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Characterization of Some Turkish Faba Bean (*Vicia faba* L.) Genotypes for Agro-morphological Traits

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Abstract

Faba bean is a good protein, starch, cellulose and minerals resource. Therefore it will have increasing importance for human and animal food in the future to meet the needs of the growing population. To choose the appropriate accessions and employ them in the breeding program, the current study's objectives were to evaluate the variety of agronomic traits in Turkish faba bean germplasm and to discover genomic areas linked to the assayed attributes. The field experiments were carried out in the Turkish province of Sivas using 330 faba bean genotypes and 3 registered cultivars as plant material according to augmented block design. There were 8 agronomic traits in total. The variance analysis reveals that, except for germination days, the variety factor had a large and significant impact on most morphological features (p<0.01). Furthermore the results showed a wide range in the following traits: flowering days (26 -39 days), plant height (25-59 cm), first pod height (10.50-42,60 cm), the number of pods per (1-33), the number of seeds per plant (2.40-106), grain weight per plant (1.80-224.9 g), the 100-grain weight (48-214 g), while a narrow range is noticed for days of germination (23-29 g). Correlation analysis showed that plant height, grain weight and the number of pods and seeds per plant are positively correlated with other. Also, it was a strong and highly significant association between the number of seeds per plant, the weight of grain per plant, and the number of pods per plant, as well as a positive and large correlation between the number of seeds and grain weight per plant. According to PCA of the defined agro-morphological variables, five principal components comprising 33.975, 15.137, 13.023, 12.626 and 10.246%, respectively, can explain 87.007% of the total variation.

Research Article

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1. Introduction

Legume crops are widely farmed worldwide as a sustainable source of high-protein food (Dhull et al., 2022). Faba bean (*Vicia faba* L.) is considered one of the oldest crops grown worldwide and due to its nutritional significance, it has an important role in both human and livestock feeding (Karkanis et al., 2018). Fava bean is an annual grain and cool season legume native to southwestern, is sown in the autumn or spring (Link et al., 2008), the seeds germination takes between 10 and 14 days in ideal growing germination (Damalas et al., 2019). Most legume seed germination is sensitive to low soil temperature but, faba bean is one of the few cool-season grain legumes, and its germination tolerance is higher than that of most grain legumes. Although it adapts to a wide pH range (6 to 9) as well as sandy-loam soils, faba bean prefers clay-lime, chalky, well-drained and textured soils with neutral pH. Regarding, the photoperiod, many faba bean cultivars (photoperiod sensitive) require long days to flower and mature, whereas others appear to be day length-neutral (Patrick and Stoddard, 2010). The optimal temperature for flowering progression has been set at 22 °C for modeling purposes (Peng et al., 2014) or 23 °C (Turpin et al., 2002).

Major faba bean producers include Ethiopia, Egypt, China, Afganistan, India, Northern Europe, and Northern Africa (Rahate et al., 2021), and around 90% of the world's more than 50 faba bean-producingcountries are in Asia, the European Union (EU), and Africa (FAO [Food and Agriculture Organization], 2020). In Türkiye, the fourth-most extensively produced pulse crop is the faba bean, which has historically been regarded as the genesis and diversification hub for many crops (Peksen, 2007). A total of 12346 t of faba bean production was produced in 2019 on an area of 4332 hectares under cultivation (Cilesiz et al., 2023).

From a nutritional and ecological standpoint (Xiao et al., 2021), the faba bean is considered an important crop; in fact is a multipurpose species that provide a variety of ecosystem services. Nurtionnaly, faba beans (*Vicia faba*) are the third most important legume after soya (*Glycine max*) and pea (*Pisum sativum*) (Rahate et al., 2021). It is a valuable protein-rich crop that serves a huge segment of the human populations in developing countries like Africa, Latin America and Asia (Duc, 1997; Awad et al., 2014; Zhou et al., 2018). Faba bean is also a significant nutrient-rich legume, particularly for its high levels of complex carbohydrates, dietary fiber, non-nutrient secondary metabolites, and bioactive compounds (antioxidants, phenols, and -aminobutyric acid), which have several reported health benefits (Khazaei et al., 2021; Liu et al., 2022). Moreover, it is a good source of numerous macro- and microelements, including minerals (Rahate et al., 2021; Haciseferogullari et al., 2003). Ecologically speaking, faba beans fix more nitrogen than peas do, according to studies on the symbiotic fixation of atmospheric nitrogen in organic farming (Schmidtke and Rauber, 2000).

Due to the significant nutritional value of faba beans, they are an important part of human diets (Etemadi et al., 2018). However, faba bean cultivation has been trending slightly downward because of the low and unstable yields, as well as a lack of cultivars that are resistant to the main faba diseases. In consequence, quality breeding and abiotic stress management are becoming major challenges in faba bean Research (Torres et al., 2011).

Plant breeding has made significant contributions to the development of a large number of crop varieties with desirable traits. Thus, the following traits should be considered when choosing faba varieties: yield potential, quality, consistent performance, suitability for human consumption or the feed market, seed size, days to maturity, standing ability, disease resistance, and abiotic stress resistance (Karkanis et al., 2018). Moreover, the critical breeding objectives for the faba bean include enhanced seed quality traits; because the size of the faba bean seed has a key role in dcrmining the market and method of consumption (Karkanis et al., 2018).

