RESEARCH PAPER

GENE DIVERSITY IN SEED CROP OF TAURUS CEDAR (*Cedrus libani* A. Rich.) OVER AN ALTITUDINAL RANGE

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ABSTRACT. There could be many environmental and biological impacts such as edaphic, geographic, climatic, age, tree structure and population on morphological, physiological and genetically seed quality in plant species. Gene diversity is an important mirror of genetically seed quality. Gene diversity in seed crops were estimated based on female and male strobili productions of fifty trees (N) randomly chosen from each population sampled over an altitudinal range as low (1200-400 meters ≤ altitude), middle (1400 m < altitude ≤ 1600 m), high (1600 m < altitude ≤ 1800 m), and very high (1800 m < altitude) in Taurus cedar also known as cedar of Lebanon (*Cedrus libani* A. Rich.) for two consecutive years (2021&2022). The variation in strobilus production was subjected to estimation of female and male fertility variation. The total fertility variation (Ψ) was estimated from the female and male fertility variation. Impacts of some growth characteristics (tree height and diameter at breast height) on strobili productions were also investigated. Strobili productions varied among the populations and individuals within population, and between years. The differences for populations and years were also found for coefficient of variations which were mirror of fertility variation of the strobili productions. Tree height and diameter at breast height seemed more reasonable predictor than age for number of strobili. Fertility variations of female parents were generally higher than that of male in both years. First year showed generally higher parental variations in individual populations. Gene diversity (GD=1-0.5Ψ/N) ranged from 0.967 to 0.974 for the populations and years. The loss of highest gene diversity was 0.004 in low population (0.967 & 0.971) between years. Results of the study indicated that altitudinal gene diversity of seed crop could be used to produce genetically quality seed and their grading. Moreover, data sets can be used to fill the Forest Landscape Restoration library (FLR-Library).

KEYWORDS: co-ancestry, effective number, quality, seed, variation, FLR-Library

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INTRODUCTION

Cedrus libani A. Rich. (Asia Minor, Lebanon, Syria) is one of the four species of the genus *Cedrus* in the family *Pineacea: C. deodora* Loud. (Himalaya Mountains, Nepal), *C. brevifolia* Hen. (Cyprus), and *C. atlantica* Manetti (Atlas Mountains) (Vidakoviç 1982). Taurus cedar also known as cedar of Lebanon (*C. libani* A. Rich.), has its main natural occurrence in the Taurus Mountains in total 23.1 million ha national forest area which of 9.6 million ha is unproductive according to the latest forest inventory of Turkey. The species has also some remain populations in other parts of Anatolia such as Sultandağı-Afyon and in the Black Sea region (Çatalan-Erbaa and Akıncıköy-Niksar) together with Taurus Mountains (Boydak 2003). The species has tall and slender trunks and can grow to old ages over than 1000 years old, impressive size by up to 2.49 m (diameter at breast height) and 46 m height, and appearances. There are also many monumental forests and trees scattered throughout the Taurus Mountains of the species (Boydak 2003). Its reported extent in southern Turkey is 405 424 ha (OGM 2022) which the main natural distribution in whole the world together with endemic to elevated mountains around the Eastern Mediterranean in Lebanon and Syria. The species is classified as one of the socio-culturally, economically and ecologically important tree species for Turkish forestry and the "National Tree Breeding and Seed Production Program" (Koski, Antola 1993). Many biological (i.e., volume, height, diameter, age, stem straight, stand purity) and environmental (i.e., distance to plantation area, altitude, size, location, edaphic and climatic characteristics) criterions are used in selection of seed collection areas from natural forests, and establishment of the areas such as seed orchards, and other forestry purposes. Altitude which is easy and cheap could be also considered as an environmental criterion in these selections for forest managers and owners. Taurus cedar used widely in afforestation practices and conversion of unproductive forest area to productive because of valuable timber species and quite striking specimen plants in the landscape and other purposes. Taurus cedar seems potential forest tree species for potential afforestation, reforestation and restoration areas both except and inside of natural distribution. It is getting importance of quantity and quality of seed supply. Seed procurement and its quality using frontier techniques (Bernardes et al. 2022; Novikova et al. 2022; Novikov et al. 2021a; Novikov et al. 2021b; Novikov et al. 2019) is an important stage of the program and practices. It is also known that quality of seed crop genetically improved together with other morphological (i.e., grading) and physiological characteristics play important roles in economical and biological succession of plantation forestry. Seeds are classified generally morphological and physiological characteristics. However, gene diversity is a mirror of genetically improved seed quality together with the other characteristics. While some studies were carried out on seed science and technology of Taurus cedar (Boydak 2003; Bilir 1997; Odabasi 1990; Saatcioglu 1971; Saatcioglu 1956), gene diversity of seed crops based on fertility variation have not been discussed well, yet. Besides, fertility studies are very limited in the species (Bilir, Kang 2014; Bilir, Ozel 2017; Bilir, Kang 2021; Yazici, Bilir 2017).

