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Annual Variability in Cone and Seed Yields Across Seed Stands of Taurus Cedar (*Cedrus libani*) and Its Impact on Gene Diversity of Seed Crops

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Abstract

The variation in annual cone and seed production was examined for three natural seed stands of Taurus cedar (*Cedrus libani* A. Rich., Pinaceae), each with distinct structural characteristics, sampled from 35 trees for three consecutive years. Fertility variation (Ψ), estimated by cone (Ψ_C) and seed (Ψ_S) yields per tree, was also analyzed to contribute to the management and development of silvicultural practices for the seed stands of the species. Significant differences ($p < 0.05$) were recorded in cone and seed production across years, between populations, and between trees within a population. Population x year interactions were also significant ($p < 0.05$), highlighting the importance of seed harvesting year in cone collection. Fertility variation in cones and filled seeds showed only small deviation [Ψ_C = 1.10 (91% of census number)–1.71 (59%), Ψ_s = 1.25 (80%)–1.71 (59%)] among the seed stands in different years, except Ψ_S = 2.38 (42%) in a population in one year. The cone and seed fertility were at acceptable levels for an ideal natural population ($\Psi \leq 3$). Figures of parental balance curves showed that the contribution to the gamete gene pool was much closer to equal for cone production across the years than for filled seed production in both individual stands and pooled stands, suggesting that the number of cones is a good indicator of overall seed production. Difference in gene diversity (GD) was 0.005 from individual year (GD = 0.992 and 0.993) to pooled years of the populations (GD = 0.997 and 0.998) for both cone and seed yields, while it was higher among years within population (e.g., 0.017 for cone yield and 0.026 for seed yield in a population).

Keywords: afforestation; fertility variation; genetic diversity; reproductive output; stand structural characteristics

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Academic Editor: Ivar Wendling

Received: 2 February 2026
Revised: 22 March 2026
Accepted: 9 April 2026
Published: 14 April 2026

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1. Introduction

Taurus cedar (*Cedrus libani* A. Rich., Pinaceae), also called the cedar of Lebanon, can grow up to 50 m in height and 2.5 m in diameter, with some growing even bigger in old forests and monumental forests over 1000 years old and occurring in various natural ecological conditions, mainly between 800 m and 2100 m asl [1,2]. Taurus cedar is an important forest tree species in its native habitat range, and is an important exotic species in Bulgaria [3], Argentina [4], Italy [5], Iran [6], and France [7]. It is valued for timber; resin production from its seeds, cones, and wood; landscape purposes; and socio-cultural

importance (i.e., ethnobotany, symbol of the Lebanese flag). Natural forests of the species occur in the Taurus Mountains in southern Türkiye, with remnant populations in Lebanon and Syria [1,2].

Taurus cedar has been widely used in afforestation, reforestation, and restoration practices in Turkish forestry. Over the past decade, its distribution area has increased from 463,521 ha to 580,515 ha (of which 42.8% was unproductive) through seeding and planting practices [8]. A total of 60 million seedlings were produced from 20 tons of seed harvested from trees selected phenotypically in 21 seed stands (3304.2 ha) identified by the General Directorate of Forestry [8,9]. There are seven seed orchards (46.4 ha) that are still juvenile [8,9] and not used yet for seed production. It is therefore important to estimate long-term fecundity, fertility variation, and genetic parameters to manage seed stands for the seed production of *C. libani*.

The species. *C. libani* generally bears cones by 30 years old in natural stands [10]. Male strobili appear in July and elongate 3–5 cm in August, while female strobili can be seen in September, depending on location and altitude, in *C. libani*. The female strobili convert to brown mature cones of 8.46 cm length and 4.9 cm width [11,12]. The opening of the cone scales begins in October, and seed dispersal occurs 25–26 months after fertilization [2]. Seed dispersal starts by the end of November and continues during the winter in natural stands. However, seeds of 23–24-month-old cones, collected in August, also have a high germination rate [11]. The frequency of good seed years in this species is generally two to three years and varies with biological characteristics, stand structure (i.e., tree density, crown closure), altitude, and related parameters such as edaphic and climatic [12,13]. However, the occurrence of good seed years is also highly variable between locations, ranging from intervals of two years to three or even six years [2,11]. The cone and seed yields also vary among provenances of *C. libani* [11,14,15].

Fertility variation (Ψ) is defined as the difference in the ability to produce progeny (i.e., reproductive success) among individuals [16]. Fertility variation is commonly estimated based on pollen, strobili, flower, cone, fruit, and seed production [17–19], and it approaches 1 when individuals contribute equally to the gamete gene pool of a population. It is used for various purposes in plant science, such as genetic management, breeding, population, and species conservation [20–22]. Although fertility variation and cone and seed yields have been studied in natural populations of *C. libani* [23] using short-term data, annual variation in cone and seed yields and related parameters have not been examined in detail using long-term data for this species.

