DETERMINATION OF SUPERIOR BEAN GENOTYPES IN COOKING AND PHYSICAL BY MULTI-CRITERIA DECISION-MAKING METHOD

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ABSTRACT

It is aimed to examine and predict the effects of bean genotypes using cooking and physicochemical properties on seed quality index and yield in this study. The seed quality index was calculated by combining the analytical hierarchical process and standard scoring functions, which is one of the multi-criteria decision-making methods, using the linear combination technique. To determine the seed quality index, a data set was created with 11 indicators. analytical hierarchical process was used to weight importance levels of examined traits depending on the genotypes. Seed quality index of registered cultivars according to investigated characteristics of cultivars and genotypes IV. Class, 6 genotype (Bombay genotype) was found to be in class V. Obtained seed quality and physical properties by determining with seed quality index obtained in this study, estimation of seed quality in beans with analytical hierarchical process was evaluated successfully. As a result, according to seed quality index of bean cultivars and genotypes, it was determined that genotype 6 had superior characteristics in terms of productivity, in addition genotypes 8 with 9 and registered cultivars could also show superior characteristics.

INTRODUCTION

Legumes are very important for human and animal nutrition, besides providing biologically fixed nitrogen by bacteria for soil (Koivunen et al., 2015). Bean (*Phaseolus vulgaris* L.) is one of the most important edible legumes used for direct human consumption (Didani and Dumlupınar, 2022). As a matter of fact, beans contribute to the nutrition, economic and social welfare of many people in developing countries (Anderson et al., 2016; Natabirwa et al., 2018). Historically, legumes like peas and certain types of beans have been traditionally grown in Nordic countries, with the latter being mainly suitable for animal fodder if grown north of latitude 60˚N (Meltzer et al., 2019). Beans are very rich in protein, energy, and dietary fibre. It is also a rich source of micronutrients such as iron, zinc, B vitamins and health-promoting bioactive compounds such as polyphenols (Blair 2013). Many dried bean varieties with different physico-chemical and sensory properties meet changing consumer preferences. In general, some of the well-known bean genotypes are black turtle beans, cranberry, borlotti beans, flageolet beans, kidney beans, pea beans, pink beans, pinto beans, and white beans, yellow beans, which are primarily grown in tropical and subtropical regions (Nicoletto et al., 2019).

According to 2019 data in the world, 33 million hectares of dry beans were harvested, and 28.9 million tons were produced. In the same year, 225 thousand tons of dry beans were produced in an area of 89 thousand hectares in Turkey. Yield for dry beans has been 874 kg ha^{-1} in the world and 2531 kg ha^{-1} in Turkey (FAO, 2019). On the other hand, production and yield amount of beans, is not at a sufficient level yet. Indeed, worldwide bean consumption is still low, estimated to be between 4-66 kg per capita per year for different countries (Blair 2013).

One of the most important goals of research programs is to increase the yield per unit area. It is necessary to develop suitable varieties for the region, to know the degree of influence of factors affecting yield and relations between each other, and to make the selections in breeding programs according to these criteria (Oner et al., 2023). The first of the main strategies for success in cultivar development programs is the breeder's understanding of interactions of characteristics with one another that constitute yield and quality of plants that are effective in regional conditions (Agarwal et al., 2013). Simple correlations are not sufficient to evaluate complex relationships between many characters related to dependent variables (MacCallum et al., 2002). It is great importance to develop new approaches to facilitate selection of superior properties genotypes together with

the determination of the characteristics that affect yield and yield in plant breeding.

Multi-criteria making decisions, multi-objective making decisions, and multidimensional making decision are frequently used by scientists (Diaz and Soares, 2022). In this context, some multivariate indexes such as the analytic hierarchy process (AHP), which is a general measurement theory, have been developed (Darko et al., 2018). AHP is frequently used in decision-making processes that use multiple criteria to estimate preference values for a particular set of features. AHP can be used for both concrete and abstract data. The method is easy to use and can help researchers combine concrete and abstract criteria and make the best decision (Ziemba 2022).

In AHP, pairwise comparison is first used to evaluate the relative importance of different alternatives for a set of criteria or attributes. Then, individual preferences are estimated using AHP and combined into group preferences using weighted goal programming (Coffey and Claudio, 2021). When groups have different opinions, weighted goal programming (WGP) based models can be

used to generate consensus preference values (Dhahri et al., 2020). AHP has generally been applied to decide on a suitable site for environmental management and different purposes (Garcia 2022). The AHP approach has also been adopted by many researchers for agricultural decisions (Sengupta et al., 2022). For example, Garcia and Guitart (2022) in rice, Gebru et al. (2023) in the identification and selection of superior genotypes in tomato used AHP.