Fertility also called fecundity is defined as an ability to produce progeny to next generation. Its estimation is used for many purposes such as seed production, managing of forest genetic resources and gene conservation, and evolutional study. Estimation of fertility variation among genotypes is one of the important tools for plant genetics and breeding purposes (Kang 2001; Kang et al. 2003; Bilir et al. 2005; Kamalakannan et al. 2015; Park et al. 2017; Kang, Bilir 2021). Fertility variation and its linkage parameters (i.e., co-ancestry, effective number, gene diversity, status number) estimated based on reproductive characters is modern, easy, cheap, and light survey in plant science. It is preferred by these advantages in plant science recently in the species and other species (e.g., Bilir, Kang 2014; Bilir, Ozel 2017; Bilir, Kang 2021; Yazici, Bilir 2017; Park et al. 2017).

The practical application of the data from this study may be as follows. The implementation of any forest restoration process will always consist of a set of technological operations. The set of these technological operations can be organized in the form of an enlarged algorithm (FLR-algorithm), decomposed into six main groups (Novikova 2022a). The third group of the FLR-algorithm responsible for the preparation of forest reproductive material includes the "Seed collection, pretreatment" operator preceding the "Seed grading" operator (Appendix A, Figure A.1, *b*). To improve seed collection before their detection and processing using frontier scientific techniques, for example, based on convolution neural networks (Bernardes et al. 2022), it is necessary to include the results presented below in block 10 of the algorithm (Novikova 2022b) (appendix A, fig. A.1, *c*).

The purpose of this study is to estimate the gene diversity in seed crop based on fertility variation among individuals in four populations sampled altitudinal range of Taurus cedar by female and male strobili counts, and to discuss the possibility of it using in genetically characteristics in grading and quality of seeds, and to contribute seed technology of the species.

MATERIALS AND METHODS

Populations and data collection

C. libani generally bears cone at about 30 years old in natural stands. Male flowers appear in July and elongate 3-5 cm in August, while female flowers can be seen in September. Pollination takes place in September or early October, depending on the elevation. The following year between April or May and June, conelets develop to normal cone sizes. Opening of the cone scales begins in October about 25-26 months after flowering. Seed dispersal begins at the end of November or December and continues throughout the winter. Seeds of cones collected in August months after flowering (Boydak 2003). However, the period can vary based on many biotic and a-biotic factors.

C. libani in the Taurus Mountains occurs generally between 800 and 2100 m elevation, but it can be also found at lower (500–600 m) and higher (2400 m) elevations as small populations and groups or individuals (Boydak 2003). Natural distribution of the species at studied area were divided into four altitudinal ranges in the southern part of Turkey as: low (1200-400 meters ≤ altitude), middle (1400 m < altitude ≤ 1600 m), high (1600 m < altitude ≤ 1800m), and very high (1800m < altitude) ranges. Some geographic and climatic characteristics of the populations were given for year 2021 in Tables 1 & 2. Numbers of female (♀21 & ♀22) and male (♂21 & ♂22) strobili productions were counted in four populations sampled altitudinal ranges and fifty trees randomly chosen in each population for two consecutive years (2021 and 2022), while tree height (H), diameter at base (D_0), and age were measured at end of growing period of first year (Table 3).

Within the occurrences of *C. libani* at backwards of the Taurus mountains and inner Anatolia sub-humid and semi-arid climatic conditions prevail, respectively. Its populations rather restricted and mostly in degraded conditions at inner Anatolia. The averages of annual temperatures of the area are between 6 and 12 °C. Mean July temperature is about I8 to 25 °C, generally more than 30 °C. Mean January temperature is ranged from 0 to -5 °C. with an absolute minimum -35 °C. Mean yearly precipitation varies between 600 and 1200 mm. Summer periods are generally rainless. Duration of snow cover period ranges 1-5 months. Relative humidity during the growing season varies from about 40 to 60 % (Boydak 2003).

Data analysis

The following ANOVA model was used to analyses the difference of strobili productions among populations and years by the SPSS software (SPSS 2011).

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

Table 1. Some geographic details of studied populations

Altitudinal ranges (m)	Population code	Latitude (N)	Longitude (E)	Average altitude (m)
Low (1200-1400)	Low	38°05'	30°42'	1278
Middle (1400-1600)	Middle	37°44'	30°49'	1486
High (1600-1800)	High	37°52'	31°17'	1714
Very high (>1800)	Vhigh	37°51'	31°18'	1884