This study aims to (i) assess annual variation in cone and seed yields and associated parameters like fertility variation among seed trees and gene diversity of seed crops in seed stands of *Cedrus libani*, (ii) compare these patterns across three consecutive years in three seed stands with different silvicultural characteristics, and (iii) provide recommendations for the cone harvest strategy and management of the seed stands.

2. Materials and Methods

2.1. Estimation of Parental Cone and Seed Production

Mature cones of Taurus cedar were collected during October for three consecutive years (2023–2025) from three seed stands where the seed harvesting area was selected phenotypically from natural forests in the largest natural distribution range in the Mediterranean region of Türkiye (Table 1). Although the seed stands occur at the same altitude, they exhibit distinct structural characteristics like differences in tree age, height, and stem density per hectare (Table 1) [9]. Thirty-five trees that were at least 100 m apart [23,24], with mature cones, were selected phenotypically (i.e., tree height, diameter at breast height, stem

straightness) [25] from each seed stand. The total number of mature cones was counted visually in the same selected and marked trees during the study period.

Table 1. Geographic information (latitude, longitude, altitude), age, tree height, size, stand density, and soil type of the seed stands (populations P_1, P_2, and P_3) of *Cedrus libani*.

Seed Stand Code	Latitude (N)	Longitude (E)	Altitude (m)	Stand Age (Year)	Tree Height (m)	Size (ha)	Density (Trees ha^{-1})	Slope (%)	Soil Type
P_1	38°05′23″	30°42′20″	1600	60	15.3	77.0	800	25	Lower Paleozoic; clayey-limestone
P_2	37°44′47″	30°49′21″	1600	118	20.6	48.9	650	25	Mesozoic; sandy-limestone
P_3	37°51′00″	31°19′10″	1550	149	23.9	23.0	450	30	Quaternary; alluvion

Average temperatures (°C) were 12.4, 11.6, and 14.4, while annual precipitation (mm = kg/m^2) was 448.7, 456.9, and 336.1 for populations (i.e., seed stands) P_1, P_2, and P_3, respectively, during the study period [26].

The average number and percentage of filled seeds per cone were calculated from four healthy cones harvested from the four directions of each tree before the opening of the cone scales. The cones were stored (at about 20 °C) indoors, with seed extraction occurring after two weeks. All cones were thoroughly dissected to count the number of seeds produced per cone. The cutting test method was used for assessing whether the seeds were filled or empty/damaged [27]. The average number of filled seeds per tree was estimated by the average number of filled seeds/cone multiplied by the number of mature cones per tree.

The parental balance curves were plotted as the cumulative proportion of reproductive output (e.g., cones, seed) against the cumulative proportion of parental seed trees [28,29]. The curves were used to identify highly fertile, underperforming, or infertile trees to guide the management of seed stands to ensure maximum genetic diversity, which is crucial for establishing resilient forests.

2.2. Data Analysis

The differences among populations and among years for the cone and seed characteristics were calculated by the following model of ANOVA [30]:

$$Y_{ij_k} = \mu + F_i + B\left(F\right)_{j(i)} + e_{ijk} \quad (1)$$

where Y_{ijk} is the observation from the kth tree of the jth stand in the ith year, μ is the overall mean of a characteristic, F_i is the effect of the ith year, $B(F)_{j(i)}$ is the effect of the jth population in the ith year, and e_{ijk} is the random error.

Differences between the seed trees in a cone and the seed yield per year in a stand were also compared using the following model of one-way analysis of variance:

$$Y_{ij} = \mu + P_i + e_{ij} \quad (2)$$

where Y_{ij} is the observation from the ith tree of the jth stand, μ is the overall mean of the cone or seed yields, P_i is the yield of the ith tree, and e_{ij} is the random error.

The fertility variation (also known as the sibling coefficient, Ψ) among seed trees was estimated based on the proportion of cone and filled seed/tree (Ψ_C & Ψ_S), representing the total contribution as zygotic parents within the population for the years [31], as

$$\Psi_C = N\Sigma_{i=1}^{N} Cone_i^2 = CV_C^2 + 1 \quad (3a)$$

$$\Psi_S = N\Sigma_{i=1}^{N} Seed_i^2 = CV_S^2 + 1 \quad (3b)$$

where $Cone_i$ and $Seed_i$ represent the cone and seed fertility (relative proportion of cone and seed production in the seed stand) of the ith tree, and CV_C and CV_S stand for the coefficients of variation in cone and seed production, respectively.