In this study, beans of different types were grown in 2019 and 2020. It aimed to determine the most productive type according to seed quality indices by weighting the yield obtained with the quality and physical properties of seeds with AHP.

MATERIALS AND METHODS

Materials

In the study, 20 bean genotypes and 2 registered cultivars were used as seed material. Some characteristics and supplied locations of bean types used in the experiment are given in Table 1.

Table 1. Seed characteristics and supplied locations of bean genotypes/varieties used in the experiment

Material code	Genotype name	Supplied location	Seed colour
G1	Bosna Hersek 1	Bosnia and Herzegovina	light brown with burgundy spots
G2	Bosna Hersek 2	Bosnia and Herzegovina	black
G3	Bosna Hersek 3	Bosnia and Herzegovina	yellow
G4	Iran	Iran	light brown with burgundy spots
G5	Taskentcity	Uzbekistan/Tashkent	light brown spots on burgundy
G6	Bombay	Turkey/Bolu	white
G7	Black Bean	Turkey/Mersin	black
G8	Dermason	Turkey/Mersin	white
G9	Bat Bean	Turkey/Mersin	white hilum and black spots at the junction
G10	Bagel Bean	Turkey/Mersin/Mut	white
G11	Claret red bean	Turkey/Mersin/Mut	claret red
G12	Purple Bean	Turkey/Mersin/Mut	purple
G13	Osmanli Bean	Turkey/Isparta	dark purple/black
G14	Ayse Kadin	Turkey/Isparta	white
G15	Isparta Bean	Turkey/Isparta	yellow
G16	Sugar Bean	Turkey/Konya	white
G17	Kirmizi-Beyaz Alaca	Kyrgyzstan	hilum and background in red color joint on white
G18	Tomanity	Kyrgyzstan	red
G19	Ryabaya	Kyrgyzstan	light brown with burgundy spots
G20	Sudan	Sudan/Al Junaynah	light brown spots on burgundy
RV1	Onceler 98*	Turkey/Isparta	white
RV2	Yunus 90*	Turkey/Isparta	white

* – registered bean varieties, G – genotype, RV – registered varieties

Setup of Experiment, Climatic and Soil Characteristics of Area

The coordinates of Isparta where the research was carried out are 37°45'59.4"N 30°33'11.8"E trial fields on (April 29) 2019 and (May 1) 2020 in Turkey. The experiment was carried out according to the randomized complete block design (RCBD) with 3 replications. The bean genotypes used in the experiment are given in Table 1. The plot size of the study was 8 m² (4 m x 2 m) and it was established to have 4 rows in each plot. The sowing

norm was set to be 50×20 cm between and above the rows. In the study, fertilization was made with 40 kg of N and 60 kg of P_2O_5 per hectare. In the study, irrigation was done with a drip irrigation system according to the moisture condition of soil. Each genotypes was checked every other day and harvested as genotypes matured and threshed after drying in a shaded area. When climate characteristics in 2019 and 2020, when study was carried out, and long-term were examined, the temperature in both years (21.2 and 22.6°C, respectively) was higher than

the long-term data (20.2°C), and total precipitation in long-term data (140.0 mm) less than second year (162.4 mm) more than first year (131.5 mm). It was observed that average relative humidity (49.2% and 45.6%) was less than long-term data (51.2%). The research was conducted in the same region in both years. When the soils taken from this region are analyzed, the results; soil texture is a clayey-loamy structure, with a slightly alkaline reaction (mean 7.60), salt content is in the slightly salty group (mean 325 μS/cm), and it is reported to be poor in terms of organic matter content (mean 1.53).

Examined Properties

After determining the yield characteristics of seeds obtained from each plot, hundred seed weight, hydration capacity, swelling index, cooking time, dry volume, seed width and length, testa rate, geometric mean diameter, volume, bulk density, and true density properties were determined.

The study calculated the hundred-seed weight by counting 100 seeds 4 times for replication and then averaging. Hydration capacity (g seed^{-1}) is the amount of water absorbed by seed in g. Therefore, after removing the unswelled hard-shelled seeds in the samples whose 100-seed weight was determined, the hydration capacity of weighed seeds was determined according to the formula below (Eq 1). Seeds that did not absorb any water at the end of the 16-hour soaking period and did not change weight were accepted as hard-shelled seeds (Karaman 2019).

Hydration capacity (g seed^{-1})= Y−[(X−(X/100) x N2)] (Eq 1)

N1 – N2

According to the equation,

Y = Wet weight (g) after non-swelling seeds are separated,

X = Dry 100 seed weight (g),

N1= Initial number of seeds (pieces),

N2= Number of unswelled hard-shelled seeds (pieces).

If there is no swelling;

hydration capacity is calculated according to the formula (Eq 2).