Table 2. Some climatic characteristics of the studied years

Months	Average temperature (ºC)				Average humidity (%)				Total rainfall (mm/m²)			
	Low & Middle		High & Vhigh		Low & Middle		High & Vhigh		Low & Middle		High & Vhigh	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
J	5.6	2.1	2.9	-0.8	78.5	75.7	76.8	75.7	182.0	104.6	69.2	72.4
F	6.2	3.5	2.5	1.3	69.1	78.1	67.9	78.1	50.6	96.6	7.4	111.4
M	6.8	3.5	3.8	0.8	66.5	70.5	72.3	70.5	60.8	61.8	92.2	80.8
A	12.9	14.3	11.1	13.1	59.1	52.5	55.1	52.5	10.0	25.4	7.4	16.0
M	19.2	16.8	17.2	15.1	52.2	62.3	47.6	62.3	7.0	25.2	5.0	35.2
J	19.9	22.0	17.5	19.8	64.2	64.0	61.6	64.0	90.0	39.0	102.2	65.2
J	25.7	24.8	23.0	20.5	49.7	47.0	44.2	51.3	6.4	8.8	11.0	5.6
A	25.5	25.1	23.1	23.2	47.6	48.5	41.2	42.5	0.0	1.4	11.6	17.2
S	19.8	20.5	17.2	21.7	57.5	48.5	55.2	49.7	15.8	38.6	16.2	28.2
O	14.0	15.0	11.9	16.1	62.6	62.3	55.1	67.3	15.6	25.2	5.2	26.8
N	10.8	10.3	8.1	7.1	70.9	64.7	70.0	69.0	64.4	14.0	42.8	10.6
D	6.2	5.8	1.4	4.7	79.1	76.8	80.4	80.1	185.8	165.7	96.6	13.2

Table 3. Averages and coefficient of variation (CV%) of tree height (H), diameter at base (D_0), and age of the populations

Characteristics	Populations							
	Low		Middle		High		Vhigh	
	x*	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV
H (m)	38.1^c	1.29	31.9^b	1.53	21.8^a	11.48	22.0^a	2.58
D^0 (cm)	36.5^b	1.59	31.8^a	2.48	35.3^b	26.27	32.5^a	2.11
Age (year)	61.1^a	15.60	68.8^{bc}	16.96	64.5^{ab}	19.47	69.8^c	14.86

* The same letters showed not significantly different at p>0.05 among altitudinal ranges.

Where Y_{ijk} is the observation from the k^{th} tree of the j^{th} population in the i^{th} year, μ is the overall mean of strobili production, F_i is the effect of i^{th} year, $B(F)_{j(i)}$ is the effect of the j_{th} population in the ith year, and e_{ijk} is the random error.

Phenotypic Pearson' correlations among strobili productions and growth characteristics were estimated in the populations by SPSS software.

The coefficients of variations for female and male fertility were calculated and applied to estimate the fertility variation in female (CV♀) and male (CV♂) parents, respectively.

The female fertility (*ψ*♀) and male fertility (*ψ*♂) variations were estimated by coefficient of variation (*CV*) by Kang, Lindgren (1999) as:

$$\psi_{♀} = N\sum_{i=1}^{N} ♀_i^2 = CV_{♀}^2 + 1;\ \psi_{♂} = N\sum_{i=1}^{N} ♂_i^2 = CV_{♂}^2 + 1 \quad (2a\&b)$$

Where *N* is the census number, $♀_i$ is the female fertility of the i^{th} individual, $♂_i$ is the male fertility of the ith individual and CV♀ and CV♂ are the coefficients of variation in female and male fertility among individuals, respectively.

Total fertility variation (Ψ) was calculated by Bilir et al. (2005) as:

$$\psi = \left(\frac{CV_{♀}^2 + CV_{♂}^2}{4}\right) + 0.5\left(N\sum_{n=1}^{N}\frac{♀_n ♂_n}{\sum ♀ \sum ♂} + 1\right) \quad (3)$$

Where *N* is the census number, CV♀ is the coefficient of variation in female fertility, and CV♂ is the coefficient of variation in male fertility, $♀_n$ and $♂_n$ are the number of female and male strobilus of the n^{th} individual; ♀ and ♂ are used as index for the female and male strobilus, respectively.

The effective number of parents were estimated for female [$N_{p(♀)}$] and male [$N_{p(♂)}$] parents and total fertility (N_p) by Kang and Lindgren (1999) as:

$$N_{p(♀)} = N/\psi_{♀};\ N_{p(♂)} = N/\psi_{♂};\ N_p = N/\psi \quad (4a, b \& c)$$

Where *N* is the census number, ψ♀ is the female fertility variation, ψ♂ is the male fertility variation, Ψ is the total fertility variation.

Gene diversity (GD) was estimated based on the effective number of parents (N_p) by Kang and Lindgren (1998) as:

$$GD = 1 - 0.5/N_p \quad (5)$$

RESULTS

Strobili productions and relations

Averages of the strobili productions varied for the altitudinal populations and years (Table 4, Figure 1). They showed also large differences among individuals within population and year (Table 4). For instance, the most productive 5 trees (10% of total trees) produced 30.1% of total ♀$_{21}$ and 27.3% of total ♂$_{21}$ in low population, while they were 4.1% and 2.1% for the lowest productive 5 trees in the population and year, respectively. There were about 10 times differences between lowest (48) and highest (486) productive trees in low altitude of ♀$_{21}$ (Table 4). The results were supported by results of analysis of variance that there were significant ($p<0.01$) differences among the populations except of ♂$_{22}$, and between years. Population and year interaction was also found significant ($p<0.01$) based on results of analysis of variance. Middle population was evidently different for ♀$_{21}$ and ♂$_{22}$ based on results of Duncan's multiple range test (Table 4).