The effective number of parents for cone ($N_P{}^{(C)}$) and seed ($N_P{}^{(S)}$) production was calculated based on the fertility variation (Ψ_C & Ψ_S) and the census number (N) of seed trees, respectively [32], as

$$N_P^{(C)} = \frac{\Psi_C}{N} \quad (4a)$$

$$N_P^{(S)} = \frac{\Psi_S}{N} \quad (4b)$$

The effective number of parents ($N_P{}^{(C)}$ & $N_P{}^{(S)}$) is also related to gene diversity (GD) for cone and seed production (GD_C & GD_S) according to Lindgren et al. [33] and Lindgren and Mullin [34], and is calculated as

$$GD_C = 1 - \frac{0.5}{N_P^{(C)}}, \text{and } GD_S = 1 - \frac{0.5}{N_P^{(S)}} \quad (5)$$

3. Results

3.1. Cone and Seed Productions, and Parental Balance Curve

Cone and seed production showed variation between populations (seed stands) across years, and also between trees within populations (Table 2). The reproductive output increased with stand age but showed a negative relationship with stand density (see Table 1 for details of the stand). Among the seed stands, the cone production per tree, filled seeds per cone, and total filled seeds per tree were highest in the oldest stand (145 years), P_3, with the lowest stocking (450 trees ha^{-1}).

Table 2. Mean, coefficient variation (*CV*), and range for the characteristics in the populations (P_1, P_2, and P_3) during the study period (2023–2025).

	P_1			P_2			P_3			Pooled	
Years	**Mean**	***CV***	**Range**	**Mean**	***CV***	**Range**	**Mean**	***CV***	**Range**	**Mean**	***CV***
2023											
N_C *	28 (2.25) **	0.48	12–90	23 (2.28)	0.58	12–86	36 (3.55)	0.58	14–110	29 (1.66)	0.59
NS_C%	73 (2.07)	0.17	37–95	93 (0.58)	0.04	83–100	94 (0.67)	0.04	80–98	87 (1.22)	0.14
NS_C	75 (3.82)	0.30	22–120	56 (4.15)	0.44	12–140	82 (4.46)	0.32	19–131	71 (2.60)	0.38
NS_T	2135 (198.4)	0.55	374–5940	1240 (106.6)	0.51	192–3080	2906 (305.1)	0.62	742–8580	2094 (142.1)	0.70
2024											
N_C	20 (2.85)	0.85	8–72	29 (3.01)	0.61	12–98	27 (2.29)	0.50	14–60	25 (1.61)	0.65
NS_C%	90 (1.65)	0.11	66–100	89 (1.59)	0.11	65–100	95 (0.61)	0.04	84–100	91 (0.82)	0.09
NS_C	44 (4.41)	0.59	13–110	88 (7.77)	0.53	18–177	93 (6.75)	0.43	16–173	75 (4.27)	0.59
NS_T	895 (180.1)	1.19	156–5040	2325 (245.1)	0.62	396–6109	2715 (315.9)	0.69	320–6688	1978 (163.8)	0.85
2025											
N_C	18 (1.41)	0.45	10–48	20 (1.03)	0.31	12–40	28 (3.00)	0.63	12–90	22 (1.22)	0.57
NS_C%	85 (2.04)	0.14	51–100	91 (0.88)	0.06	72–97	94 (0.62)	0.04	85–100	90 (0.84)	0.01
NS_C	61 (5.48)	0.53	16–120	75 (5.49)	0.43	18–130	90 (5.71)	0.37	19–164	75 (3.39)	0.45
NS_T	1165 (168.2)	0.85	160–5472	1482 (154.7)	0.62	288–5000	2518 (321.5)	0.76	760–10,152	1722 (142.0)	0.85
Pooled											
N_C	22 (1.35)	0.63	8–90	24 (1.32)	0.58	12–98	31 (1.75)	0.59	12–110	26 (0.88)	0.61
NS_C%	83 (1.32)	0.16	37–100	91 (0.65)	0.07	65–100	94 (0.37)	0.04	80–100	89 (0.58)	0.11
NS_C	60 (2.93)	0.50	13–120	73 (3.65)	0.51	12–177	88 (3.30)	0.38	16–173	74 (2.01)	0.48
NS_T	1399 (116.8)	0.86	156–5940	1682 (111.7)	0.68	192–6109	2713 (180.5)	0.68	320–10,152	1931 (86.6)	0.80

*—N_C is the number of cones per tree, NS_C% is the percentage of filled seeds per cone, NS_C is the number of filled seeds per cone, and NS_T is the total number of filled seeds per tree. **—standard errors in parentheses.

The highest cone production (N_C) was recorded in P_3 in 2023, while the lowest was observed in P_1 in 2024. Similarly, the percentage of filled seeds per cone (NS_C%) and the total number of filled seeds per tree (NS_T) were also the highest in P_3 in 2023 (Table 2, Figures 1 and 2). All cones from the P_3 seed stand had 100% filled seed production in 2023 (149% higher than the lowest value recorded in P_1 in 2025). The percentage of filled seeds per cone (NS_C%) ranged from 73% in P_1 in 2023 to 95% in P_3 in 2024 (Table 2).