Hydration capacity (g seed^{-1}) = (Wet weight-Dry weight) / 100 (Eq 2)

The swelling index was determined according to following formula (Karaman 2019; Eq 3).

Swelling index (%) = [Wet volume-100) / (Dry volume-50)] (Eq 3)

Dry volume (ml), 100 bean seeds were taken into a 100 ml measuring cylinder, 50 ml of distilled water was added, and the data obtained was recorded as dry volume

(Karaman 2019). Cooking time (min) was recorded when 50 soaked samples were thrown into boiling water, and then checked every 3 minutes, When testa was peeled, the seed split into two and the white dot inside disappeared (Ozaktan 2021; Luo et al. 2023;). The testa (seed coat) ratio (%) was separated from the testa of 10 seeds from bean seeds soaked for 16 hours, and separated testa and cotyledon were dried in an oven at 65°C until their weight stabilized. Then, their individual weights were determined. It was obtained by dividing the determined dry testa weight by the total dry seed weight and multiplying it by 100. Seed width and length (mm); width and length sizes of seeds used in the study were measured with the help of a caliper.

Geometric mean diameter (Dp, mm) feature was determined by using the formula below (Eq 4). The volume (V) property is calculated using the formula below (Eq 5). The B value in formula expresses the spherical diameter of seed and determined from the formula below at Eq 6 (Taner et al., 2018). Bulk density (Pb) Eq 7 for small seeds (Unal et al., 2008); for large seeds Eq 7 calculated from formulas. True density (Pt) was determined from the formula below (Eq 8).

Dp = (Width*Length*Thickness)$^{1/3}$ (Eq 4)

V=π*B2*L2 / 2a6*(2*Length-B)   (Eq 5)

B= (Width*Thickness)$^{1/2}$ (Eq 6)

Pb= (843.3-6.2)*Moisture content   (Eq 7)

Pt = (Dry weight / Dry volume)*10000   (Eq 8)

Descriptive statistics of data in the study were made in the Minitab 17 statistical package program, variance analysis. The difference between the averages Tukey multiple comparison in determining differences test was used. The obtained data were subjected to path analysis, and according to data obtained from this analysis, AHP weights were created by considering the direct impact shares.

Determination of Seed Quality

In the realization of the study, 22 bean genotypes were used as material. Since each seed material has different units, it was first transformed into a unitless state by applying the standard scoring function. Then, the indicators were weighted with AHP developed by Saaty (1980) in order to determine the effect levels of seed quality indicators. Firstly, seed quality indicators were converted to unitless scores between 0.1 and 1.0 to be comparable with each other using standard scoring functions (SSF) (Keshavarzi et al., 2022). Generally, three different scoring functions (SSF) are used: 'more is better', 'less is better' and 'mid-point is optimum' (Gozukara et al., 2021). The SSF equations for parameters are listed in Table 2.

Table 2. Standard scoring functions and parameters for quantitative seed parameters

Parameters	FT*	SSF Equation**
Testa ratio	LB	$f(x) = \begin{cases} 0.1 & x \leq L \\ 1 - 0.9 \times \frac{x-L}{U-L} + 0.1 & L \leq x \leq U \\ 1 & x \geq U \end{cases}$
Cooking time	LB	
Dry weight	MB	
Dry volume	MB	
Hydration capacity	MB	
Swelling index	MB	
Hundred seed weight	MB	$f(x) = \begin{cases} 0.1 & x \leq L \\ 0.9 \times \frac{x-L}{U-L} + 0.1 & L \leq x \leq U \\ 1 & x \geq U \end{cases}$
Seed width	MB	
Seed length	MB	
Geometric mean diameter	MB	
Volume	MB	
Bulk density	MB	
True density	MB	

*FT: means function type; MB: means more is better; LB: means low is better; **SSF means standard scoring function; L and U are the lower and the upper threshold value, respectively.

In line with the values obtained in this study, more is better and less is better approaches were used. In more is better function, dry weight, dry volume, hydration capacity, swelling index, hundred seed weight, seed width, seed length, geometric mean diameter, volume, bulk and true density are taken, while in the 'less is better' approach, testa rate and cooking time characteristics were taken. With the AHP method, it is possible to make pairwise comparisons to determine the weights and priorities of both qualitative and quantitative factors and it has proposed a comparison that evaluates importance degree ranging from 1 to 9. Pairwise comparison is applied to criteria and sub-criteria according to expert opinions and evaluations (Rouyendegh and Savalan, 2022). The numerical values indicating the relative importance of each other according to the Saaty scale are given in Table 3.

