.47	0.29	0.24	0.47
La Victoria	0.14	0.33	0.53	0.16	0.26	0.58
Region	0.17	0.34	0.49	0.21	0.27	0.52



Yellow = Infested; Blue = Aborted; Green = Full.

Figure 2. X-ray and classification of the seeds.

The maximum percentages of aborted seeds for *P. cooperi* were for *La Ciudad* (0.36 %) and *San Esteban* (0.36 %), while *P. durangensis* exhibited a percentage of 0.42 % in *La Ciudad*. Both these figures are low, compared to the 0.82 % registered by Flores *et al.* (2012) for *Picea martinezii* T.F. Patt., but they are similar to those cited by Prieto and Martínez (2006) for *P. cooperi* (0.33 %) in two seed areas in the *San Dimas* municipality, *Durango*.

The average percentage of viable seeds in the region is below 0.21 % for the two species. At the area level, the highest percentage for *P. durangensis* was obtained in *San Esteban* (0.29 %) and for *P. cooperi* in *La Ciudad* (0.18 %); the lowest percentage was registered in *La Victoria*. These results are similar to those documented for *P. cooperi* (0.31 %) (Prieto and Martínez, 2006), but higher than those registered for *Picea martinezii* (0.12 %) (Flores *et al.*, 2012).

Correlation analysis

The results evidenced the absence of high correlations ($R<0.33$) between the variables of cones and seeds and the dasometric variables in both species (Table 5). In this regard, other researches showed controversies; certain authors cite correlations with the age, crown size, temperature, and precipitation, for example, in *Picea mariana* Mill.) Britton, Sterns & Poggenb. (Caron, 1995), *Pinus echinata* Mill. (Innes, 1994), and *P. taeda* L. (Cain and Shelton, 2000). However, García and Gómez (1988) did not obtain good correlations between the average production of cones per tree and the tree mensuration variables.

Table 5. Coefficients of correlation of Pearson (p≤0.05) for *Pinus cooperi* C. E. Blanco and *Pinus durangensis* Martínez in the *El Salto* region, *Durango*.

Sp	**V**	***Nd***	***Cd***	***Nc***	***Cl***	***Cd***	***Ds***	***Bp***	***Sp***
P. cooperi	*Nd*	1	0.7	0.33	0.12	0.03	0.01	0.06	0.18
	Cd	0.7	1	0.3	0.26	0.18	0.15	0.07	0.03
	Nc	0.33	0.3	1	0.1	0.3	0.05	0.04	0.2
	Cl	0.12	0.26	0.1	1	0.54	0.37	0.01	0.24
	Cd	0.03	0.18	0.3	0.54	1	0.53	0.11	0.3
	Ds	0.01	0.15	0.05	0.37	0.53	1	0.21	0.66
	Bp	0.06	0.07	0.04	0.01	0.11	0.21	1	0.25
	Sp	0.18	0.03	0.2	0.24	0.3	0.66	0.25	1
P. durangensis	*Nd*	1	0.59	0.11	0.16	0.33	0.04	0.07	0.01
	Cd	0.59	1	0.29	0.3	0.41	0.31	0.1	0.16
	Nc	0.11	0.29	1	0.06	0.12	0.08	0.03	0.11
	Cl	0.16	0.3	0.06	1	0.52	0.65	0.47	0.28
	Cd	0.33	0.41	0.12	0.52	1	0.4	0.34	0.13
	Ds	0.04	0.31	0.08	0.65	0.4	1	0.32	0.47
	Bp	0.07	0.1	0.03	0.47	0.34	0.32	1	0.38
	Sp	0.01	0.16	0.11	0.28	0.13	0.47	0.38	1

V = Variable, *Nd* = Normal diameter, *Cd* = Crown diameter, *Nc* = Number of cones, *Cd* = Cone diameter, *Cl* = Cone length, *Ds* = Developed seed, *Bp* = Biological potential and *Sp* = seed potential.

It is a fact that the production of cones and seeds varies year after year; therefore, it is difficult to predict the number of cones alone based on the dasometric characteristics, partly because it is significantly influenced by the age of the individuals, by heterozygosis, and by the individual and collective ability to interact with the environment in order to produce seeds, as well as by the annual climate conditions that vary significantly in time and space (Aparicio *et al.*, 2002; Alba *et al*., 2005; Márquez *et al*., 2007).

Prominent among the variables of cones and seeds are the correlations of the cone length and diameter with the developed seeds, the biological potential, and the seed potential. As in the present study, González *et al.* (2006) registered that the number of seeds per cone is significantly ($p<0.0001$) and positively correlated with the cone diameter and length in a *P. cembroides* plantation aged 15 years, assessed during the two evaluated years.

Conclusions

Correlations of less than 0.33 occur between the number of cones and seeds with the normal diameter and the crown diameter, making it difficult to estimate these reproductive indicators in terms of the dasometric variables for the studied species.

Neither the result of the number of seeds developed by each cone nor the percentages of viable, aborted and infested seeds in the region of *El Salto* are good indicators of the health status of the forest; for this reason, silvicultural practices are required to improve the potential of viable seeds in order to avoid jeopardizing the continuity of the forest mass.

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Conflict of interests

The authors no conflict of interests.

Contribution by author

José Alexis Martínez Rivas: field data collection, capturing of data, data analysis, interpretation of the results, and drafting and edition of the manuscript; Francisco Cruz Cobos: data analysis, statistical analysis, interpretation of the results and revew of the manuscript; José Gonzalo Gurrola Amaya: data analysis, analysis of the results and review of the manuscript; Juan Abel Nájera Luna: review of the final manuscript.

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