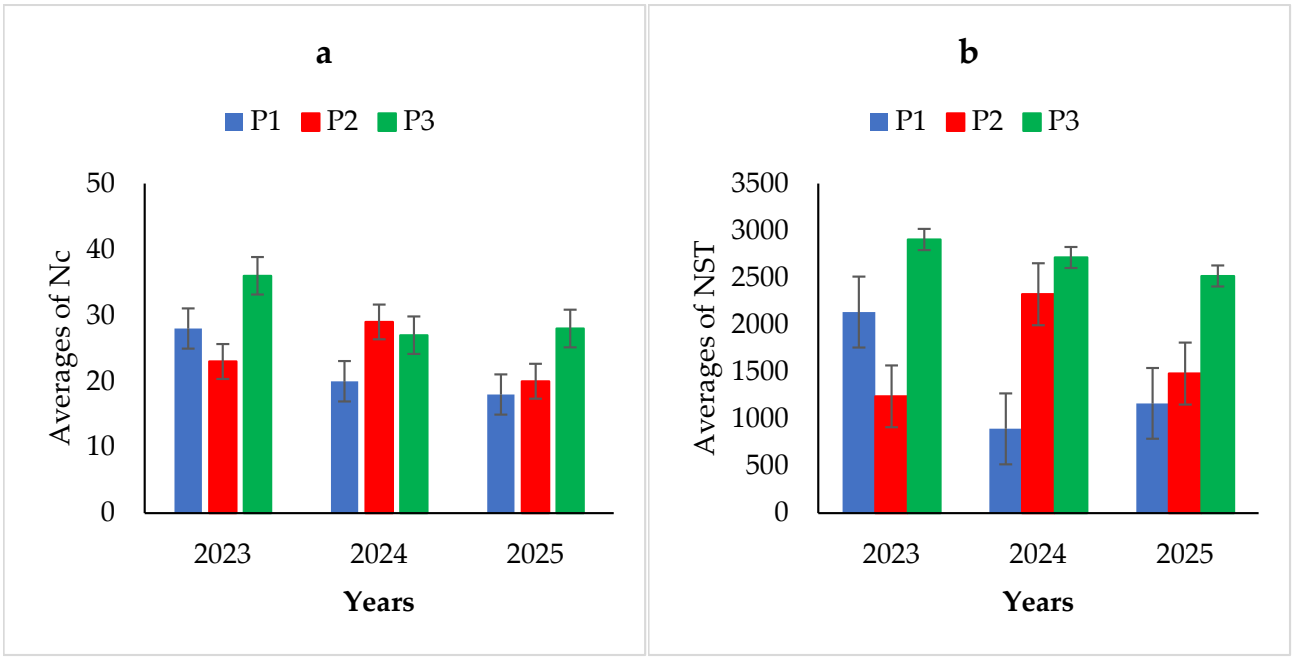

Figure 1. Number of cones (N_C) (**a**) and number of filled seeds per tree (NS_T) (**b**) in the populations (P_1, P_2, and P_3) of *C. libani* during the study period (2023–2025).

