RESEARCH PAPER

VARIATION IN CONE AND SEED PRODUCTIONS OF TAURUS CEDAR (*CEDRUS LIBANI* A. RICH.) POPULATIONS

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ABSTRACT. Reproductive characteristics are important tools for sustainable forestry and to transmit present gene diversity to future generations by forestry practices. Knowledge and estimation of fertility variation and its linkage parameters, such as population size and gene diversity in seed crops calculated by reproductive traits, are used widely because of their many advantages. Forestry practices use estimates of these parameters for various purposes, including natural regeneration, establishment, and management of seed sources.. In this study, cone and seed production and their effect on fertility variation were examined in two natural populations (P1 & P2) of Taurus cedar (*Cedrus libani* A. Rich.) sampled from the southern part of Türkiye. Numbers of mature cones, which were two years old and filled with seeds, were counted from fifty trees selected phenotypically from each population in 2023. The averages of cone and seed number were 90 and 33, and 5321 and 3115 per tree in the populations P1 and P2, respectively. Among individuals within a population, and between populations, there were large differences in cone and seed production. The percentages of filled seeds were 94% in P1 and 83% in P2. There were significant differences ($p<0.05$) between populations in terms of the production and percentage of filled seeds, according to results of analysis of variance. Estimated fertility variations ($\Psi<2$) were in good accordance with the target ($\Psi<3$). The effective number of parents ranged from 30.1 (60% of number of individuals) to 41.4 (83%). Besides, data sets can be used to fill the FLR-Library.

KEYWORDS: gene diversity, population size, reproductive, sibling coefficient, stand, FLR-Library

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INTRODUCTION

C. libani is widely distributed in the Taurus Mountains of southern Türkiye, along with some local populations in the Black Sea region of Türkiye, and there are remaining populations in Lebanon and Syria (Boydak 2003). The species occurs mainly between 800 and 2100 m asl. Taurus cedar also has natural distribution as small populations, groups, or individuals both at 500-600 m and 2400 m as lower and higher altitudes (Boydak 2003; Odabaşı 1990). To improve legibility, replace with: Taurus cedar, which is a remarkable evergreen conifer, can live for up to 1000 years or more, growing into a monumental tree with a 3 m stem diameter and 50 m height (Boydak 2003).. Monoecious Taurus cedar has 3-5 cm male and 1-1.5 cm female strobili with mature cones that are 8-10 cm in length and 4-6 cm in diameter (Boydak 2003; Odabaşı 1990) (Fig. 1).

Depending on its elevation, pollination occurs in September or early October. Between April and June of the following year, cone lets develop into mature cones in about 25-26 months after flowering (Evcimen 1963; Bilir, Kang 2021). *C. libani* is classified as one of the important species ecologically and commercially for Turkish forestry. It is also a target species of the "National Tree Breeding and Seed Production Programme" (Koski, Antola 1993) because of its valuable wood and non-wood products, social-cultural importance for rural area, and adaptation ability to various and changeable ecological conditions such as climate. Taurus cedar is widely used in plantation, afforestation, and other forestry practices such as forest restoration as a natural or exotic species due to these characteristics (Bilir, Kang 2021). Fertility data is one of the important guides to establishing successful plantations in different environmental conditions and to giving future direction to breeding programs and other forestry practices. Fertility is also one of the major tools used for various purposes in theoretical and applied forestry (Griffin 1982; Xie, Knowles 1992; Bila 2000; Kang et al. 2003; Kang, Bilir 2021).

Fig. 1. Male strobili and cones of Taurus cedar

However, differences in fertility and related factors have been measured using reproductive features like strobili, cones, flowers, and seeds in different plant species. (Xie, Knowles 1992; Roeder et al. 1989; Savolainen et al. 1993). Although many studies have looked at fertility differences mainly through individual strobili production, there has been very little research on cone and seed production in different plant species like *C. libani* (i.e., Bilir, Kang 2014; Yazıcı, Bilir 2017; Bilir, Özel 2017; Bilir, Kang 2021; Yazıcı et al. 2023). Additionally, variation in cone and seed production and their fertility in *C. libani* has not yet been comparatively investigated.

The importance of both the quantity and quality of seed supply is being understood. Seed procurement and its quality using frontier techniques (Bernardes et al. 2022; Novikova et al. 2022; Novikova et al. 2023; Novikov et al. 2021a; Novikov et al. 2021b; Novikov et al. 2019a, 2019b) is an important stage of the program and practices. It is also known that the quality of genetically improved seed crops, along with other morphological (i.e., grading) and physiological characteristics, is very important for successful forestry practices (Yazıcı et al. 2023) like planting.

