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Assessing the cooking and quality traits diversity in the seeds of faba bean germplasm

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Abstract: Faba bean is protein-enriched legume crop consumed in the form of pods, and cooked seeds and is a part of the traditional food of many Mediterranean countries. It shows variations in its phenotypes, especially in seed size and color. Therefore, it is very important to investigate faba bean genotypes having less cooking time. Keeping this in view, a total of 399 faba bean accessions including three commercial varieties were obtained from International Center for Agricultural Research in the Dry Areas (ICARDA) and Aegean Agricultural Research Institute National Gene Bank for the investigation of cooking traits variations. The field experiments were conducted according to the augmented block design in three provinces (Sivas, Adana, and İzmir) of Türkiye for two consecutive years (2017 and 2018). A good range of variations was observed for all studied traits and the mean cooking time was 114.16 min. İzmir10 had better cooking properties due to its shorter cooking time than other cultivars and landraces. Higher values of the swelling index revealed the higher swelling ability of Balıkesir74. Correlation analysis was performed and swelling capacity showed significant and positive correlations with swelling index and hydration capacity at a significance level of $p = 0.05$. As this germplasm was collected from 45 provinces, the landrace from Şanlıurfa reflected minimum cooking time and maximum swelling capacity. Principal component analysis (PCA) was performed and the 1st five PCs accounted for a total of 100.00% variations. Biplot analysis resulted in a total of 63.02% variations and the studied germplasm was divided based on cooking time, hydration capacity, and swelling capacity. İzmir10 showed minimum cooking time, it should be also used as a candidate parent to develop faba bean cultivars requiring lesser cooking time to save time and energy. We believe that the results presented herein will be very helpful for the faba bean breeding community interested in quality and cooking traits.

Key words: *Vicia faba* L., germplasm screening, hydration capacity, swelling capacity, cooking time

1. Introduction

Climate change and rapidly increasing population are big threats in the present scenario. Both of these factors are contributing largely to a food shortage (Godfray et al., 2010; Tilman et al., 2011). A huge population of the world goes to bed without the availability of sufficient food (Khush et al., 2012; Nadeem et al., 2021). Therefore, it is very important to investigate and develop climate-resilient cultivars with high production. The most effective way to combat the above-raised issue is to take advantage of the genetic diversity of plants. Genotypic and phenotypic variations can be discovered by characterizing genetic sources and can be used for the breeding perspectives (Baloch et al., 2017; Nadeem et al., 2020; Nadeem, 2021; Shimira et al., 2021). As the world population is increasing at a rapid pace, climatic changes are exerting huge production loss. There is a need to establish a policy framework in which the sustainability of production/consumption patterns becomes central (Stagnari et al., 2017). In this context, the legumes production system can play a vital role in sustainable agriculture production systems through multipurpose contribution. Legumes are one of the most important groups in human and animal nutrition worldwide due to their important agricultural properties and rich protein content (Dita et al., 2006). They can fix atmospheric nitrogen and result in low inputs. Moreover, they can be easily fit in any cropping system and can be used to break the cycle of disease and pest for major crops (Nemecek et al., 2008; Jensen et al., 2010; Köpke et al., 2010)

Faba bean (*Vicia faba* L.) is one of the oldest crops belonging to the family Leguminosae. It is considered a highly nutritious crop having higher protein contents (25%–35%) than other legumes (Singh et al., 2013). Besides

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protein source, it is a good source of *levadopa* (*L-dopa*) which is largely used as a medicine for the treatment of Parkinson's disease (Vered et al., 1997). The Near East region is considered the origin center and it is one of the early domesticated crops after chickpeas and peas. Faba bean is a diploid (2n = 2x = 12) and predominantly a cross-pollinating species (35%–55%) having a large genome size of 13G bp (Suso et al., 2001; Cottage et al., 2012). The Mediterranean basin is the core diversity area of faba bean, while Ethiopia, Afghanistan, and China are considered secondary centers of diversity for the crop (Zong et al., 2009; Tekalign et al., 2019). Currently, the faba bean is widely cultivated and produced on a large scale in Egypt, Morocco, Spain, Italy, Turkey, Southwest Asia, and China (Zohary et al., 2012). Faba bean was cultivated in an area of 2577201 ha worldwide in 2019 and production was 5,431,503 t (FAO, 2021).