Table 3. Saaty scale

Significant level	Explanation	Description
1	equality important	Two items are equally important
3	one less important than other	Criterion 1 is slightly more important than criterion 2
5	necessary or strongly important	1 criterion is more important than criterion 2
7	strongly important	1 criterion very important, practically dominant or demonstrable situations relative to criterion 2
9	absolutely important	1 criterion is the strongest (extremely) significant and the highest accuracy to criterion 2
2, 4, 6, 8	intermediate values	It is used when indecisive between two evaluations that are close to each other and when a compromise is needed between two values.

Considering the importance of criteria, a comparison matrix (n x n dimensions) was created between criteria (Eq 9).

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{1n} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{2n} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{3n} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{4n} \\ a_{n1} & a_{52} & a_{53} & a_{54} & a_{nn} \end{bmatrix}$$ (Eq 9)

In this matrix created, all data must have positive values. A: pairwise comparison matrix a_{ij}: importance of element i relative to element J (i, J……n). Properties of pairwise comparison matrix;

$a_{ji} = 1/a_{ji}$ $\quad a_{ij}>0(i, j=1, 2….,n)$ for pairwise comparison to be fully consistent,

$a_{ik}=a_{ji} \, a_{jk}$ (I, j, k=1, 2,….n)

If it is consistent; $a_{ij}=W_i/W_J$

(W_i=priority value for element i, W_j: priority value for element J)

After the comparison matrix table was created, the matrix was normalized. Normalization is done by the data in each cell is divided by the column total of that cell. The W column vector, called the priority vector, is obtained by taking the arithmetic average of sum of data in each row in the normalization table obtained from pairwise comparisons. This vector represents the percentage importance weights of the criteria (Eq 10).

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{n}$$ (Eq 10)

W_i= priority vector or weight of i criterion; a_i = element i in normalization table; a_j = element j in normalization table; n = is number of criteria.

The pairwise comparison matrix (A) is multiplied by the priority vector (w) to get vector D (Eq 11).

$$D_i = A_i \times W_i = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ --- \\ --- \\ --- \\ w_n \end{bmatrix} \qquad \text{(Eq 11)}$$

E_i values in Eq12 are obtained by the elements (d_i) of vector D column are divided by elements (W_i) of priority vector.

$$E_i = \frac{d_i}{w_i} \qquad \text{(Eq 12)}$$

The sum of E_i values is divided by a number of criteria and the arithmetic average is taken. With this process, the largest eigenvalue of matrix called λ_{max} (Eq 13) is found.

$$\lambda_{max} = \frac{\sum_{i=1}^{n} E_i}{n} \qquad \text{(Eq 13)}$$

λ_{max} = Maximum eigenvalue; n = number of criteria

In order to measure consistency in comparisons, eigenvector method is used, and consistency index (CI-Consistency Index) is obtained (Eq 14).

$$CI = \lambda_{max} - n/n-1 \qquad \text{(Eq 14)}$$

Consistency ratio (CR) value; As seen in the equation in Equation 15, it is obtained by dividing Consistency index (CI) by the Random index (RI) (Table 4) value (Eq 15) If CR value is less than 0.10, comparisons made by decision maker are consistent, If CR value is 0.10 greater, it indicates that the comparisons are inconsistent or there is a computational error. In this case, comparisons should be reconsidered (Saaty 1980).

$$CR = CI/RI \qquad \text{(Eq 15)}$$

Table 4. Random index values (RI) depending on number of criteria

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

After features weighted with AHP were standardized with SSF, seed quality index values were determined using linear combination technique approach (Eq 16), and they were classified according to Table 5.

Table 5. Classification of seed quality index (SQI)

Class	Definition	SQI
I	Very low	< 0.40
II	Low	0.40 – 0.50
III	Moderate	0.50 – 0.60
IV	High	0.60 – 0.70
V	Very high	> 0.70

$$SQI = \sum_{i=1}^{n}(Wi.Xi) \qquad \text{(Eq 16)}$$

Where SQI: Seed quality index for agricultural usage, Wi: Weighting of parameter i, Xi: Sub-criterion score of parameter i. The above formula was applied to each seed material.

RESULTS AND DISCUSSIONS

Seed Characteristics

Descriptive statistics on seed characteristics of bean genotypes and cultivars are given in Table 6 and the difference between bean and bean genotypes is shown in Table 7 and Table 8.