The aims of this study are to estimate variations of cone and seed productions, to calculate the fertility variation and linkage parameters (i.e., population size, gene diversity) in two natural populations of *C. libani* based on cone and seed productions, and to discuss possible forestry practices of the species.

MATERIALS AND METHODS

Data collection

Two natural populations of Taurus cedar were sampled in the southern part of Türkiye (Fig. 2, Table 1). Data on the numbers of mature cones, two-years (N_C) and filled seeds (N_S) were collected from fifty trees selected phenotypically and 100 m apart in 2023. Four cones were harvested from each direction of sampled trees for seed extraction. Extracted seeds were floated to separate empty and filled seeds on water for 12-16 hours. Thereafter, the number of empty and filled seeds was counted (Fig. 3), and the percentage of filled seeds (N_S%) was calculated.

Data analysis

The ANOVA-test of the SPSS statistical package (SPSS 2011) was used for analyzing the productivity indicators of cones and seeds in the Taurus cedar populations. If we define the letter l for the number of each surveyed tree, and the letter k for the population number, then the indicator variant is expressed by the symbol $Y_{kl(C)}$ or $Y_{kl(S)}$ for the productivity of cones (*C*) or productivity of seeds (*S*), respectively. A variant of the productivity indicator Y_{kl} includes the terms $\mu+R_l+e_{kl}$, denoting for each specific Taurus cedar population *k* the average value of μ, the random effect of R_l in the *k*-th population (in this study *k*=2, the populations were designated as P1 and P2), and the error e_{kl} of determination of the model. Guided by the methodology for calculating the fertility of cones (Ψ_C) and seed fertility (Ψ_S), presented by Kang and Lindgren (1999), and Bilir (2011), the fertility of the *l*-th tree was determined as the proportion of individual cones or individual seeds in the *k* population. In this case (Ψ_C) is the sum of one and the square of the coefficient of variation CV_{CF} of the fertility values of cones, and (Ψ_S) is the sum of one and the square of the coefficient of variation CV_S of the fertility values of seeds of each *l*-th (*l* = 1...N) tree. Further, as shown in Kang, Lindgren (1998), Park et al. (2017), Genetic Diversity (GD) was calculated as the difference between one (1) and half (1/2) of the N_p index characterized by Kang et al. (2003) a quotient of dividing the census number *N* by the corresponding fertility Ψ.

Table 1. Geographic details of studied Taurus cedar populations

Populations	Age (year)	Latitude (N)	Longitude (E)	Average Altitude (m)	Aspect
P1	60	38º49'	30º45″	1500	North
P2	120	37º40′	30º51′	1580	Northwest

(a) (b)

Fig. 2. Sampled P1 (a) and P2 (b) Taurus cedar populations

(a) (b)

Fig. 3. Mature cones (a) and filled seeds (b) of the species used in this study

RESULTS AND DISCUSSION

Cone and seed production

The averages of cone and seed numbers in P1 and P2 populations were 90 and 33, and 5321 and 3115 per tree, respectively. Averages of cone production were 46 ranging from 19 to 76 for years of pooled aspects (Yazıcı, Bilir 2017), and 20 and 22 in two populations of Taurus cedar (Bilir, Kang 2014). The percentages of filled seeds were 94% and 83% in the populations. Among individual trees within a population and between populations, the numbers of cones, seeds, and filled seeds showed large differences (Table 2). For instance, there were more than twenty times the differences among individuals in both populations for the number of filled seeds (Table 2). Populations had significant differences ($p<0.05$) for cone and seed production and percentage of filled seeds as shown by results of analysis of variance. The results showed the importance of the selection of individual trees and populations for higher reproductivity. The most productive 10 trees (20% of total trees) produced 40% and 35% of total cone production in P1 and P2, respectively, while the percentages were 48% and 41% for the number of filled seeds in P1 and P2, respectively. Many biotic (i.e., population) and abiotic (i.e., altitude, crown closure) factors could explain these differences (i.e., Bila, Lindgren 1998; Bilir et al. 2005; Yazıcı, Bilir 2017 and 2023; Çatal et al. 2018; Çerçioğlu, Bilir 2018; Kang, Bilir 2021; Yazıcı et al. 2023; Bilir, Yazıcı 2024). Parental-balance curves in the populations were shown by means of cumulative gamete contribution in Fig. 4. In both populations, individual seed productions were much closer to equal contribution than cone production (see Fig. 4). However, forestry practices could balance both characteristics.