Türkiye has been considered the origin and diversity center for many crops and played important role in the distribution of various crops due to its geographical conditions (Baloch et al., 2017; Nadeem et al., 2018). A continuous decrease in sowing area and export of grain legumes have been observed in Turkey in recent years (Ton and Anlarsal, 2016). In 2014, the sowing and production area for food legumes in Turkey was 806,000 ha and 1,147,000 t respectively (TÜİK, 2014). Faba bean is the fourth most widely grown pulse crop in Turkey (Peksen et al., 2007). During 2019, the faba bean was cultivated in an area of 4332 ha and its production was 12346 t.

Germplasm collection and screening are very important as they provide novel variations for breeding perspectives (Nadeem, 2021). Faba bean reflects variations in its seed size and its gene pools are defined as major, minor, and equina types. South Mediterranean countries and China has prevalence of major type, Middle East, North Africa, and Australia have equina type faba bean while small seeded faba bean can be found in North Europe (Alghamdi et al., 2012). Legumes are generally consumed after processes like soaking, cooking, milling, roasting, puffing, and germinating (Urbano et al., 2000). However, soaking followed by cooking is the most common way to consume food legumes (Vadivel and Pugalenthi, 2009). Soaking is carried out below the gelatinization temperature and is intended for increasing the water content to accelerate the following cooking step (Rehman et al., 2001). In addition, the soaking process helps to soften the seed coat and decrease the time required for cooking (Vidal-Valverde et al., 1998; Singh et al., 2013). Cooking is done above the gelatinization temperature for gelatinizing starch and to produce a tender edible product, to develop aroma, and to improve the overall acceptability of the legumes (Chavan et al., 1986; Tharanathan and Mahadevamma, 2003).

There are not many studies on the cooking properties of the faba bean. There are few studies investigating the effects of different cooking methods on faba beans. Previous studies aimed to explore the effect of different cooking methods on faba bean seed's cooking traits (Santos et al., 2018). Abdel-Hameed et al. (2019) explored the effect of soaking and cooking on the nutritional and quality properties of faba bean and suggested soaking for 12 h with 1% baking powder, discarding the soaking solution and using fresh water for cooking is the best treatment to reduce cooking time and improve the nutritional and quality properties of cooked faba beans.

Cooking time is one of the important factors used for evaluating cooking quality in pulse crops (Nadeem et al., 2020). Faba beans should be cooked with appropriate methods and at a suitable time so that digestion is easier. Boiling the faba beans for a long time reduces their nutritional value (Topçu and Topçu, 2001). Cooking time and the quality of cooked food is important for the consumer in the consumption of legumes. For this reason, it is necessary to discover and develop varieties with high nutritional value and cooked in a short time. Keeping this in view, the present study aimed to characterize a total of 399 faba bean accessions for cooking traits.

2. Materials and methods

2.1. Plant material

In this study, 396 faba bean landraces and 3 commercial cultivars (Filiz-99, Kıtık-2003, Salkım) were used as material. Studied germplasm was obtained from Aegean Agricultural Research Institute National Gene Bank and ICARDA (International Center for Agricultural Research in the Dry Areas). Identification numbers and locations of studied germplasm are presented in Table 1 and Figure 1.

Field experimentation was performed in three different locations (Adana, Sivas, and İzmir) in 2015–2016 and 2016–2017 growing years according to the augmented block design. Filiz-99, Kıtık-2003, and Salkım were used as control. The whole germplasm was grown in plots of two rows, every 2 m in length, with 10 cm between plants within a row and 45 cm between rows. All plots were treated identically with standard local agricultural practices. Harvesting was performed at 90% pods maturity and seeds were stored before their usage for cooking traits.

2.2. Cooking properties

2.2.1. Hundred seed weight and hundred seed volume calculation

A total of 100 fresh and undamaged seeds were counted manually for each accession. The weights of 100 seeds were determined by weighing on a digital scale. One hundred seeds were placed in graduated cylinders. The dry volume was calculated by adding 200 mL of distilled water. Seeds

Table 1. Information about faba bean germplasm collected from different ecological regions of Turkey used in this study.