Averages of female strobili were higher than that of male in all populations. Vhigh population showed the highest performances for the strobili productions (149.1 for ♀$_{21}$, 912.6 for ♂$_{21}$ and 94.5 for ♂$_{22}$) except of the lowest ♀$_{22}$ (27.0) in the population (Table 4).

Coefficient of variations which were mirror of fertility variation of the strobili productions changed for the populations and years (Table 4, Figure 2).

Table 4. Averages and coefficient of variation (CV%) and range for strobilus production of the populations and years

Characteristics	Low			Middle			High			Vhigh		
	$\bar{x}$*	CV	range	$\bar{x}$	CV	range	$\bar{x}$	CV	range	$\bar{x}$	CV	range
♀21	127.8[b]	74.3	48-486	73.9[a]	68.5	25-322	146.7[b]	49.6	36-323	149.1[b]	45.6	22-342
♀22	31.7[a]	58.5	12-105	53.3[b]	59.2	13-140	31.0[a]	52.4	9-75	27.0[a]	46.7	8-75
♂21	589.9[b]	82.1	100-1800	129.2[a]	51.5	35-300	647.8[b]	79.3	60-2020	912.6[c]	87.4	115-3020
♂22	75.8	61.2	25-242	79.3	44.1	26-225	91.5	36.1	34-205	94.5	60.2	22-252

* The same letters showed not significantly different at p>0.05 within year.

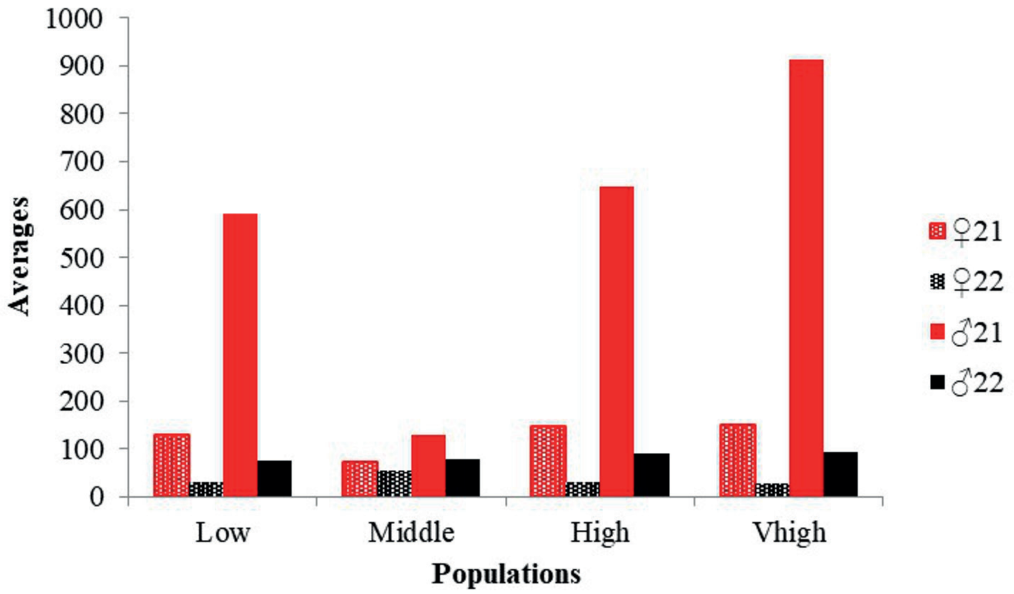

Fig. 1. Averages of strobili productions for the populations and years

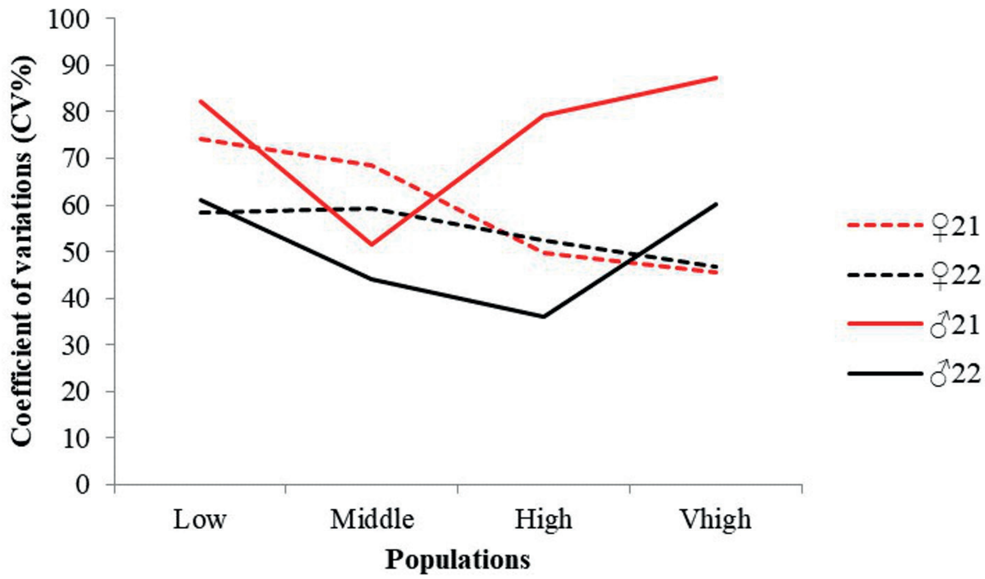

Fig. 2. Coefficient of variations strobili productions for the populations and years