Many investigations have been using the breeding strategy in order to obtaining high-yielding cultivars of faba beans. In their research, Ton et al. (2021) demonstrated that plant height, branches per plant, and 100-grain weight all played a significant influence in increasing faba bean grain yield. As a result, effective selection for the traits indicated above can be done to increase faba bean grain yield. Moreover, Karakoy et al. (2014) found that several accessions of faba bean had a very good agronomic performance for some parameters and their results showed that the gene pools contain a variety of valuable qualities and a large range of phenotypic variation, which is a good source of diversity for use in contemporary faba bean breeding programs. Neda et al. (2021) discovered that the average squares owing to accession seemed to be significant to highly significant for the greater part of traits in all environments, revealing that the characteristics had a sufficient level of genetic diversity and that mean-based selection would be effective in enhancing faba bean traits. Moreover, germination percentage is a critical factor that can significantly decrease the selling price of seeds. According to Singh et al. (2017), the duration required for faba bean germplasm to reach 50% germination indicates that there is a good amount of variability in this particular trait, which may be used to shorten the length of the entire crop cycle as early as the seedling stage. Even though research on faba bean inbred lines has generated interest, there aren't as many registered faba bean cultivars currently on the market as there are for cereals (Fouad et al., 2013; Duc et al., 2015).

In context with the aforementioned, the intent of this research is to define the genetic variation of 334 genotypes rising in the province of Sivas in order to determine the most suitable high genotypes for breeding strategies that focus on improving crop yield and incorporating resistance to both abiotic and biotic stresses and creating novel high yielding cultivars.

2. Material and Methods

2.1. Plant material

Total 330 genotypes, were selected from a collection of faba bean landraces derived from 22 regions of Türkiye (Adana, Amasya, Antakya, Antalya, Aydın, Balıkesir, Çanakkale, Diyarbakır, Edirne, Elazığ, Erzincan, Eskişehir, Giresun, İzmir, Manisa, Mardin, Mersin, Muğla, Samsun, Sinop, Sivas, Tekirdağ) and three registered faba bean cultivars (Kıtık 2003, Filiz 99, Salkım) served as control group were used as plant material. Information about plant material is provided in Table 1.

Table 1. Origin and collection sites of 330 Turkish faba bean populations and three cultivars used in the study

Accession Number	Names of Landraces	District	Coordinates	Accession Number	Names of Landraces	District	Coordinates
5	Adana 5	Center	E35 19 / N37 00	225	Giresun 4	Stored product	-
6	Adana 6	Center	E35 19 / N37 00	226	Giresun 5	Faba field	
8	Amasya 1	Bean field	-	227	İzmir 1	Center	E27 10 / N38 25

10	Amasya 3	Bean field	-	228	İzmir 2	Center	E27 10 / N38 25
12	Antakya 1	Center	E36 11 / N36 12	229	İzmir 3	Center	E27 10 / N38 25
13	Antakya 2	Center	E36 11 / N36 12	230	İzmir 4	Center	E27 10 / N38 25
14	Antakya 3	Küçüknehi r	-	231	İzmir 5	Center	E27 10 / N38 25
15	Antakya 4	Yukarıokç ular	E36 08 / N36 06	232	İzmir 6	Center	E27 10 / N38 25
19	Antalya 3	Center	-	234	İzmir 8	Center	E27 10 / N38 25
21	Antalya 5	Center	-	235	İzmir 9	Center	E27 10 / N38 25
27	Aydın 1	Center	E27 50 / N37 51	236	İzmir 10	Center	E27 10 / N38 25
29	Aydın 3	Center	E27 50 / N37 51	237	İzmir 11	Center	E27 10 / N38 25
30	Aydın 4	Center	E27 50 / N37 51	238	İzmir 12	Center	E27 10 / N38 25
31	Aydın 5	Center	E27 50 / N37 51	239	İzmir 13	Center	E27 10 / N38 25
33	Balıkesir 1	Center	E27 51 / N39 37	240	İzmir 14	Karsiyaka	E27 06 30 / N38 27 30
34	Balıkesir 2	Center	E27 51 / N39 37	241	İzmir 15	Karsiyaka	E27 06 30 / N38 27 30
35	Balıkesir 3	Center	E27 51 / N39 37	242	İzmir 16	Karsiyaka	E27 06 30 / N38 27 30
37	Balıkesir 5	Center	E27 51 / N39 37	244	İzmir 18	Karsiyaka	E27 06 30 / N38 27 30
38	Balıkesir 6	Center	E27 51 / N39 37	245	İzmir 19	Karsiyaka	E27 06 30 / N38 27 30
42	Balıkesir 10	Center	E27 51 / N39 37	246	İzmir 20	Karsiyaka	E27 06 30 / N38 27 30
44	Balıkesir 12	Center	E27 51 / N39 37	247	İzmir 21	Karsiyaka	E27 06 30 / N38 27 30
45	Balıkesir 13	Center	E27 51 / N39 37	248	İzmir 22	Karsiyaka	E27 06 30 / N38 27 30
49	Balıkesir 17	Center	E27 51 / N39 37	249	İzmir 23	Karsiyaka	E27 06 30 / N38 27 30
50	Balıkesir 18	Center	E27 51 / N39 37	250	İzmir 24	Karsiyaka	E27 06 30 / N38 27 30
53	Balıkesir 21	Center	E27 51 / N39 37	251	İzmir 25	Karsiyaka	E27 06 30 / N38 27 30
58	Balıkesir 26	Center	E27 51 / N39 37	252	İzmir 26	Karsiyaka	E27 06 30 / N38 27 30
59	Balıkesir 27	Center	E27 51 / N39 37	253	İzmir 27	Karsiyaka	E27 06 30 / N38 27 30
60	Balıkesir 28	Center	E27 51 / N39 37	254	İzmir 28	Karsiyaka	E27 06 30 / N38 27 30
63	Balıkesir 31	Center	E27 51 / N39 37	255	İzmir 29	Karsiyaka	E27 06 30 / N38 27 30
70	Balıkesir 38	Center	E27 51 / N39 37	256	İzmir 30	Karsiyaka	E27 06 30 / N38 27 30
72	Balıkesir 40	Center	E27 51 / N39 37	257	İzmir 31	Karsiyaka	E27 06 30 / N38 27 30
73	Balıkesir 41	Center	E27 51 / N39 37	258	İzmir 32	Faba field	-
74	Balıkesir 42	Center	E27 51 / N39 37	259	İzmir 33	Faba field	-
75	Balıkesir 43	Center	E27 51 / N39 37	260	İzmir 34	Faba field	-
77	Balıkesir 45	Center	E27 51 / N39 37	262	İzmir 36	Faba field	-
78	Balıkesir 46	Center	E27 51 / N39 37	263	İzmir 37	Faba field	-
81	Balıkesir 49	Center	E27 51 / N39 37	265	İzmir 39	Faba field	-
82	Balıkesir 50	Center	E27 51 / N39 37	266	İzmir 40	threshing floor	-