Accession number	Names of landraces	Collection site	District	Coordinates
1	Adana 1	Adana	Center	E35 19 / N37 00
2	Adana 2	Adana	Center	E35 19 / N37 00
3	Adana 3	Adana	Center	E35 19 / N37 00
4	Adana 4	Adana	Center	E35 19 / N37 00
5	Adana 5	Adana	Center	E35 19 / N37 00
6	Adana 6	Adana	Center	E35 19 / N37 00
7	Adana 7	Adana	Faba bean field	NA
8	Amasya 1	Amasya	Faba bean field	NA
9	Amasya 2	Amasya	Faba bean field	NA
10	Amasya 3	Amasya	Faba bean field	NA
11	Amasya 4	Amasya	Faba bean field	NA
12	Antakya 1	Antakya	Center	E36 11 / N36 12
13	Antakya 2	Antakya	Center	E36 11 / N36 12
14	Antakya 3	Antakya	Küçüknehir	NA
15	Antakya 4	Antakya	Yukarıokçular	E36 08 / N36 06
16	Antakya 5	Antakya	Serinyol	E36 16 / N36 22
17	Antalya 1	Antalya	Center	E30 42 / N36 53
18	Antalya 2	Antalya	Center	E30 42 / N36 53
19	Antalya 3	Antalya	Center	E30 42 / N36 53
20	Antalya 4	Antalya	Center	E30 42 / N36 53
21	Antalya 5	Antalya	Center	E30 42 / N36 53
22	Antalya 6	Antalya	Taşağıl	E31 13 / N36 55
23	Antalya 7	Antalya	Kestel	E32 04 / N36 31
24	Antalya 8	Antalya	Karabucak	E31 18 / N37 02
25	Antalya 9	Antalya	Çamyuva	E30 33 / N36 33
26	Artvin 1	Artvin	Stored product	NA
27	Aydın 1	Aydın	Center	E27 50 / N37 51
28	Aydın 2	Aydın	Center	E27 50 / N37 51
29	Aydın 3	Aydın	Center	E27 50 / N37 51
30	Aydın 4	Aydın	Center	E27 50 / N37 51
31	Aydın 5	Aydın	Center	E27 50 / N37 51
32	Aydın 6	Aydın	Gökçealan	E27 23 / N37 50
33	Balıkesir 1	Balıkesir	Center	E27 51 / N39 37
34	Balıkesir 2	Balıkesir	Center	E27 51 / N39 37
35	Balıkesir 3	Balıkesir	Center	E27 51 / N39 37
36	Balıkesir 4	Balıkesir	Center	E27 51 / N39 37
37	Balıkesir 5	Balıkesir	Center	E27 51 / N39 37
38	Balıkesir 6	Balıkesir	Center	E27 51 / N39 37
39	Balıkesir 7	Balıkesir	Center	E27 51 / N39 37
40	Balıkesir 8	Balıkesir	Center	E27 51 / N39 37
41	Balıkesir 9	Balıkesir	Center	E27 51 / N39 37
42	Balıkesir 10	Balıkesir	Center	E27 51 / N39 37

Table 1. (Continued).