There were positive and significant (p<0.05) correlations between female and male productions in all populations within year, while they were generally significant between years (Table 5). Tree height had negative impacts significantly (*p<0.05*) on strobili productions of first year and on ♂$_{22}$, while it was positive on ♀$_{22}$ in pooled populations (Table 5). While altitude had positive impacts significantly (*p<0.05*) on strobili productions except of negative effect on ♀$_{22}$ in pooled populations of both years, diameter at base had positive effective on strobili productions of first year. Besides, impacts of age varied for the populations and years (Table 5).

Fertility variation, gene diversity and parental balance

Fertility variations of female (ψ♀) parents were higher than that of male (ψ♂) in low and Vhigh populations in both years, and first year of high population (Table 6). First year showed generally higher parental variations (ψ♀ & ψ♂) in individual populations. All populations had higher total fertility variation (Ψ) in first year than second year. It ranged from 2.76 (meaning 36% fertile trees) to 3.32 (30%) in first year, and varied between 2.65 (38%) and 2.92 (34%) in second year (Table 6). The cumulative contribution curve described the relative proportion of trees to the accumulative gamete contribution. The parental cumulative contributions of trees were shown in Figure 3 for the populations and years.

As seen from Figure 3, ♂21 showed skewed evidently distribution in low, high and Vhigh populations.

Gene diversity (GD) varied between 0.967 (first year of low population) and 0.974 (second year of high population) in the populations. The loss of highest gene diversity was 0.004 in low population (0.967 & 0.971) between years (Table 6, Figure 4).

DISCUSSION

Strobili productions and relations

There were large differences for strobili production among populations and among individuals within population, and between years (Table 4, Figure 1). Similar results were also reported for strobili productions in natural populations of Taurus cedar (Bilir, Kang 2021; Yazici, Bilir 2017) and different forest tree species (Kang et al. 2003; Bilir et al. 2005; Kamalakannan et al. 2015; Park et al. 2017; Ozbey, Bilir 2022). It was reported that good seed year of the species in natural stands was once in two or three years (Boydak 2003). Strobili production difference between years was in well accordance with the good flowering year of the species. Differences among populations and between years were also well accordance with results

Table 5. Pearson's correlation coefficients (r) among the strobili productions for the populations and years

	r	N♀21	N♂21	N♀22	N♂22
Low Middle High Vhigh Total	N♂21	.614** .460** .453** .298* .500**	-		
Low Middle High Vhigh Total	N♀22	.436** .187^{NS} 464** .432** .099^{NS}	.501** .220^{NS} .219^{NS} .309* -.035^{NS}	-	
Low Middle High Vhigh Total	N♂22	.356* .225^{NS} .436** .329* .099^{NS}	.446** .234^{NS} .400** .451** .419**	.690** .423** .533** .529** .419**	-
Low Middle High Vhigh Total	H	.111^{NS} .089^{NS} .295* .191^{NS} -.173*	-.001^{NS} .071^{NS} .065 ^{NS} .068^{NS} -.235**	.065^{NS} .161^{NS} .221^{NS} .004^{NS} .186**	-.104^{NS} .092^{NS} .108^{NS} -.149^{NS} -.169*
Low Middle High Vhigh Total	D_0	.444** -.121^{NS} .501** .461** .306**	.386** .206^{NS} .216^{NS} .159^{NS} .151*	.256^{NS} .081^{NS} .538** .368** .098^{NS}	.202^{NS} .142^{NS} .243^{NS} .165^{NS} .082^{NS}
Low Middle High Vhigh Total	Age	.503** .090^{NS} .081^{NS} .306* .188**	.459** .115^{NS} .099^{NS} .178^{NS} .148^{NS}	.336* -.126^{NS} .164^{NS} .186^{NS} .104^{NS}	.358* .123^{NS} .060^{NS} .283* .219**
Low Middle High Vhigh Total	Altitude	-.163^{NS} -.209^{NS} .123^{NS} -.295* .168*	-.312* -.289* .079^{NS} -.274^{NS} .239**	-.175^{NS} -.413** -.171^{NS} -.275^{NS} -.230**	-.224^{NS} .042^{NS} -.056^{NS} -.098^{NS} .151*

**; Correlation is significant at the 0.01 level, *; Correlation is significant at the 0.05 level, ^{NS}; Correlation is not statistically significant *(p<0.05)*.