83	Balıkesir 51	Center	E27 51 / N39 37	268	İzmir 42	threshing floor	-
84	Balıkesir 52	Center	E27 51 / N39 37	270	İzmir 44	Kizilcaayas	E27 38 / N38 14
85	Balıkesir 53	Center	E27 51 / N39 37	271	İzmir 45	Menemen	E27 06 / N38 35
86	Balıkesir 54	Center	E27 51 / N39 37	272	İzmir 46	Kurfalliyi	E27 04 35 / N39 01 29
87	Balıkesir 55	Center	E27 51 / N39 37	276	Kahramanmaras 2	Center	-
88	Balıkesir 56	Center	E27 51 / N39 37	277	Kahramanmaras 3	Afşin	-
89	Balıkesir 57	Center	E27 51 / N39 37	278	Kars 1	Center	E43 05 / N40 35
90	Balıkesir 58	Center	E27 51 / N39 37	279	Kars 2	Center	E43 05 / N40 35
91	Balıkesir 59	Center	E27 51 / N39 37	281	Kars 4	Stored product	-
93	Balıkesir 61	Center	E27 51 / N39 37	282	Kastamonu 1	Center	-
94	Balıkesir 62	Center	E27 51 / N39 37	283	Kastamonu 2	Center	-
95	Balıkesir 63	Center	E27 51 / N39 37	284	Kayseri 1	Stored product	-
96	Balıkesir 64	Center	E27 51 / N39 37	286	Kayseri 3	Faba field	-
97	Balıkesir 65	Center	E27 51 / N39 37	287	Kayseri 4	Faba field	-
98	Balıkesir 66	Center	E27 51 / N39 37	288	Kirklareli 1	Faba field	-
99	Balıkesir 67	Center	E27 51 / N39 37	289	Kirklareli 2	Faba field	-
100	Balıkesir 68	Center	E27 51 / N39 37	290	Kirklareli 3	Center	E27 12 / N41 42
101	Balıkesir 69	Center	E27 51 / N39 37	291	Kirklareli 4	Center	E27 12 / N41 42
102	Balıkesir 70	Gokçeagac	E27 37 55 / N39 37 45	293	Kirklareli 6	Vize	E27 46 37 / N41 34 43
103	Balıkesir 71	Gokçeagac	E27 37 55 / N39 37 45	294	Kiırsehir 1	Stored product	
105	Balıkesir 73	Kusadasi	E27 27 00 / N39 47 00	295	Kirsehir 2	Faba field	
106	Balıkesir 74	Pasakoy	E27 58 48 / N39 33 23	296	Kocaeli	Stored product	
107	Balıkesir 75	Kayabası	E28 08 23 / N39 21 57	297	Konya 1	Center	E32 30 / N37 51
108	Balıkesir 76	Selimiye	E27 54 19 / N39 30 35	298	Konya 2	Center	E32 30 / N37 51
109	Balıkesir 77	Kayapinar	E27 26 46 / N39 29 31	299	Konya 3	Center	E32 30 / N37 51
110	Balıkesir 78	Can	E27 02 22 / N39 37 23	300	Konya 4	Center	E32 30 / N37 51
111	Balıkesir 79	Tepeoren	E28 02 38 / N40 08 44	301	Konya 5	Center	E32 30 / N37 51
112	Balıkesir 80	Gundogdu	E27 38 03 / N40 10 21	302	Konya 6	Center	E32 30 / N37 51
113	Balıkesir 81	Gecitli	E27 29 01 / N40 10 24	303	Konya 7	Center	E32 30 / N37 51
114	Balıkesir 82	threshing floor	-	304	Kutahya 1	threshing floor	-
115	Balıkesir 83	Stored product	-	305	Malatya 1	Stored product	-
116	Balıkesir 84	Stored product	-	306	Malatya 2	Stored product	-
117	Batman 1	Center	-	307	Malatya 3	Faba field	-
118	Batman 2	Center	-	308	Malatya 4	Faba field	-
119	Bilecik 1	Center	-	309	Manisa 1	Center	E27 29 / N38 36
121	Burdur 2	Center	E30 16 / N37 43	310	Manisa 2	Center	E27 29 / N38 36