Large differences in reproductivity were reported among trees within populations and among populations in Taurus cedar (i.e., Evcimen 1963; Odabaşı 1990; Bilir, Kang 2014; Çatal et al. 2018; Bilir, Kang 2021; Yazıcı, Bilir 2023), and in various plant species (e.g., Shea 1987; Kang et al. 2003; Bilir et al. 2005; Kang, Bilir 2021). Estimated coefficient of variations (*CV*) of the productions (Table 2) could be acceptable for natural populations *CV* ≤ 40% (Kang, Bilir 2021).

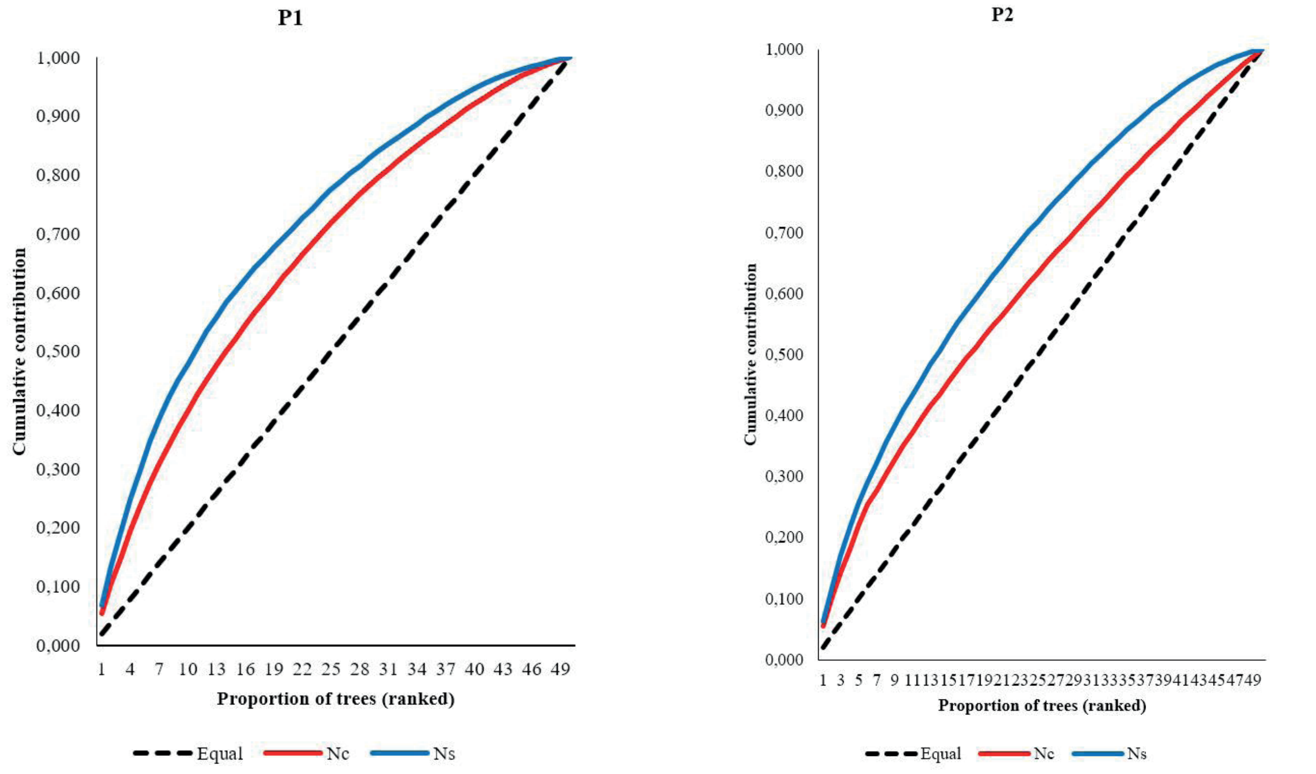
The average mature cone number was reported as 21 in the species (Bilir, Kang 2014), while the average cone number was 47 (Yazıcı, Bilir 2017), while the result of the study had higher cone production (Table 2). The results indicated the importance of populations and years in cone production. Good seed years occur once every two to three years, depending on altitude, in natural populations of the species (Boydak 2003). However, the present study had one-year data. Differences in biotic and abiotic characteristics of populations may have an impact on reproductive traits in the natural forest. Also, similar differences were found among individuals in populations regarding cone production and the number of filled seeds in natural populations of Taurus cedar (Evcimen 1963).