Yield values of bean genotypes and varieties varied between 1209.9 and 3088.9 kg ha^{-1} (Table 6). Yield in beans varies depending on the climate and soil conditions of the region where it is grown, cultural practices and genetic structure of bean varieties (Bakure et al., 2023; Çukurcalıoğlu et al., 2023). In addition, seed yield comes to the fore at the beginning of selection criteria in beans. On the other hand, dry volume of bean seeds varied between 62.00 and 95.00 ml and mean dry volume value was determined as 79.53 ml. Dry volume varies depending on the dry weight of seeds. As a matter of fact, Aydogan et al. (2020) stated that dry volume values of bean genotypes and varieties vary between 76.50-98.50 ml, and there is a positive and significant relationship between dry weight and dry volume. hydration capacity, which is one of the important selection criteria in bean, varied between 0.04-0.66 g seed[-1] with swelling index 1.14%-2.47% (Table 6). Shimelis and Rakshit (2005) determined that the hydration capacity of bean varieties varies between 0.08-0.19 g seed[-1]. In addition, researchers stated that bean varieties with high hydration capacity and high hydration index require less cooking time, thus saving fuel energy. Cooking time in beans is one of the main factors used to determine cooking quality. As a matter of fact, in the study, the cooking time of bean genotypes and varieties varied between 30.00-85.00 minutes, and mean cooking time was determined as 43.38 minutes (Table 6). Longer cooking times result in nutrient loss and limit end uses. Therefore, it is of great importance to consider cooking time (Shimelis Rakshit 2005).

Table 6. Descriptive statistics of bean seeds

Variable	Min.	Max.	Mean	Std. Deviation	Skewness	Kurtosis
Seed yield (kg ha^{-1})	1209.9	3088.9	1893.7	48.08	0.40	-0.55
Dry volume (ml)	62.00	95.00	79.53	10.10	-0.08	-1.15
Hydration capacity (g seed^{-1})	0.04	0.66	0.33	0.17	-0.16	-0.79
Swelling index (ml seed^{-1})	1.14	2.47	1.69	0.32	0.45	-0.15
Cooking time (min)	30.00	85.00	43.38	11.73	2.08	4.82
Coat ratio (%)	6.19	11.31	8.68	1.22	0.12	-0.59
Hundred seed weight (g)	26.02	93.23	47.42	15.15	1.41	2.07
Seed width (mm)	6.39	11.94	8.39	1.18	1.00	1.22
Seed length (mm)	10.76	17.76	14.46	1.96	0.09	-0.92
Geometric mean diameter (mm)	7.21	11.55	9.08	0.93	0.36	0.33
Volume	22.86	58.71	36.74	7.57	0.67	0.83
Bulk density (kg m^{-3})	826.10	848.14	835.01	4.30	0.94	1.33
True density (kg m^{-3})	1005.90	1364.20	1204.20	95.80	-0.42	-0.87

Table 7. Average values of seed yield and cooking characteristics of bean genotypes as a result of two years combined analysis

Genotypes	GY	DV	HC	SI	CT	CR	HGW
G1	2361.50[d]	84.83[cd]	0.34[e]	1.43[l-n]	35.67[k-m]	8.90[b-h]	47.47[e-h]
G2	1747.79[hı]	65.00[j]	0.10[gh]	1.67[f-k]	36.00[k-m]	7.07[h]	45.53[g-ı]
G3	1249.89[m]	62.67[j]	0.08[h]	1.90[c-e]	31.00[o]	8.60[c-h]	37.84[jk]
G4	1890.83[g]	84.17[cd]	0.35[e]	1.23[no]	38.00[ı-k]	9.52[a-d]	81.21[b]
G5	2161.50[e]	71.17[ı]	0.18[fg]	1.85[d-g]	63.00[b]	8.07[d-h]	46.12[f-h]
G6	2998.90[a]	87.17[bc]	0.45[b-d]	2.04[b-d]	84.00[a]	9.49[a-e]	91.21[a]
G7	1574.09[k]	70.83[ı]	0.24[f]	1.47[j-m]	47.00[d]	10.76[ab]	26.88[m]
G8	1754.41[h]	94.33[a]	0.64[a]	1.68[e-j]	43.33[e-g]	10.29[a-c]	53.09[de]
G9	1985.59[f]	94.33[a]	0.52[b]	1.65[g-l]	40.00[hı]	7.46[f-h]	50.41[d-g]
G10	1400.71[l]	77.17[fg]	0.37[de]	2.12[bc]	35.00[lm]	8.09[d-h]	40.01[ı-k]
G11	1665.59[ıj]	76.17[f-h]	0.35[e]	1.46[j-n]	39.00[h-j]	9.22[a-g]	30.38[lm]
G12	1259.61[m]	65.33[j]	0.05[h]	1.73[e-ı]	39.00[h-j]	8.35[c-h]	38.92[jk]
G13	2321.81[d]	90.00[b]	0.33[e]	1.27[m-o]	55.00[c]	8.51[c-h]	50.92[d-g]
G14	1579.29[k]	79.67[ef]	0.40[c-e]	1.61[h-l]	44.67[de]	10.96[a]	60.65[c]
G15	1642.99[jk]	82.50[de]	0.43[cd]	1.15[o]	34.00[mn]	7.36[gh]	35.90[j-l]
G16	1267.01[m]	78.33[fg]	0.41[c-e]	1.89[d-f]	37.00[j-l]	8.00[d-h]	36.99[jk]
G17	2033.31[f]	75.67[gh]	0.34[e]	2.24[ab]	52.33[c]	7.27[gh]	35.11[kl]
G18	2588.90[b]	87.67[bc]	0.46[bc]	1.64[g-l]	41.33[f-h]	9.47[a-f]	34.10[kl]
G19	2311.10[d]	73.00[hu]	0.10[gh]	1.44[k-n]	44.00[ef]	8.36[c-h]	52.00[d-f]
G20	1254.41[m]	65.17[j]	0.05[h]	1.55[ı-l]	43.00[e-g]	9.49[a-e]	41.87[h-j]
RV1	2448.29[c]	94.33[a]	0.43[cd]	1.81[e-h]	31.33[no]	7.50[e-h]	54.47[cd]
RV2	2164.09[e]	90.17[b]	0.61[a]	2.43[a]	40.67[g-ı]	8.23[d-h]	52.00[d-f]
F-Value	972.48**	215.00**	144.38**	59.31**	493.25**	8.92**	170.35**
CV	1.43	1.52	7.60	10.47	2.14	7.42	4.28