122	Bursa 1	Yenice	E29 30 30 / N40 00 06	311	Manisa 3	Center	E27 29 / N38 36
123	Bursa 2	Yenice	E29 30 30 / N40 00 06	312	Manisa 4	Center	E27 29 / N38 36
124	Bursa 3	Center	-	313	Manisa 5	Center	E27 29 / N38 36
125	Bursa 4	Center	-	314	Manisa 6	Center	E27 29 / N38 36
126	Bursa 5	Murseller	E29 01 45 / N40 05 42	315	Manisa 7	Center	E27 29 / N38 36
127	Bursa 6	Center		316	Manisa 8	Center	E27 29 / N38 36
128	Bursa 7	Orhaneli	E28 58 18 / N40 08 12	317	Manisa 9	Center	E27 29 / N38 36
129	Bursa 8	Center	-	318	Manisa 10	Center	E27 29 / N38 36
130	Bursa 9	Center	-	319	Manisa 11	Center	E27 29 / N38 36
131	Canakkale 1	Center	E26 25 / N40 09	320	Manisa 12	Center	E27 29 / N38 36
132	Canakkale 2	Center	E26 25 / N40 09	322	Manisa 14	Faba field	-
134	Canakkale 4	Center	E26 25 / N40 09	323	Manisa 15	Faba field	-
135	Canakkale 5	Center	E26 25 / N40 09	324	Manisa 16	Faba field	-
136	Canakkale 6	Center	E26 25 / N40 09	325	Manisa 17	Kınık	E27 31 43 / N39 10
138	Canakkale 8	Center	E26 25 / N40 09	327	Mardin 2	Center	-
139	Canakkale 9	Center	E26 25 / N40 09	328	Mardin 3	Kızıltepe	-
140	Canakkale 10	Center	E26 25 / N40 09	329	Mersin 1	Center	-
141	Canakkale 11	Center	E26 25 / N40 09	330	Mersin 2	Center	-
142	Canakkale 12	Center	E26 25 / N40 09	331	Mersin 3	Center	-
143	Canakkale 13	Center	E26 25 / N40 09	332	Mersin 4	Center	-
144	Canakkale 14	Center	E26 25 / N40 09	333	Mersin 5	Center	-
145	Canakkale 15	Center	E26 25 / N40 09	334	Mersin 6	Center	-
146	Canakkale 16	Center	E26 25 / N40 09	335	Mersin 7	Faba field	-
147	Canakkale 17	Center	E26 25 / N40 09	336	Mersin 8	Faba field	-
148	Canakkale 18	Center	E26 25 / N40 09	337	Mersin 9	Faba field	-
149	Canakkale 19	Center	E26 25 / N40 09	338	Mersin 10	Stored product	-
150	Canakkale 20	Center	E26 25 / N40 09	339	Mugla 1	Center	E28 22 / N37 13
151	Canakkale 21	Faba field	-	341	Mugla 3	Center	E28 22 / N37 13
152	Canakkale 22	Faba field	-	342	Mugla 4	Center	E28 22 / N37 13
154	Canakkale 24	Faba field	-	343	Mugla 5	Center	E28 22 / N37 13
156	Canakkale 26	Faba field	-	344	Mugla 6	Center	E28 22 / N37 13
157	Canakkale 27	Faba field	-	345	Mugla 7	Center	E28 22 / N37 13
158	Canakkale 28	Faba field	-	346	Mugla 8	Center	E28 22 / N37 13
160	Canakkale 30	Faba field	-	347	Mugla 9	Fethiye	E29 08 / N36 37
161	Canakkale 31	Faba field	-	349	Mugla 11	Faba field	-

163	Canakkale 33	Faba field	-	350	Mugla 12	Faba field	-
164	Canakkale 34	Can	-	351	Mugla 13	Faba field	-
165	Canakkale 35	Can	-	352	Samsun 1	Stored product	-
166	Canakkale 36	Can	-	353	Samsun 2	Stored product	-
167	Canakkale 37	Can	-	355	Sinop 1	Stored product	-
168	Canakkale 38	Ezine	E26 21 / N39 43	357	Sivas 2	Stored product	-
169	Canakkale 39	Ezine	E26 21 / N39 43	358	Sivas 3	Stored product	-
170	Canakkale 40	Ezine	E26 21 / N39 43	359	Sivas 4	Faba field	-
171	Canakkale 41	Ezine	E26 21 / N39 43	362	Tekirdag 1	Center	E27 31 / N41 00
173	Canakkale 43	Stored product	-	363	Tekirdag 2	Center	E27 31 / N41 00
174	Canakkale 44	Stored product	-	364	Tekirdag 3	Center	E27 31 / N41 00
175	Canakkale 45	Guvemala n	E26 25 / N40 09	365	Tekirdag 4	Center	E27 31 / N41 00
176	Canakkale 46	Guvemala n	E26 25 / N40 09	366	Tekirdag 5	Faba field	-
177	Canakkale 47	Guvemala n	E26 25 / N40 09	367	Tekirdag 6	Stored product	-
178	Canakkale 48	Turkmenel i	E26 17 / N39 47	368	Tekirdag 7	Stored product	-
180	Canakkale 50	Adatepe village	E27 07 / N40 16	369	Tekirdag 8	Lapseki	E26 51 36 / N40 73 51
181	Canakkale 51	Altinoluk	E26 39 17 / N39 33	371	Tekirdag 10	Malkara	E26 55 06 / N40 51 25
182	Canakkale 52	Alcitepe	-	372	Tekirdag 11	Kumbag	E27 24 46 / N40 50 33
184	Canakkale 54	Bayramic	-	373	Tekirdag 12	Ucmakdere	E27 21 54 / N40 49 51
185	Canakkale 55	Bihramli village	E26 17 13 / N40 07	374	Tekirdag 13	Naip village	E27 24 04 / N40 52 28
186	Canakkale 56	Burhaniye village	E26 32 23 / N40 13	375	Tekirdag 14	Yaci village	E27 26 24 / N41 00 03
187	Canakkale 57	Edge	E26 27 / N40 08	376	Tekirdag 15	Cerkezkoy	E27 53 25 / N41 14 59
188	Canakkale 58	Eskipazar	E26 30 50 / N40 09	377	Tekirdag 16	Hayrabolu	E27 19 51 / N41 03 33
189	Canakkale 59	Ecebat-Gelibolu		378	Tekirdag 17	Ortaca	E27 15 01 / N41 04 59
190	Canakkale 60	Goktepe village	E27 08 / N40 13	379	Tokat 1	Faba field	-
191	Canakkale 61	Hurmakoy	E26 59 35 / N39 59	380	Tokat 2	Faba field	-
192	Canakkale 62	Intepe	E26 19 14 / N40 00	381	Tokat 3	Faba field	-
193	Canakkale 63	Karkin	E27 13 19 / N39 48	382	Tokat 4	Faba field	-
194	Canakkale 64	Kepez	E26 23 07 / N40 05	383	Tokat 5	Faba field	-
197	Canakkale 67	Pasakoy	E26 19 10 / N39 31	384	Tokat 6	Faba field	-
198	Canakkale 68	Seddulbahi r	E26 11 49 / N40 03	385	Urfa 1	Ezgil	-
199	Canakkale 69	Serbetli village	E26 51 59 / N40 00	386	Van 1	Center	-
200	Diyarbakır 1	Center	-	387	Yozgat 1	Stored product	-
201	Edirne 1	Center	E26 34 / N41 41	388	Yozgat 2	Stored product	-
202	Edirne 2	Center	E26 34 / N41 41	389	NA	NA	NA