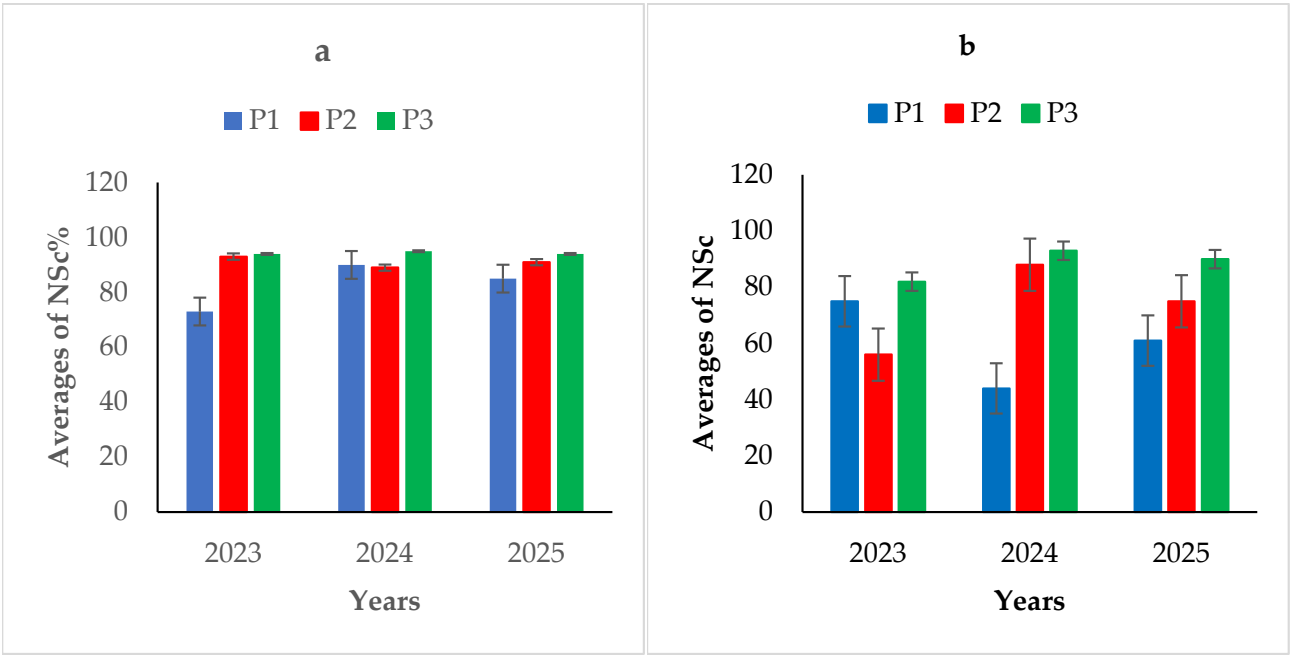

Figure 2. The percentage of filled seeds per cone (NS_C%) (**a**), and number of filled seeds per cone (NS_C) (**b**) in the populations (P_1, P_2, and P_3) of *C. libani* during the study period (2023–2025).

In the year 2023, the three seed stands had the highest pooled mean number of cones (29) and the filled seeds per tree (2094), while the percentage of filled seeds per cone (NS_C%) and number of filled seeds per cone (NS_C) were the lowest, i.e., 87% and 71%, respectively (Table 2, Figures 1 and 2).

There were significant differences ($p < 0.05$) in cone production and seed yield per tree, whereas the effect of year was significant only for the number of cones (N_C) and the percentage of filled seeds per cone (NS_C%) (Table 3). Population x year interactions were significant ($p < 0.01$ or $p < 0.05$) for the reproductive output (Table 3).

Table 3. Analysis of variance (ANOVA) for the characteristics among years and populations.

Source	Variable ***	d.f.	Mean Square	*F*	*p*
Population (*P*)	N_C	2	2103.6	9.427	**
	NS_C%	2	3774.4	60.731	**
	NS_C	2	20,765.3	19.774	**
	NS_T	2	50,229,040.1	26.239	**
Year (*Y*)	N_C	2	1287.1	5.768	*
	NS_C%	2	661.0	10.636	**
	NS_C	2	557.9	0.531	NS
	NS_T	2	3,811,995.0	1.991	NS
P × Y interaction	N_C	4	625.9	2.805	*
	NS_C%	4	1204.0	19.373	**
	NS_C	4	8862.3	8.439	**
	NS_T	4	11,881,578.6	6.207	**
Error	N_C	306	223.1		
	NS_C%	306	62.1		
	NS_C	306	1050.1		
	NS_T	306	1,914,322.0		

, *, and NS indicate statistically significant difference at the probability level 0.01, 0.05, and non-significant, respectively. *—N_C is the number of cones, NS_C% is the percentage of filled seeds per cone, NS_C is the number of filled seeds per cone, and NS_T is the total number of filled seeds per tree.

The parental balance curves in P_1 showed more deviation from the equal contribution for cone and seed characteristics compared to the stands of P_2 and P_3 (Figure 3). The observed parental balance curves of all stands pooled for the number of cones (N_C) and filled seeds per tree (NS_T) did not deviate substantially from the equal production line, while they showed differences for the individual seed stands (Figures 3 and 4). For instance, the cone production over the years for pooled populations was much closer to having an equal contribution to the gamete gene pool than that of filled seeds (Figure 4).

3.2. Fertility Variation, Effective Number of Parents, and Gene Diversity

The fertility variation in cone (Ψ_C) and filled seed (Ψ_S) did not vary substantially among populations across years, nor across years within the population (Table 4). For instance, the pooled-year seed fertility (Ψ_S) in P_2 was 1.46 ($N_P^{(S)}$ = 72.0, 69% of census number in the population), ranging from 1.25 (28.0, 80% in year 23) to 1.38 (25.4, 73%) in year 24. For the data pooled across years and populations, the Ψ_C values were 1.36 (231.5, 74% of the census number in the year 23), 1.32 (79.6, 76% in year 25), and 1.42 (74.0, 71% in year 24) (Table 4).