** Significant at P<0.01, Means followed by the same letter in the columns are not significantly different at P ≤ 0.05, GY: Seed Yield; HGW: Hundred Seed Weight; H: Hydration Capacity; CT: Cooking Time; SI: Swelling Index; DV: Dry Volume; CR: Coat Ratio

The coat rate of bean genotypes and varieties varied between 6.19% and 11.31%. As a matter of fact, Sozen and Karadavut (2020) stated that coat rate in bean seeds is an important quality criterion and that it can show differences in changing environmental conditions. The 100 seeds weight varied between 26.02-93.23 g, and the mean 100 seed weight was determined as 47.42 g. The 100-seed weight of beans is an important feature affecting yield, and large-sized bean varieties are preferred in terms of market value. The mean seed width and length of bean genotypes and cultivars were determined as 8.39 and 14.46 mm, respectively. Bean seed width and length are important in terms of marketing and vary depending on cultural practices, region where it is grown and the genetic structure of variety. Cirka and Ciftci (2018) determined that seed length varies between 11.15-16.40 mm, seed width 6.41-10.26 mm in amplectant bean types, and seed length 12.24-13.18 mm and seed width 6.34-8.45 mm in dwarf types. The mean geometric mean diameter of bean genotypes and varieties was 9.08 mm, the mean volume was 36.74, the mean bulk density was 835.01 kg m^{-3}, and the mean true density was 1204.20 kg m^{-3}. The normal distribution is symmetrical. The degree of deterioration of symmetry in a normal distribution is called skewness. The distribution is called right (positive) skewed if it is long-tailed to the right and skewed to the left (negative) if it is

long-tailed to the left. The degree of sharpness or roundness of the normal distribution curve is called kurtosis. Except for the skewness coefficients, dry volume and hydration capacity of the bean seeds, it was determined that the other properties showed positive distributions away from the normal distribution. It is seen that true density, dry volume and hydration capacity values are seed traits with negative skewness among all examined traits (Table 6). The trait with the furthest distribution from normal distribution was determined as cooking time, and cooking time values were generally lower than mean values. The characteristics that show the closest distribution to normal are dry volume, hydration capacity, coat ratio and seed size.

Table 8. Average values of seed physical characteristics of bean genotypes as a result of two years combined analysis