203	Edirne 3	Center	E26 34 / N41 41	390	Kıtık 2003	-	-
204	Edirne 4	Alic	E26 38 27 / N41 03	394	Filiz 99	-	-
205	Edirne 5	Center	E26 34 / N41 41	395	Salkım	-	-
206	Edirne 6	Center	E26 34 / N41 41	401	NA	NA	NA
207	Edirne 7	Center	E26 34 / N41 41	402	NA	NA	NA
208	Edirne 8	Faba field	-	403	NA	NA	NA
209	Elazığ 1	Center	E39 13 / N38 41	404	NA	NA	NA
210	Elazığ 2	Center	E39 13 / N38 41	405	NA	NA	NA
211	Elazığ 3	Center	E39 13 / N38 41	407	NA	NA	NA
212	Elazığ 4	Center	E39 13 / N38 41	408	NA	NA	NA
213	Elazığ 5	Center	E39 13 / N38 41	409	NA	NA	NA
214	Elazığ 6	Center	E39 13 / N38 41	410	NA	NA	NA
215	Elazığ 7	Faba field	-	411	NA	NA	NA
216	Erzincan 1	Stored product	-	412	NA	NA	NA
217	Erzincan 2	Stored product	-	415	NA	NA	NA
218	Erzincan 3	Faba field	-	416	NA	NA	NA
220	Eskisehir 1	Center	-	417	NA	NA	NA
221	Eskisehir 2	Center	-	418	NA	NA	NA
222	Giresun 1	Center	-	420	NA	NA	NA
223	Giresun 2	Stored product	-	421	NA	NA	NA
224	Giresun 3	Stored product	-	422	NA	NA	NA
233	İzmir 7	Center	E27 10 / N38 25	425	NA	NA	NA
				621	NA	NA	NA

*NA: Not available

2.2. Field experimentation

The field study was carried out in the province of Sivas (Agricultural Research and Development Center, University of Science and Technology) during the 2021-2022 growing season. The trial area is located at an altitude of approximately 1285 m above sea level, at the location N39, 720656 - E36,917248 (Figure 1).

Figure 1. The trial field

In Sivas province, a continental climate with cold and snowy winter and hot and dry summer is dominant. Important climatic parameters such as temperature, precipitation, and humidity related to the period of research are given in Table 2. The temperature was minimal in April at -4.2 (°C) and was maximal in August at 23.7 (°C). The total precipitation between April and August was 137.9 mm and it was higher than the long-term average (133.5 mm). The average relative humidity value according to the months varied between 44.5% and 55.8% and it was lower than the long-term average (51.58%).

Table 2. Precipitation, temperature and relative humidity values of the period of the experiment (Ministry of Agriculture and Forestry General Directorate of Meteorology)

Month	Precipitation (mm)		Temperature (°C)				Relative Humidity (%)			
	Mean	LYA	Min.	Max.	Mean	LYA	Min.	Max.	Mean	LYA
April	4.3	23.2	-4.2	12.2	12.2	11.1	7.0	92.0	44.5	50.0
May	5.6	18,9	0.8	12.5	12.5	13.9	10.0	91.0	53.1	53.8
June	116.6	77.7	9.8	18.8	18.8	18.6	7.0	93.0	55.8	55.2
July	0.0	4.6	7.2	19.1	19.1	20.3	5.0	85.0	51.9	50.5
August	11.4	9.1	13.4	23.7	23.7	22.3	10.0	99.0	47.5	48.4
Mean	137.9	133.5			86.3	86.2			50.56	51.58

LYA: Long-term average

The physical and chemical properties of the experimental site are provided in Table 3. The Sivas location soil had a silty clay loam texture, the value of the pH was 7.28 and characterized by a lime content of 19.6 %, high potassium content (K_2O) (93.59 kg da^{-1}), low phosphorus (P_2O_5) and salt contents (3.40 kg da^{-1}, 0.33 mmhos cm^{-1} respectively) and a low organic matter (1.7%). The drainage of the field was done properly and there was no groundwater problem during the study.

Table 3. Physical and chemical properties of the soil of the trial site

Depth	Texture	pH	Calcitic (%$CaCO_3$)	Salinity (%)	P_2O_5 (kg da^{-1})	K_2O (kg da^{-1})	Organic matter (%)
0-30 cm	Silty clay loam	7.28	19.6	0.33	3.40	93.59	1.7

Experiments were set up using the Augmented approach design approach. The trial consisted of six blocks, each with three control genotypes (Kıtık-2003, Filiz-99 ve Salkım) and 55 genotypes. Each genotype was planted in one row of 2 m length with an inter-row spacing of 70 cm and intra rows spacing of 10 cm, and 20 seeds were sown in each row. Fertilizer, 4 kg of N (nitrogen) and 8 kg of phosphorus (P_2O_5) fertilizer per decare were applied. Plant material was sown on 25th April and harvested on 20th August. Appropriate insecticides had been used to prevent uncontrolled *Aphis fabae* Scopoli activity during the flowering period.