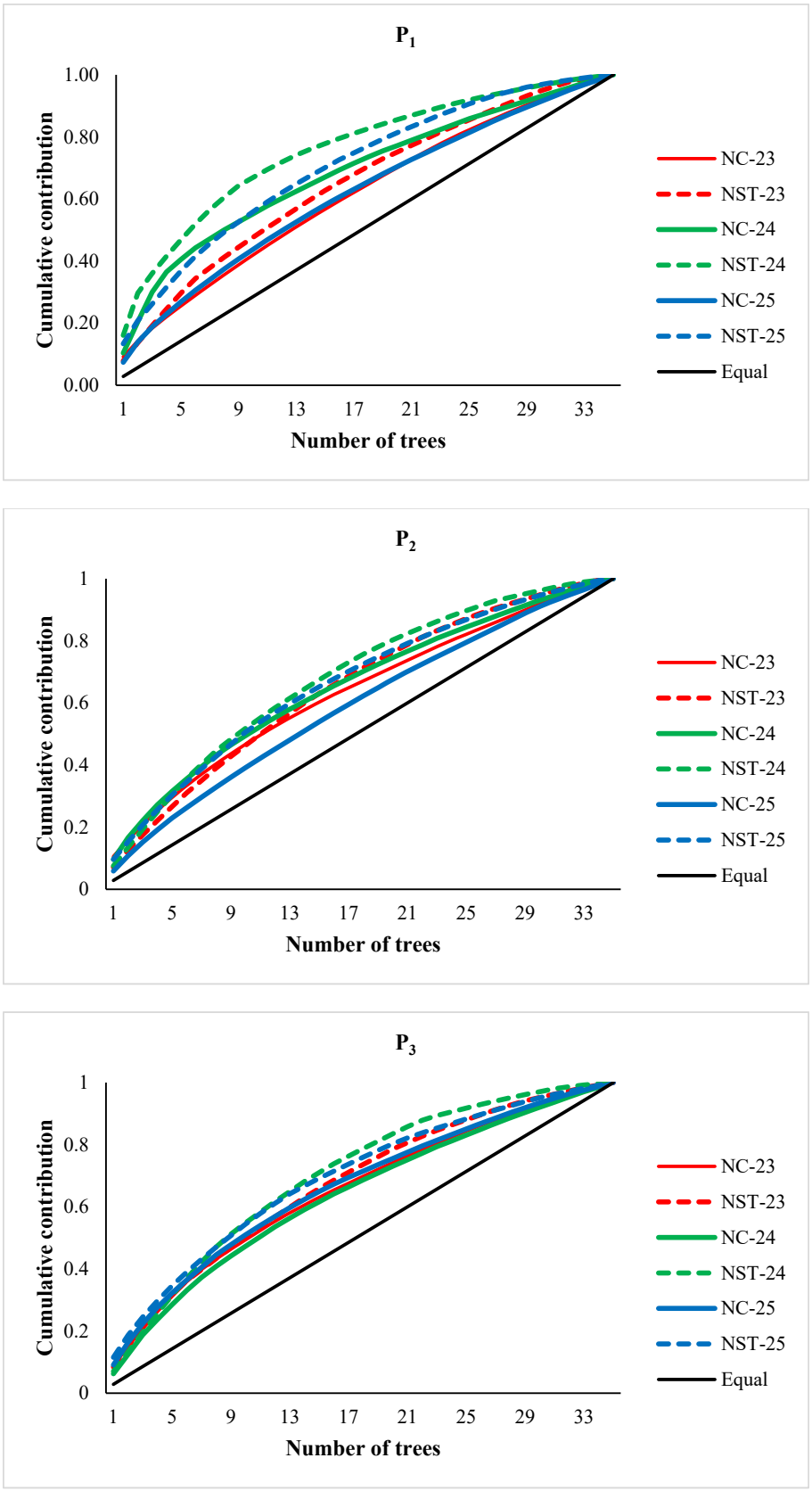

Figure 3. Parental balance curves for cone number (N_C) per tree, and total number of filled seeds per tree (NS_T) in the populations (P_1, P_2, and P_3) of *C. libani* during the study period (2023–2025).

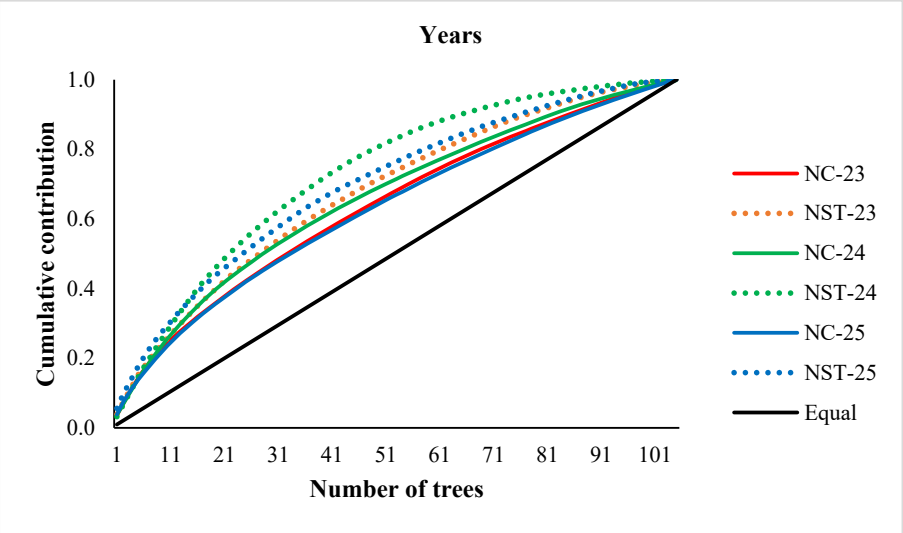

Figure 4. Parental balance curve in the bulked individuals and years of the three *C. libani* seed stands for cone number (N_C) per tree, and total number of filled seeds per tree (NS_T) during the study period (2023–2025) of the three seed stands.