Genotypes	SW	SL	GMD	V	BD	TD
G1	8.17[f-j]	13.94[d-g]	8.97[f-ı]	35.34[f-ı]	841.17[ab]	1266.68[a-c]
G2	8.22[f-ı]	11.66[ı]	8.44[ij]	31.66[ij]	832.28[de]	1074.51[de]
G3	6.67[k]	13.14[gh]	7.63[kl]	25.68[kl]	832.45[de]	1028.56[e]
G4	8.35[f-ı]	13.73[e-g]	9.11[e-h]	36.56[e-h]	846.98[a]	1252.89[a-c]
G5	8.88[d-f]	15.74[c]	9.32[d-g]	38.28[d-g]	840.55[b]	1134.32[c-e]
G6	11.67[a]	17.32[a]	11.42 [a]	57.40[a]	836.07[b-d]	1242.34[a-c]
G7	6.62[k]	11.72[ı]	7.35[l]	23.75[l]	835.54[b-d]	1139.73[c-e]
G8	9.27[c-e]	17.52[a]	9.85[b-d]	42.94[b-d]	836.02[b-d]	1350.80[a]
G9	8.45[f-h]	16.12[bc]	9.85[b-d]	42.71[b-d]	832.06[de]	1301.97[ab]
G10	7.40[jk]	13.58[f-h]	8.22[jk]	29.75[jk]	831.66[de]	1190.31[b-d]
G11	7.37[jk]	14.80[d]	8.20[jk]	29.81[jk]	833.70[c-e]	1213.24[bc]
G12	7.62[ıj]	14.50[d-f]	8.75[g-j]	33.66[g-j]	832.41[de]	1068.36[de]
G13	10.16[b]	13.50[gh]	9.59[b-e]	40.77[b-e]	837.36[b-d]	1308.78[ab]
G14	7.86[g-j]	13.07[gh]	8.61[h-j]	32.63[h-j]	838.48[bc]	1238.00[a-c]
G15	7.91[g-j]	12.74[h]	8.59[h-j]	32.55[h-j]	836.51[b-d]	1258.47[a-c]
G16	7.88[g-j]	10.88[ı]	8.30[j]	30.98[ij]	835.35[b-d]	1232.63[a-c]
G17	9.67[b-d]	14.79[d]	10.16[b]	45.54[b]	833.58[c-e]	1185.29[b-d]
G18	8.29[f-ı]	17.38[a]	9.48[c-f]	39.90[c-f]	828.92[e]	1278.05[ab]
G19	8.63[e-g]	16.94[ab]	9.86[b-d]	42.87[b-d]	831.60[de]	1143.24[c-e]
G20	7.72[h-j]	13.44[gh]	8.60 [h-j]	32.57[h-j]	833.10[c-e]	1056.77[de]
RV1	9.85[bc]	14.62[de]	9.93[bc]	43.48[bc]	831.81[de]	1217.03[a-c]
RV2	7.87[g-j]	17.05[ab]	9.43[c-f]	39.39[c-f]	832.59[de]	1309.81[ab]
F-Value	62.82**	131.60**	70.81**	71.48**	14.03**	13.47**
CV	3.06	2.06	2.11	4.23	0.23	3.55

** Significant at P<0.01, Means followed by same letter in the columns are not significantly different at P ≤ 0.05, SW: Seed Width; SL: Seed Length; GMD: Geometric Mean Diameter; V: Volume; BD: Bulk Density; TD: True Density

The direct effects and contribution margins of characteristics examined in the study on yield are given in Table 9.

Yield is a quantitative trait that is under the influence of more than one genetic factor. Some characteristics affect the yield directly and some indirectly (Pushkarnath et al., 2022). Since correlation coefficients do not provide sufficient information by the breeders, path coefficient, which is accepted as the standard partial regression coefficient, which allows the separation of direct and indirect effects of correlation coefficients into their components, is used (Khan et al., 2022). With this method, it gives a clear idea about effect of a feature on yield or other features. It is especially important to reveal the selection criteria. When Table 9 is examined, the highest direct effect on yield was determined in volume property (42.07%), and the lowest in the seed width with 0.97% contribution margin. The volume property is calculated by formulating the seed size (length, width, and thickness). The higher volume feature, the higher yield efficiency.

Table 9. Path coefficients and contribution margins related to direct effects of seed characteristics on seed yield in beans

Characteristic	Direct impact %	Characteristic	Direct impact %
Dry volume	17.59	Seed width	0.97
Hydration capacity	16.81	Seed length	5.61
Swelling index	1.63	Geometric mean diameter	39.89
Cooking time	4.07	Volume	42.07
Coat ratio	8.75	Bulk density	25.40
100 seed weight	2.31	True density	1.13