Fertility variation

Estimations of the cone and seed fertility and linkage parameters were given in Table 3. As seen from Table 3, seed fertility (Ψ_S) was higher than cone fertility (Ψ_C) in both populations.

Table 2. Basic statistical values for cone and seed production in the populations

Statistics	P1			P2		
	N_C	N_S	N_S%	N_C	N_S	N_S%
Mean	90.2	5320.5	93.5	32.9	3114.9	83.3
Range	20-250	750-18144	78.3-99.7	20-90	418-9685	39.5-97.2
CV%	60.1	82.3	5.2	46.1	64.2	16.9



(a) (b)

Fig. 4. Parental-balance curves in the P1 (a) and P2 (b) populations

Table 3. Cone and seed fertility (Ψ_C & Ψ_S), effective number of parents ($N_{p(c)}$ & $N_{p(s)}$) and gene diversity (GD) in the populations

	P1		P2	
	N_C	N_S	N_C	N_S
Ψ_C & Ψ_S	1.35	1.66	1.21	1.41
$N_{p(c)}$ & $N_{p(s)}$	36.97 (0.74)*	30.06 (0.6)	41.40 (0.83)	35.41 (0.71)
GD	0.987	0.983	0.988	0.986

* relative effective number of parents in the parenthesis.

Cone and seed fertility variations (Ψ_c & Ψ_s) estimated of the proportion of individual production in the population were acceptable for the ideal population suggested for natural stands (Ψ<3) (Kang 2001; Kang, Bilir 2021). Seed fertility (Ψ_S) was lower than that of cone (Ψ_C) in both populations (Table 3). Fertility variations varied according to populations, years, and reproductive traits in Taurus cedar (Bilir, Kang 2014 and 2021; Yazıcı, Bilir 2023; Yazıcı et al. 2023).

The effective number of parents (N_p) which a mirror of the fertility variation, ranged from 30.1 (for Ns in P1, for 60% of census number) to 41.4 (for N_c in P2 for 83%) (Table 3). The results of the present study indicated that about 83% of individuals for N_C in the P2 behavior are under the ideal population. The size, equivalent to the target populations, was 12% (N_c) larger than N_s in P2. The difference in gene diversity was 0.004 between N_c and N_s (0.987 and 0.983) in P1 (see Table 3). The results indicated the importance of reproductive traits used in the estimations. Gene diversity was higher in P2 than P1 in both traits (see Table 3). However, it could be increased by forestry practices to harvest seed crops that have higher gene diversity for sustainable and adaptable forestry to different environmental conditions such as climate change.

Various reproductive traits, such as cone, strobili, fruit, and seed production, have been used to estimate fertility variation and linkage parameters in many plant species (Shea 1987; Roeder et al. 1989; Savolainen et al. 1993; Kang 2001; Bilir 2011; Kang, Bilir 2021). However, cone and seed were the last stage of reproductivity after pollination. Furthermore, collecting data on cone and seed production offers numerous advantages over strobilus counts. These advantages include ease of use, lower costs, and greater accuracy due to the longer lifespan and larger size of cones, as highlighted by various studies (Bilir, Kang 2014; Bilir, Kang 2021). The reproductive data for the study belonged to only two populations and one year. Therefore, more data is needed from different populations and years, including good and poor seed years, for estimating fertility variation and linkage parameters in the species.

The following steps are necessary for the practical application of the data from this study. In the tenth block (Novikova 2022a) (Fig. A.1(b)) of the third group of the FLR-algorithm, the which has six basic groups (Novikova 2022b) (Fig. A.1(a)) on the technological operations of the forest restoration process, it is necessary to additionally include data from this study (Fig. A.1(c)), along with data from a previous study (Yazıcı et al. 2023).

CONCLUSIONS

Results of the present study belong to one year and a limited area and number of populations of Taurus cedar. Future studies should be carried out to give large conclusions depending on geographic variation in the natural distribution of Taurus cedar. However, results of the study could be used in the local area of the species for different purposes, such as balancing variation in seed crop for higher gene diversity by various forestry practices. Local foresters should observe fertility variation to transmit gene diversity to future generations in an environmentally friendly way.