Table 4. Fertility variation among seed trees in cone (Ψ_C) and filled seed (Ψ_S) fertility, effective number of parents for cone ($N_P^{(C)}$) and filled seed ($N_P^{(S)}$), and gene diversity for cone (GD_C) and seed (GD_S) in the populations (P_1, P_2, and P_3) during the study period (2023–2025).

	P_1				P_2				P_3				Pooled			
Years	**23**	**24**	**25**	**Total**	**23**	**24**	**25**	**Total**	**23**	**24**	**25**	**Total**	**23**	**24**	**25**	**Total**
Ψ_C *	1.22	1.71	1.20	1.40	1.33	1.36	1.10	1.33	1.33	1.24	1.38	1.34	1.34	1.42	1.32	1.36
Ψ_S	1.29	2.38	1.71	1.73	1.25	1.38	1.37	1.46	1.38	1.46	1.56	1.46	1.48	1.71	1.71	1.63
$N_P^{(C)}$	28.7	20.5	29.2	75.6	26.4	25.7	32.0	79.0	26.3	28.6	25.3	78.3	78.4	74.0	79.6	231.5
$N_r^{(C)}$ **	0.82	0.59	0.84	0.72	0.75	0.73	0.91	0.75	0.75	0.81	0.72	0.75	0.74	0.71	0.76	0.74
$N_P^{(S)}$	27.1	14.7	20.5	60.9	28.0	25.4	25.5	72.0	25.4	24.0	22.5	71.9	71.0	61.3	61.5	193.8
$N_r^{(S)}$	0.77	0.42	0.59	0.58	0.80	0.73	0.73	0.69	0.73	0.69	0.64	0.69	0.68	0.58	0.59	0.62
GD_C	0.983	0.976	0.983	0.993	0.981	0.981	0.984	0.994	0.981	0.982	0.980	0.994	0.994	0.993	0.994	0.998
GD_S	0.982	0.966	0.976	0.992	0.982	0.980	0.980	0.993	0.980	0.979	0.978	0.993	0.993	0.992	0.992	0.997

*—*C* and *S* represent cone and filled seed productions, respectively. **—relative effective number $N_r = N_p/N$ [33].

Depending on fertility variation, the effective number of parents and gene diversity of the seed crop varied across years and populations, and across years within populations (Tables 2 and 4).

In P_2, the effective number of parents $N_P^{(C)}$ was 18% higher in the highest crop year (year 24), compared to the poorest seed year (year 25), while for $N_P^{(S)}$, it was 7% lower in the highest crop year (year 24) than the poor seed year (year 23) (Table 4). Similar results were also obtained for the other populations. $N_P^{(C)}$ decreased by 2% and $N_P^{(S)}$ increased by 9% in the populations between the highest (year 23) and lowest (year 25) production years. The results indicated the importance of selecting the year for seed harvesting.

The highest gene diversity (GD) was estimated for pooled seed crops of all populations (0.998 for GD_C and 0.997 for GD_S) and for different years within population for both cone (GD_C) and seed (GD_S) than for the individual population and year (Table 4). As seen from Table 4, the lowest gene diversity (GD_C = 0.976 and GD_S = 0.966) was in year 23 for P_1, which increased to 0.993 (GD_C) and 0.992 (GD_S) when the seed crops of the population from different years were analyzed together.

4. Discussion

The present study demonstrates pronounced variation in cone and seed production between individual trees and among seed stands across years and individual trees, highlighting the complex and heterogeneous nature of reproductive output. The variability at the population (seed stand) level and within populations across years indicates that several stand-level characteristics and temporal factors influence the reproductive potential of trees. The reproductive characteristics of forest tree species are influenced by many biotic (e.g., species, tree growth, age, tree density, and crown closure) [35–37] and abiotic factors (e.g., light, temperature, year, humidity, and site quality) [25,38,39], as well as a combination of the two [24,40,41] or forestry practices [42].

In natural *C. libani* stands, good seed years occur approximately every two to three years [1], and the position of individual trees within the stand can also affect species reproductive output [11]. It has been reported that even during good seed years, not all trees in a population are expected to produce abundant seed crops [11]. Similar variation in cone and seed production was reported in *C. libani* by Bilir et al. [23], with higher cone (90) and seed production (5321) per tree in two populations compared to the present study (33 and 3115, respectively).