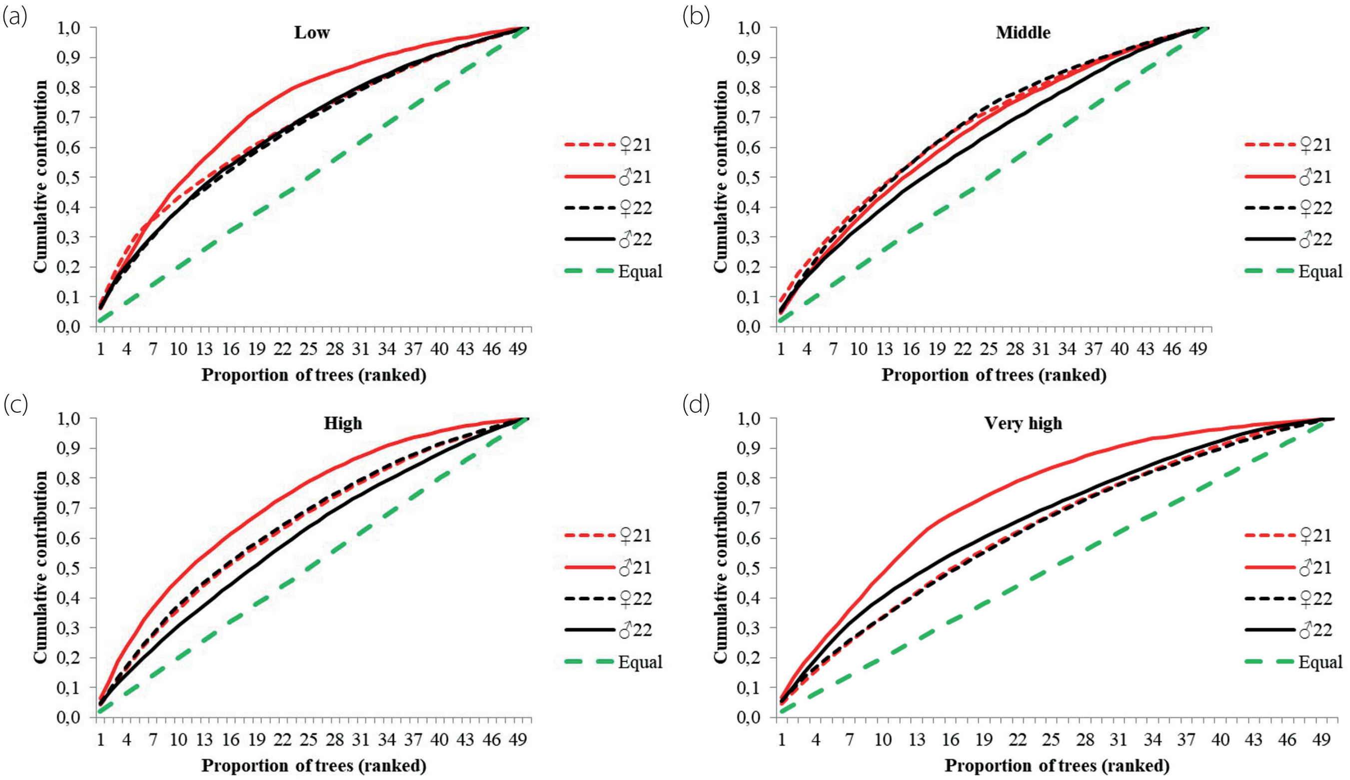

Fig. 3. Parental-balance curves in the populations for the years

Table 6. Female (ψ_f), male (ψ_m), and total fertility variation (Ψ), the female ($N_{p(f)}$) and male ($N_{p(m)}$), and total (N_p) effective number, and gene diversity (GD) for the populations and years

Populations	Low		Middle		High		Vhigh	
Years	2021	2022	2021	2022	2021	2022	2021	2022
ψf*	1.54 (.65)	1.34 (.75)	1.46 (.68)	1.34 (.74)	1.24 (.81)	1.27 (.79)	1.20 (.83)	1.21 (.82)
ψ^m	1.66 (.60)	1.37 (.73)	1.26 (.79)	1.19 (.84)	1.62 (.62)	1.13 (.89)	1.75 (.57)	1.36 (.74)
Ψ	3.32 (.30)	2.92 (.34)	2.93 (.34)	2.75 (.36)	2.82 (.35)	2.65 (.38)	2.76 (.36)	2.70 (.37)
$N_{p(f)}$	32.45	37.45	34.24	37.21	40.30	39.39	41.53	41.21
$N_{p(m)}$	30.11	36.58	39.69	42.00	30.93	44.34	28.59	36.88
N_p	15.05	17.13	17.04	18.18	17.74	18.87	18.13	18.53
GD	0.967	0.971	0.971	0.973	0.972	0.974	0.972	0.973

*; Parentheses indicates the relative effective number of parents (Nr=Np/N).