2.3. Agronomic traits measurements

At the maturity stage, the agro morphological traits mentioned below were measured (1) Germination days, (2) Days to flowering, (3) Plant height (cm), (4) First pod height (cm), (5) Number of pods per plant, (6) Number of seeds per plant (7) Grain weight per plant (g), (8) 100-grain weight (g).

2.4. Statistical analysis

JMP 14.1.0 statistical software (2018, SAS Institute Inc., Cary, NC, USA) was used to conduct the analysis of variance (ANOVA). The statistical software XLSTAT was used to calculate various parameters such as minimum, maximum, and mean (www.xlstat.com). The principal component analysis (PCA) and biplot analysis were both performed using the same software.

3. Results

ANOVA analysis showed that the effect of the variety was highly significant ($P \leq 0.01$) on days to flowering, plant height, first pod height, number of pods per plant, number of seeds per plant and 100-grain weight traits. The effect of the block showed a weak significant level ($P \leq 0.05$) on plant height, number of pods per plant and number of seeds per plant but, it had an insignificant effect on days to flowering, first pod height and 100 grain weight. On the other hand, variety and block had no significant effect on days to germination, although both had a sustained impact ($P \leq 0.01$) on the trait of the grain weight (Table 4).

Table 4. Analysis of variance for eight traits of faba bean germplasm

Source	DF	Sum of Squares	F Ratio	Prob > F
Days to germination				
Block [Year, Location]	5	11.16667	2.1613	0.1403
Variety	332	166.06322	0.4841	0.9733
Days to flowering				
Block [Year, Location]	5	10.9444	1.2236	0.3663
Variety	332	3578.5766	6.0254	0.0017
Plant height				
Block [Year, Location]	5	2.3335	4.7303	0.0178
Variety	332	7773.1181	237.3047	<.0001
First pod height				
Block [Year, Location]	5	0.49	1.3050	0.3358
Variety	332	173312.33	7013.638	<.0001
Number of pods per plant				
Block [Year, Location]	5	0.8503	3.5666	0.0413
Variety	332	6868.5983	433.9093	<.0001
Number of grain per plant				
Block [Year, Location]	5	0.758	3.5579	0.0415
Variety	332	37092.455	2622.983	<.0001
Grain weight per plant				
Block [Year, Location]	5	1.633	6.3122	0.0068
Variety	332	67861.100	3949.274	<.0001
100 Grain weight				
Block [Year, Location]	5	23.17	2.8958	0.0717
Variety	332	119915.62	225.7448	<.0001

3.1. Agronomical traits diversity

The means and ranges of the traits in Table 5 revealed that, with the exception of days of germination, all of the examined features showed a broader range of variability. Flowering days for accessions ranged from 26 to 39 days, with an average of 31.42 days, and plant height ranged from 25 to 59 cm, with an average of 44.86 cm. Furthermore, the first pod height varied between 10.50 and 42.60 cm with an overall value of 19.54 cm; in addition the number of pods per plant fluctuated between 1 and 33.33 with an average main of 12.89. Furthermore, the number of seeds per plant ranged from 2.40 to 106 with a median value of 25.04. The lowest grain weight per plant was 1.80 g, the highest was 224.90 g, and the overall main was 22.54 g. Furthermore, the 100-grain weight ranged between 48 and 214 g with an average main of 90.99 g. On the other hand, the variation range for days of germination was extremely narrow, ranging from 23 to 29 days, with a median value of 24.81.

Table 5. Minimum, maximum and mean values for studied traits in Turkish faba bean germplasm

Variable	Minimum	Maximum	Mean
Days to germination	23.00	29.00	24.81
Days to flowering	26.00	39.00	31.41
Plant height (cm)	25.00	59.20	44.86
First pod height (cm)	10.50	42.60	19.54
Number of pods per plant	1.00	33.33	12.89
Number of seeds per plant	2.40	106.00	25.04
Grain weight per plant (g)	1.80	224.90	22.45
100-grain weight (g)	48.00	214.00	90.99

3.2. Correlation coefficients among the studied traits

Table 6 lists correlations between 8 morphological features from 334 genotypes. As a result, there was a significant positive correlation between NPPL, NSPL, GW, and PH (0.625**, 0.560** and 0.371**). Moreover, there were a positive and substantial correlation between NSPL and GWPL (0.674**), as well as strong and highly significant correlations between NSPL, GWPL and NPPL (0.835**and 0.574**respectively).

Table 6. Estimates of correlation coefficients at a genotypic level among eight traits of faba bean accessions

Variables	DF	DG	PH (cm)	FPH (cm)	NPPL	NSPL	GWPL (g)	100 GW (g)
DF	**1**	0.022	**-0.176****	0.004	-0.133	-0.056	-0.012	0.051
DG		**1**	-0.041	0.083	0.068	0.021	0.042	**-0.176****
PH (cm)			**1**	0.090	**0.625****	**0.560****	**0.371****	-0.006
FPH (cm)				**1**	0.015	-0.024	-0.007	-0.022
NPPL					**1**	**0.835****	**0.574****	**-0.190****
NSPL						**1**	**0.674****	-0.135
GWPL (g)							**1**	0.042
100 GW (g)								**1**

** Significant test at 0.01 level. DF: days to flowering, DG: days to germination, PH: plant height, FPH: first pod, NPPL: Number of pods per plant, NSPL: number of seeds per plant, GWPL: grain weight per plant, 100 GW (g): 100-grain weight

3.3. Principal component analysis for the studied traits

The purpose of the principal component analysis was to identify the essential agronomical trait that contributed the most variability among plant genotypes. With eigen values ranging from 0.820 to 2.878 the five main components in the current study were able to account for about 35.975% of all the data variances. The first principal component (PC1) was essential and accounted for 35.975% of the overall variation; number of pods per plant, number of seeds per plant, grain weight per plant and plant height (0.919, 0.757 and 0,746, respectively) were the most agronomical traits to PC1. The second principal component (PC2), which was heavily reliant on days of flowering (0.740), accounted for 15.137% of the variability. The third main component, which accounted for 13.023% percent of overall variability, mainly was based on days of germination (0.909). The fourth principal component contributed to 12.626% of genotype diversity. The last major component represented a percentage of 10.246% of the overall variance; the significant eigenvectors for PC4 and PC5 were first Pod Height (cm) and days to flowering (0.906 and 0.615 respectively) (Table 7).