The reproductive output increased with stand age and exhibited a clear negative relationship with stand density. The consistently higher cone production per tree, filled seeds per cone, and total filled seeds per tree observed in the P_3 seed stand throughout the whole study period suggest that older seed stands with lower tree density provide more favorable conditions for reproductive development. Reduced competition for resources like light, water, and nutrients enhances individual tree vigor in low-density stands, which supports increased reproductive investment. The high reproductive output of the P_3 seed stand, particularly during 2023, underscores the importance of stand structure in determining fecundity. Previous studies have reported that tree size, age, and provenance could impact cone and seed yields [11] and the percentage of filled seed and germination [14,15,43].

Interannual variation was also substantial, with the highest cone and filled seed production per tree in the three seed stands in 2023. However, this year was also characterized by a lower proportion of filled seeds per cone, indicating a trade-off between cone output and seed quality.

The significant population × year interaction ($p < 0.05$) observed for reproductive output (Table 3) underscores the importance of the environmental conditions, which may vary from 'year to year' within a forest stand, and the 'temporal variation' that affects the reproductive performance of populations [32]. Multiplying the tree density (Table 1) and total number of filled seeds per tree (NS_T) (Table 2), the number of filled seeds was estimated to be 1.119,200, 1.093,200, and 1.220,850 per hectare, assuming the seed productivity of all trees in the populations P_1, P_2, and P_3, respectively. Given that 13 kg seeds ha^{-1} are required at a spacing of 1.5 m × 3 m (~2222 seedlings ha^{-1}) for reforestation, afforestation, and restoration practices for *C. libani* [13], the abundant seed production of particular trees or stands will skew the representation (Table 2) in future planting. It is also important to collect as much seed as possible from low-flowering trees. Guidelines and training for simple, cost-effective seed harvesting, the selection of mother trees, and the management of seed stands are necessary for abundant seed collection from a large number of superior parent trees.

Coefficients of variation in cone and seed production (Table 2) were at acceptable levels for an ideal natural population (CV < 140%) [44]. However, cone output gives a more balanced picture of the contribution to the gamete gene pool than the number of filled seeds (Figures 3 and 4). Genetic contributions can be explained by the parental balance curve, and the cumulative percentage curve is often used to quantify fertility variation in

forest populations [17,29]. Unequal contributions of seed parents to the gamete gene pool were not pronounced, indicating that they can be balanced through silvicultural practices, such as tending or equal seed collection from parent trees.

The parental balance curve helps to assess the gene diversity of the resulting seed crop. The sibling coefficient (Ψ) is a related measure that quantifies this variation in fertility, indicating greater disparity in contribution with greater deviation of values from 1. This study clearly shows that gene diversity can be improved when the cones (seeds) are pooled across seed stands and/or collection years (Figures 3 and 4).

Variation in fertility (cone Ψ_C, and filled seed Ψ_S) among populations across years (Table 4) was within the acceptable limits (below the threshold of $\Psi \leq 3$) for natural stands [35]. However, the results indicate the importance of identifying good seed stands and the seed harvesting year. Loss of gene diversity can be mitigated by pooling seeds from different populations and years to support afforestation practices in adaptive areas, thereby enhancing the resistance to biotic and abiotic stresses. This approach relies on the greater adaptability of seed crops due to higher gene diversity when seeds are mixed from different native regions of the species [45]. However, we suggest that a balance between the effective number of parents (gene diversity) and the number of populations and/or years should be carefully considered to ensure a sustained seed supply from the seed stands of Taurus cedar. The long-term seed storage capacity of the species, up to 5–6 years [11,43], could be considered for this purpose.

5. Conclusions

Low fertility variation across consecutive years in the three seed stands indicates that abundant seed collection is possible annually for afforestation with this species. Additionally, the option of mixing seed from different seed stands and harvest years would ensure adequate diversity in the planting stock even during low-flowering years. Marking good parent trees and collecting seeds with parent identity would help to maintain the effective population size of seed crops. As seed output increases with reduced stocking and the seed germination rate differs only marginally, it would be worth culling inferior trees to improve the genetic quality and seed output. Simplifying the guidelines and harvest methods would help to provide easy and cheap selection, management, and harvesting practices for forest managers. Proper records of the seed collection area and year should be maintained to ensure the genetic quality of the seed crop. Since the CVs of cone and seed output are at acceptable levels, it would be easy to quantify the seed output by making a quick estimate of the cone production per tree.

Author Contributions: N.B. conducted data collection. K.-S.K., M.T. and N.B. conducted data validation. K.-S.K. and N.B. performed data analysis. M.T., K.-S.K. and N.B. prepared the draft manuscript, figures, and tables. M.T., K.-S.K. and N.B. conducted review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out with the support of 'R&D Program for Forest Science Technology (Project No. RS-2024-00404133)' provided by Korea Forest Service (Korea Forestry Promotion Institute).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors would like to thank the anonymous reviewers who made valuable comments that helped to improve the manuscript. The authors are also thankful to the graduate students and the regional forest directorate in Türkiye for their help in data collection. The authors would like to acknowledge Mohan Varghese from India for his helpful comments on the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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