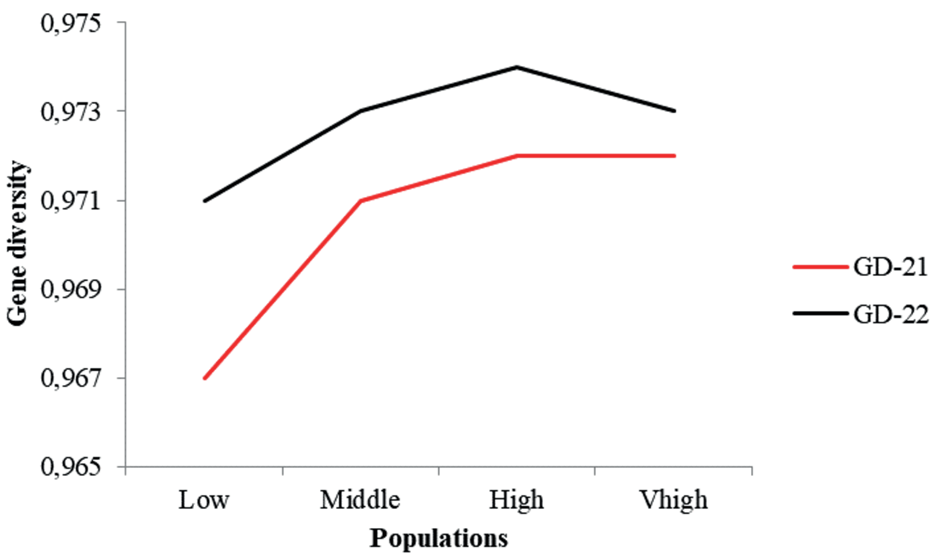

Fig. 4. Gene diversity for the populations and years

of analysis of variance. The results showed also that population and year interaction was significant (*p<0.01*). There could be many environmental or genetical effects in these differences. It was found that age, elevation and crown closure were important factors in seed yield of natural populations of *Pinus brutia* (Eler 1990). Differences in age and environmental variation, mainly in soil properties, may have influenced the observed variation in fruiting and seed set within each population in the natural forest (Bila, Lindgren 1998), or other biological and environmental factors such as population, habitat, aspect, altitude (Yazici, Bilir 2017; Bilir et al. 2005; Bilir 2011) and crown closure (Yazici, Bilir 2023).

Averages of female strobili were higher than that of male in all populations, while their coefficient of variations changed for the populations and years (Table 4, Figure 2). The results were well accordance with findings of strobili production in the species (Bilir, Kang 2021). Low coefficients of variation (CV) were welcomed by forest managers for maintaining higher genetic diversity.

Positive and significant (*p<0.05*) correlations between female and male productions were estimated in all populations within year (Table 5). Similar correlations were also found in natural populations of *C. libani* (Bilir, Kang 2021) and *Pinus brutia* (Bilir et al. 2005) opposite to negative genetic correlation between female and male flowering in *P. sylvestris L.* (Savolainen et al. 1993).

Tree height had generally negative impacts on strobili productions in pooled populations opposite to diameter at base while impacts of age changed for the populations and years (Table 5). It could be said that height and diameter at breast height seemed more reasonable predictor than age for number of strobili. Altitude had positive impacts significantly (*p<0.05*) on strobili productions except of negative effect on $♀_{22}$ in pooled populations (Table 5). However, no significant impact of altitude on strobili production was reported in *Pinus brutia* (Bilir et al. 2005).

Fertility variation, gene diversity and parental balance

Fertility variations of female (ψ♀) parents were generally higher than that of male (ψ♂) in the populations (Table 6). First year showed mostly higher parental variations (ψ♀ & ψ♂) in individual populations. All populations had higher total fertility variation (Ψ) in first year than second year (Table 6). Similar fertility variations were reported for strobili (Bilir, Ozel 2017; Bilir, Kang 2021) and cone productions (Bilir, Kang 2014; Yazici, Bilir 2017) in natural populations of Taurus cedar. The results indicated importance of population and years in forestry practices of the species.

The effective number of parent ($N_{p(♀)}$), $N_{p(♂)}$ & N_p) mirrored to the gene diversity showed that about 30% of individuals in the low population of first year behavior as they were under the ideal population, while they were 38% in high population of second year. It showed the size equivalent to the ideal populations was 8% larger in high population than low population based on the fertility variation of individuals in the populations (Table 6). It was suggested as a rough generalized heuristic rule that CV lower than 140% (Ψ≤3) for natural populations (Kang 2001; Kang, Bilir 2021). The low populations were close to the value (Ψ≤3) in both years and first year of middle population (Table 6).

Gene diversity (GD) varied between 0.967 (first year of low population) and 0.974 (second year of high population) in the populations (Table 6, Figure 4). They emphasized importance of seed collection year and population sampled altitudinal range in the study. The result was in well accordance with the report that altitude is an important environmental factor in selection and establishment of seed sources in forestry (Wright 2012). However, the GD could be balanced by different forestry practices. For instance, gene diversity of seed crop could be increased from 0.967 to 0.970 (Ψ=2.73) by removing/uncollected of five the most/lowest productive trees in first year of low population. GD could play important role to establish resistance forest to different environmental conditions.

Seed harvesting and other forestry practices (e.g., natural regeneration practices) were suggested in good seed year. The strobili productions were clearly higher in first year than second year in the populations (Table 4), while GDs were similar between years within population (Table 6, Figure 4). It indicated that poor seed year could be also suitable for forestry practices based on gene diversity.