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APPENDIX A

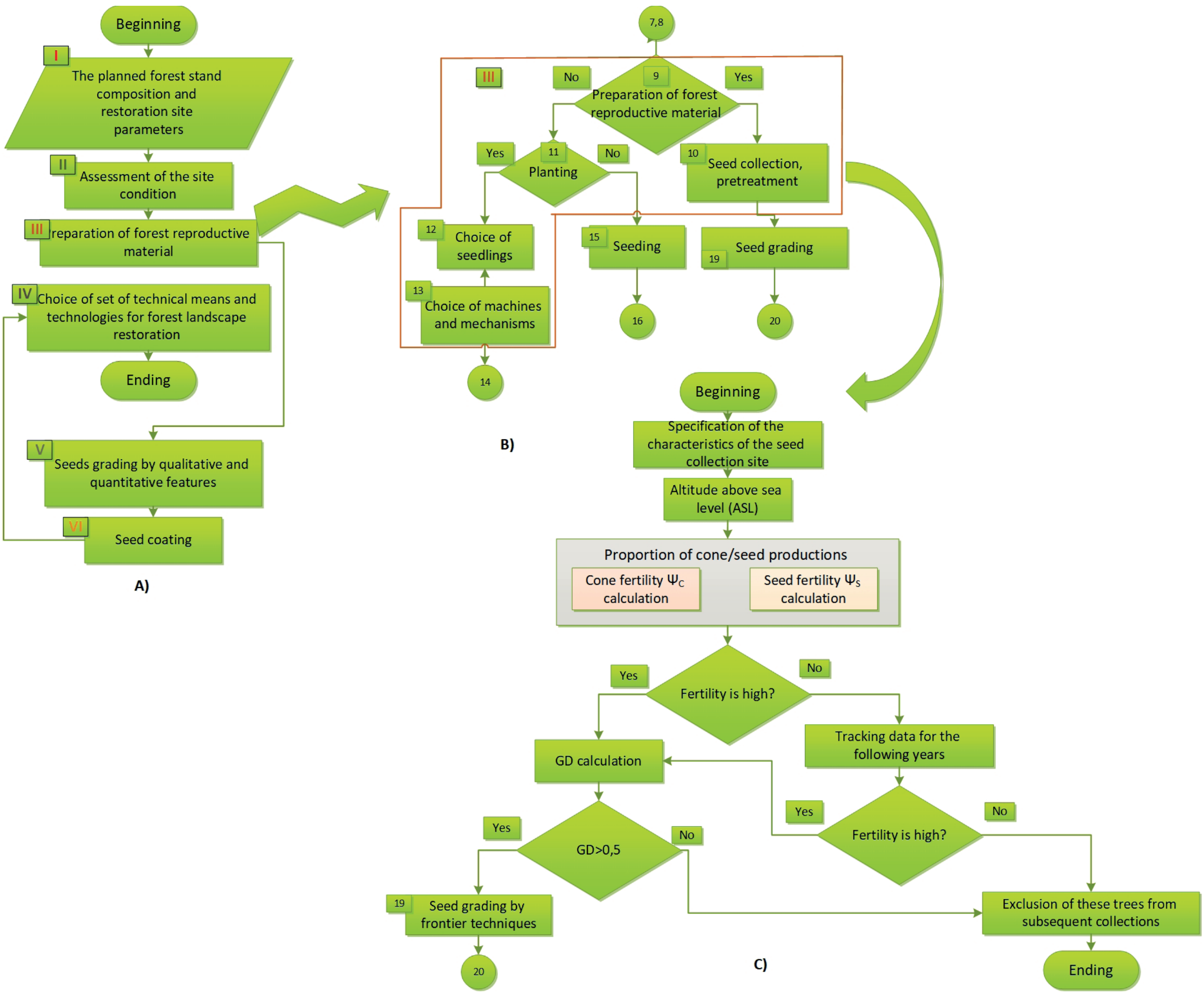

Fig. A.1. FLR-algorithm of the forest restoration technology (A), decomposing of the «Preparation of forest reproductive material» module (B), modification of block III of module 10 (Yazıcı et al. 2023) by evaluation algorithm operators of Taurus cedar cone and seed fertility (C) used in this study. Figures A) and B) are adapted and modified from the paper by co-author T.N. (Novikova 2022a), figure (C) is the T.N.'s own composition