The three sets of faba bean landraces could be easily distinguished on the principal component graph (Figure 2). In PC1, the number of pods per plant, number of seeds per plant, grain weight per plant and plant height were important variants; days of flowering were significant variants in PC2, whereas important variables in PC3 included days of germination.

Table 7. Principal component analysis results of traits investigated in faba bean genotypes plants

Variables	PC1	PC2	PC3	PC4	PC5
Days of germination	-0.171	-0.014	0.909	0.094	-0.308
Days of flowering	0.058	0.740	0.224	0.000	0.615
Plant height (cm)	0.746	-0.120	-0.207	0.181	-0.040
First pod height (cm)	0.033	0.327	-0.108	0.906	-0.187
Number of pods per plant	0.919	0.061	-0.003	-0.050	-0.058
Number of seeds per plant	0.919	-0.029	0.126	-0.070	-0.053
Grain weight per plant (g)	0.757	-0.143	0.275	0.025	0.173
100-grain weight (g)	-0.155	-0.719	0.138	0.373	0.524
Eigenvalue	2.878	1.211	1.042	1.010	0.820
Variability (%)	35.975	15.137	13.023	12.626	10.246
Cumulative %	35.975	51.112	64.135	76.761	87.007

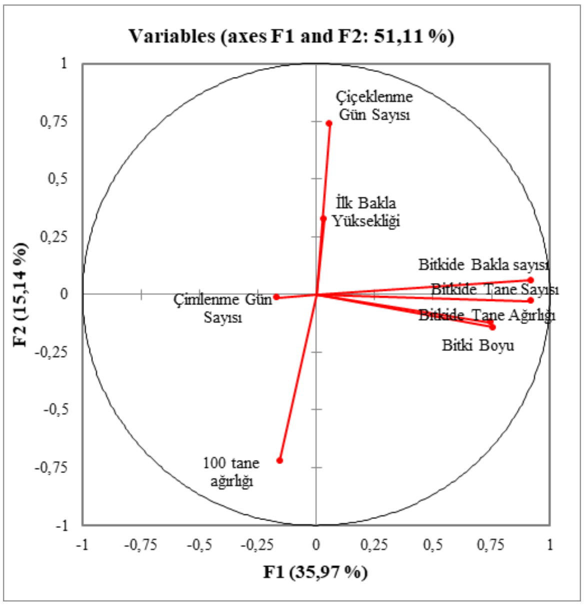

Figure 2. Biplot plot showing the relationship between the investigated features

4. Discussion

Landraces are crucial genetic resources for faba bean breeding programs and can be kept as inbred lines (Terzopoulos and Bebeli, 2008). Characterizing the local genotypes is crucial, given the high value of plant germplasm collections. In order to effectively use different landraces in breeding programs to create novel height yielding faba bean cultivars, it is vital to identify the agronomic features of different landraces. Turkey, the most significant hub of variation, has yielded a sizable number of distinct faba bean landraces. In the current work, the agronomical traits for a sizable germplasm collection are thoroughly analyzed. Also, a wide range of environmental and geographic areas was used to collect the landraces, which tends to promote diversity. Indeed, results showed that the variety had a highly significant ($P \leq 0.01$) impact on the morphological traits examined, including days to flowering, plant height, first pod height, number of pods per plant, number of seeds per plant, and 100-grain weight. In addition, the block and variety had a sustained ($P \leq 0.05$) influence on the feature of grain weight. However, despite a weakly significant level of the block ($P \leq 0.05$) on plant height, the number of pods per plant, and the number of seeds per plant, it had no significant impact on the number of days till flowering, the height of the first pod, and the weight of 100 grains. The two criteria under investigation had no effect beyond days of germination. In line with the findings of our study, Wang et al. (2023) shown that the faba bean's genotype is the main predictor of agronomic features, including those for stem, leaf, and flowering. Moreover, Gutiérrez et al. (2023) showed that the selection of faba bean accessions from various sources, with enough genetic variation, indicated a wide variance in parameters including maturity date; plant height, number of pods per plant; number of seeds per plant, hundred seed weight; and plot yield, indicating that the panel is genetically varied. similarly, Boots-Haupt et al. (2022) reported that the effect of faba bean genotype was significant for all parameters examined, including flowering date, plant height, total nodes, and a number of first fruiting nodes, while for all traits except harvest index, the impacts of the testing environment were substantial. According to Karakoy et al. (2014) the differences between 182 accessions were meaningful for all of the studied characters, such as days to emergence, days to flowering, days to pods, days to maturity, plant height (cm), the height of the first pod (cm), number of branches per plant, as well as the length of the pods. On the other hand, Essa et al. (2023) research, in contrast to our findings, asserted that the analysis of variance showed that environmental influences might have a considerable impact on cultivars performance of faba beans.