AHP is applied in different areas such as planning, choosing the best alternative, resource allocation, conflict resolution, optimisation and numerical extensions of AHP, and there are many studies for this purpose. With the AHP method, purpose-oriented priorities and important criteria are revealed, especially in breeding studies. In this study, bean genotypes as a result of evaluation of seed quality with physical characteristics and yield with weights of AHP are given in Figure 1. The contribution weight of the seed parameters calculated by AHP to seed quality was determined as the highest yield with 0.176, and the lowest for true density with 0.020. Among characteristics examined, the highest yield feature, following hundred seed weight of 0.134 and hydration capacity of 0.131 take part in. An important indicator in seed yield is the hundred seed weight, and in seed quality is hydration capacity. The higher hundred seed weight of a variety, the higher yield is parallel to this feature. Another important quality feature is its hydration capacity, and it has been stated by many researchers that the more seed absorbs water, the shorter the cooking time of seed (Karaman 2019, Aydogan et al., 2020). This feature is especially important in marketing. There are also important environmental and genetic factors that affect both hundred seed weight and hydration capacity.
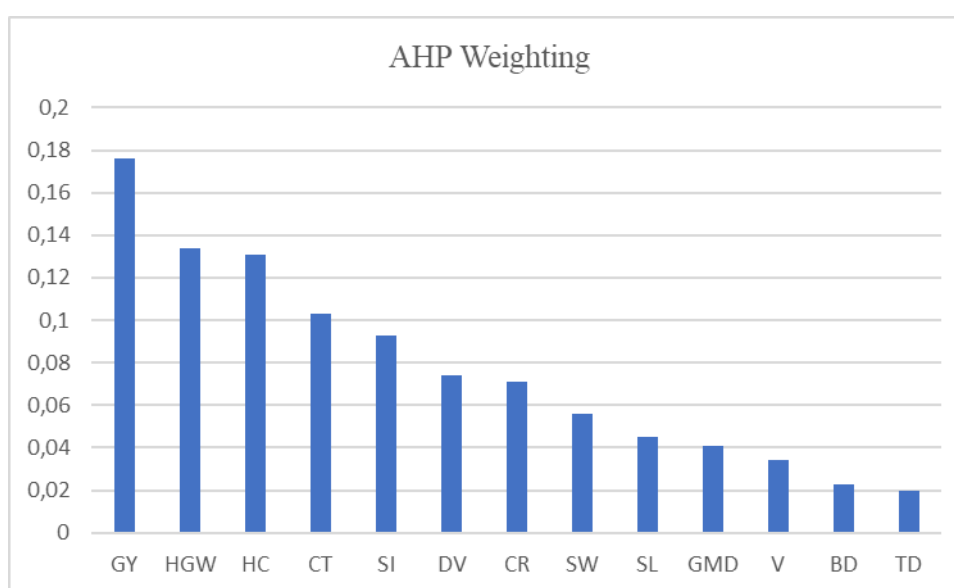

Figure 1. Contribution weight of seed parameters to seed quality calculated by the AHP

Weighting of the total data set; GY: Seed Yield; HGW: Hundred Seed Weight; H: Hydration Capacity; CT: Cooking Time; SI: Swelling Index; DV: Dry Volume; CR: Coat Ratio; SW: Seed Width; SL: Seed Length; GMD: Geometric Mean Diameter; V: Volume; BD: Bulk Density; TD: True Density

According to the analytical hierarchy analysis, the quality of the seeds obtained, including physical properties and yield values, varied depending on the genotypes. The seed quality index (SQI) values obtained from the evaluation of the scores obtained as a result of AHP weights and standard scoring functions with the linear combination technique are given in Table 10.

Table 10. Seed quality index (SQI) values and classes of bean genotypes and varieties

SQI	Genotype	Class	SQI	Genotype	Class
0.279	G7	1	0.500	G21	3
0.298	G22	1	0.545	G13	3
0.322	G3	1	0.548	G1	3
0.338	G12	1	0.550	G4	3
0.403	G11	2	0.556	G19	3
0.410	G2	2	0.585	G20	3
0.432	G18	2	0.605	G8	4
0.446	G15	2	0.625	G9	4
0.463	G10	2	0.685	Yunus 90	4
0.463	G17	2	0.687	Onceler 98	4
0.481	G5	2	0.751	G6	5

According to the obtained quality index values, genotypes 3, 7, 12, and 22 were Class I quality 'very low' genotypes G2, G5, G10, G11, G15, G17 and G18 were II. Quality 'low'; genotypes G1, G4, G13, G19, G20 and G21 III. class 'moderate', G8, G9, G14 and G16 genotypes were IV. Class 'high' and G6 genotype was classified as Class V 'very high'. The highest value in SQI obtained by using 11 indicators was determined in G6 genotype.

CONCLUSION

As a result of the evaluation of obtained datas, the yield values and seed quality index were correlated, and productivity estimates of the genotypes were made. Among the indicators in obtained data, it was determined that a hundred seeds weight contributed the most effectively to yield. Among all materials, it was determined that the seed quality of registered cultivars was high (IV class), and genotypes varied between low and very high. In the study, it was determined that seed quality of genotype 6 was higher (V class) than the registered varieties. It was determined that genotype 6, with high seed quality, also had high productivity. With this study, it has been concluded that a successful evaluation will be made in terms of productivity by creating weighting with AHP in the evaluation of seed quality. Many features examined in the studies were weighted with AHP, and the seed quality index was calculated and predicted with high accuracy with these estimation models. These prediction models are significant for the selection stages of plant breeders. In this way, it is thought that it will save breeders less labour and time. As a result, according to the seed quality index of bean varieties and genotypes with different characteristics, it was determined that genotype 6 had superior characteristics in terms of productivity. In addition 8 with 9 genotypes and registered varieties could also show superior characteristics.

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DISCLOSURE STATEMENT

The authors declare that they have no known competing personal relationships that could have appeared to influence the work reported in this paper.

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