CONCLUSIONS

Variation of strobili productions among individuals within population indicated importance of individual selection in seed harvesting. Similar gene diversity between years showed that forestry practices (e.g., seed harvesting, natural regenerations) could be also carried out in poor seed year. Gene diversity (GD) was higher in high and very high altitudes than that of low and middle. The result could be a guide in altitudinal forestry practices. However, many ecological (i.e, altitude, aspect, edaphic, climatic) and biological factors (i.e, adaptation capacity and genetic diversity of the species, crown closure, tree size) could impact on gene diversity. The study was carried out in limited area of the species to be decreased effect of other factors. Effects of ecological and other factors which were changed altitudinal on gene diversity could be examined in large area by long term and future studies. Low gene diversity in seed crop could be increased by forest practices such as harvesting from similar productive trees. GD of seed crop should be taken into consideration in seed quality/grading together with other seed characteristics. Relations among the characters can be a guide for future studies, and establishment and management of seed sources. Present study included two-year data and limited area of the species. New studies should be carried out by different populations and years in the species to give accurate conclusions.

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APPENDIX A

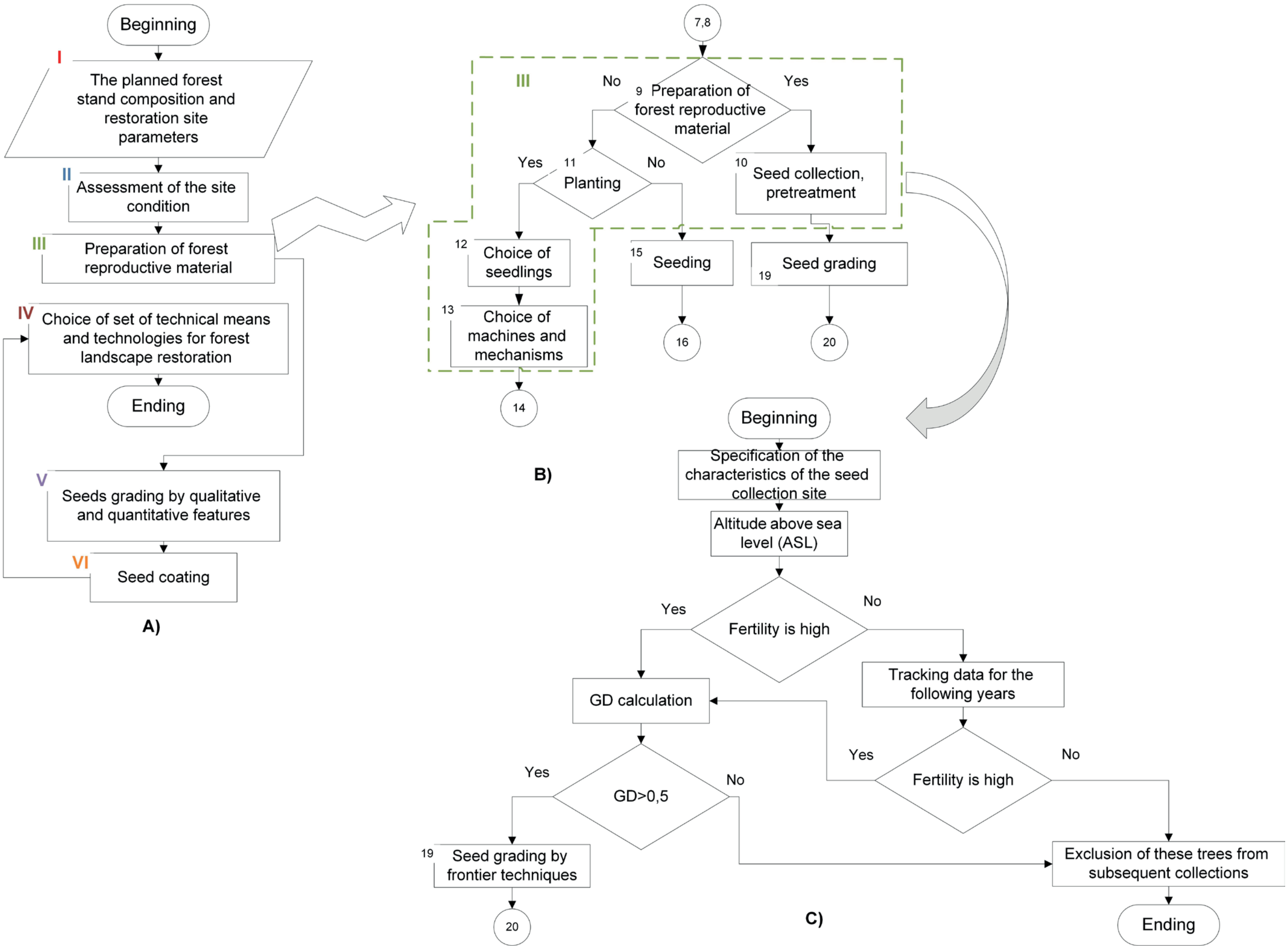

Fig. A.1. Practical application of the parameters of the genetic diversity of seeds (C) in the decomposition of the FLR-model for the preparation of forest reproductive material (B), which is the III-group of the generalized algorithm for choosing the technology of forest restoration (A). Figures A) and B) are adapted from the paper by co-author T.N. (Novikova 2022b), figure C) is the T.N. own composition