Nonetheless, the quantitative agronomic characteristics are crucial for characterizing and assessing faba bean landraces. Consequently, our findings indicated that the genotypes exhibit a more comprehensive range of variability in the parameters of flowering days, plant height, first pod height, the number of pods per plant, the number of seeds per plant, grain weight per plant, and 100-grain weight, however, the range of variance for days of germination among genotypes was minimal. In accordance with our study, Ammar et al. (2015) found that there was a vast variation in plant height, number of pods/plant, the number of seeds per plant, and the days before 50% flowering. Furthermore, Kumar et al. (2017), in agreement with our findings, showed that a higher range of variability was observed for the parameters of plant height, the number of pods per plant, 100 seed weight and seed yield per plant. These findings show that breeding programs like selection and hybridization can help to increase performance by providing selection opportunities for certain qualities. Similar to the study by Malek et al. (2021), a high degree of phenotypic diversity was observed for the metrics days to 50% flowering, plant height (cm), number of pods per plant, number of seeds per pod, and 100-seed weight across Algerian faba bean landraces. Moreover, Wafa and Heakel's (2022) findings, which concur with ours, showed that the tested genotypes exhibited substantial differences in plant height, number of pods per plant, number of seeds per pod, 100-seed weight, and seed yield. Also, according to Backouchi et al. (2015), there was a striking variation in the morphological variables, including plant height, number of pods, number of seeds, and weight of 100 seeds across the three main populations of *Vicia faba*.

Besides, the improvement of one feature might also improve another desired quality, according to positive correlations between various parameters (Yücel et al., 2009; Comertpay et al., 2012). The selection of the appropriate character is also essential because of the associations between various qualities. As a result, we found that plant height, grain weight and the number of pods and seeds per plant are positively correlated with other. Moreover, there was a strong and extremely significant association between the number of seeds per plant, the weight of grain per plant, and the number of pods per plant, as well as a positive and large correlation between the number of seeds and grain weight per plant. Robertson and El-Sherbeeny (1998), in contrast to our findings, discovered that there was a positive correlation between seed yield and seed weight rather than a significant link between pods per plant and seed yield. Musallam et al. (2004) also discovered a positive association between seed production and hundred seed weight, which is inconsistent with our findings. On the other hand, Ton et al. (2021), based on the correlation coefficients between grain yield and yield components, discovered that, in keeping with our findings plant height, pods per plant, and grains per plant all had a positive and significant correlation with grain yield, respectively. No meaningful relationships between grain yield and first podding height were found. Yeken et al. (2019) discovered that the grain weight was significantly and favorably connected with plant height and the number of pods per plant; also plant height and the number of pods per plant showed a sustainable and positive association which is consistent with our findings. As with our finding, a strong and positive association was marked between the number of pods per plant and the grain weight per plant in the investigation of Syed (2016).

Furthermore, for breeding enhancement, understanding the genetics behind intriguing features of species is crucial. The genetic improvement of a group of traits, as opposed to the genetic improvement of individual features, is the typical goal of breeding programs since it is intriguing for breeders to understand how changing one trait can affect other traits (Venkovsky and Barriga, 1992). Plant breeders must therefore take account of the relationship that already exists between the features in order to improve multiple attributes at once. Plant breeders may be helped by information collected through principal component analysis to determine the number of highly diverse populations for use in crossing and selection programs (Veronesi and Falcinelli, 1988). According to PCA of the defined agro-morphological variables, five principal components comprising 33.975, 15.137, 13.023, 12.626 and 10.246%, respectively, can explain 87.007% of the total variation. Moreover. The number of pods per plant, number of seeds per plant, grain weight per plant, and plant height were significant variants in PC1, days of flowering were significant variants in PC2, and days of germination were an essential variable in PC3, when taking into account the plot defined by the PC1 and PC2 and their projection on the third plan (PC3). According to Yadav et al. (2016) assessment, the first five principal components (PC1 to PC5) gave Eigen-values> 1.0 and collectively accounted for 62.8% of the overall variation. With a more significant impact on leaflet length, leaf width, and the number of nods per main branch, PC1 explained 17.0% of the overall variance. PC2 was positively connected with the number of branches per plant, the length, width, and the number of ovules per pod, and it explained 15.9% of the total variation. In regard to plant height and chlorophyll content, PC3 explained a variation of 11.7%. In their assessment (Tiwari ve Singh, 2019) employed principal component analysis (PCA), and he found that the top five PCs collectively accounted for 75.53% of the variations. The first principle component, which accounted for 44.0% of the total variance, was deemed to be the most significant component. Days to maturity, plant population per plot, number of branches per plant, number of pods per plant, pod width, and number of seeds per pod were significant eigenvectors for PC1. 15.60% of the variation in genotypes was contributed by the second main component. Days to maturity had a beneficial impact on PC2; in addition, plant height had a positive impact on the third principal component, which made for 15.13 percent of the variation overall.

Besides that, for a multitude of quantitative traits, such as days until flowering, plant height, number of stems per plant, pods per node, seeds per pod, pod length, and 100-seed weight, among others, the first three principal components (PCs) attributed for 40.56% of the total variation, of which PC1, PC2, and PC3 explained 20.64, 11.22, and 8.70% of the variation among 21 populations of faba bean (Rebaa et al., 2017). Moreover, Girgel (2021) discovered that the cumulative ratio of the three primary components in the entire variance was 73.780%. Of the overall variation, the first main component accounted for 37.899%. (PC1). 19.975% of the overall variation was explained by the second principle component (PC2). The highest coefficients in the first principal component were for the number of pods per plant, pod length, branch number, first pod height, and thousand seed weight.

The PCA method has been employed in numerous studies, including (Madakbas et al., 2010; Tiwari and Singh, 2019; Zayed et al., 2022; Sharan et al., 2021) which highlights how crucial it is for quickly grouping genotypes with similar characteristics.

5. Conclusion

To sum up, the knowledge of the genetics concerning interesting agronomical traits of faba beans is very important for breeding programs. Indeed our investigation based on many types of analysis including the ANOVA analysis and the means squares showed that it was a wide range of genetic variation for almost the assased traits among the genotypes, in addition, the correlations and principal compound analysis between variables made a view of the possibility of improving a set of many traits at once, what makes our study so valuable for breeding programs and the development of new height-yielding cultivars to meet the demand of a growing global population. The broad bean genotypes used as material in the study were evaluated in terms of anthracnose disease. Moreover, none of the varieties used as material in our research showed anthracnose disease.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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