43	Balıkesir 11	Balıkesir	Center	E27 51 / N39 37
44	Balıkesir 12	Balıkesir	Center	E27 51 / N39 37
45	Balıkesir 13	Balıkesir	Center	E27 51 / N39 37
46	Balıkesir 14	Balıkesir	Center	E27 51 / N39 37
47	Balıkesir 15	Balıkesir	Center	E27 51 / N39 37
48	Balıkesir 16	Balıkesir	Center	E27 51 / N39 37
49	Balıkesir 17	Balıkesir	Center	E27 51 / N39 37
50	Balıkesir 18	Balıkesir	Center	E27 51 / N39 37
51	Balıkesir 19	Balıkesir	Center	E27 51 / N39 37
52	Balıkesir 20	Balıkesir	Center	E27 51 / N39 37
53	Balıkesir 21	Balıkesir	Center	E27 51 / N39 37
54	Balıkesir 22	Balıkesir	Center	E27 51 / N39 37
55	Balıkesir 23	Balıkesir	Center	E27 51 / N39 37
56	Balıkesir 24	Balıkesir	Center	E27 51 / N39 37
57	Balıkesir 25	Balıkesir	Center	E27 51 / N39 37
58	Balıkesir 26	Balıkesir	Center	E27 51 / N39 37
59	Balıkesir 27	Balıkesir	Center	E27 51 / N39 37
60	Balıkesir 28	Balıkesir	Center	E27 51 / N39 37
61	Balıkesir 29	Balıkesir	Center	E27 51 / N39 37
62	Balıkesir 30	Balıkesir	Center	E27 51 / N39 37
63	Balıkesir 31	Balıkesir	Center	E27 51 / N39 37
64	Balıkesir 32	Balıkesir	Center	E27 51 / N39 37
65	Balıkesir 33	Balıkesir	Center	E27 51 / N39 37
66	Balıkesir 34	Balıkesir	Center	E27 51 / N39 37
67	Balıkesir 35	Balıkesir	Center	E27 51 / N39 37
68	Balıkesir 36	Balıkesir	Center	E27 51 / N39 37
69	Balıkesir 37	Balıkesir	Center	E27 51 / N39 37
70	Balıkesir 38	Balıkesir	Center	E27 51 / N39 37
71	Balıkesir 39	Balıkesir	Center	E27 51 / N39 37
72	Balıkesir 40	Balıkesir	Center	E27 51 / N39 37
73	Balıkesir 41	Balıkesir	Center	E27 51 / N39 37
74	Balıkesir 42	Balıkesir	Center	E27 51 / N39 37
75	Balıkesir 43	Balıkesir	Center	E27 51 / N39 37
76	Balıkesir 44	Balıkesir	Center	E27 51 / N39 37
77	Balıkesir 45	Balıkesir	Center	E27 51 / N39 37
78	Balıkesir 46	Balıkesir	Center	E27 51 / N39 37
79	Balıkesir 47	Balıkesir	Center	E27 51 / N39 37
80	Balıkesir 48	Balıkesir	Center	E27 51 / N39 37
81	Balıkesir 49	Balıkesir	Center	E27 51 / N39 37
82	Balıkesir 50	Balıkesir	Center	E27 51 / N39 37
83	Balıkesir 51	Balıkesir	Center	E27 51 / N39 37
84	Balıkesir 52	Balıkesir	Center	E27 51 / N39 37
85	Balıkesir 53	Balıkesir	Center	E27 51 / N39 37

Table 1. (Continued).

86	Balıkesir 54	Balıkesir	Center	E27 51 / N39 37
87	Balıkesir 55	Balıkesir	Center	E27 51 / N39 37
88	Balıkesir 56	Balıkesir	Center	E27 51 / N39 37
89	Balıkesir 57	Balıkesir	Center	E27 51 / N39 37
90	Balıkesir 58	Balıkesir	Center	E27 51 / N39 37
91	Balıkesir 59	Balıkesir	Center	E27 51 / N39 37
92	Balıkesir 60	Balıkesir	Center	E27 51 / N39 37
93	Balıkesir 61	Balıkesir	Center	E27 51 / N39 37
94	Balıkesir 62	Balıkesir	Center	E27 51 / N39 37
95	Balıkesir 63	Balıkesir	Center	E27 51 / N39 37
96	Balıkesir 64	Balıkesir	Center	E27 51 / N39 37
97	Balıkesir 65	Balıkesir	Center	E27 51 / N39 37
98	Balıkesir 66	Balıkesir	Center	E27 51 / N39 37
99	Balıkesir 67	Balıkesir	Center	E27 51 / N39 37
100	Balıkesir 68	Balıkesir	Center	E27 51 / N39 37
101	Balıkesir 69	Balıkesir	Center	E27 51 / N39 37
102	Balıkesir 70	Balıkesir	Gökçeağaç	E27 37 55 / N39 37 45
103	Balıkesir 71	Balıkesir	Gökçeağaç	E27 37 55 / N39 37 45
104	Balıkesir 72	Balıkesir	Burhaniye	E26 59 38 / N39 31 14
105	Balıkesir 73	Balıkesir	Kuşadası	E27 27 00 / N39 47 00
106	Balıkesir 74	Balıkesir	Paşakoy	E27 58 48 / N39 33 23
107	Balıkesir 75	Balıkesir	Kayabaşı	E28 08 23 / N39 21 57
108	Balıkesir 76	Balıkesir	Selimiye	E27 54 19 / N39 30 35
109	Balıkesir 77	Balıkesir	Kayapınar	E27 26 46 / N39 29 31
110	Balıkesir 78	Balıkesir	Can	E27 02 22 / N39 37 23
111	Balıkesir 79	Balıkesir	Tepeören	E28 02 38 / N40 08 44
112	Balıkesir 80	Balıkesir	Gündogdu	E27 38 03 / N40 10 21
113	Balıkesir 81	Balıkesir	Geçitli	E27 29 01 / N40 10 24
114	Balıkesir 82	Balıkesir	Threshing floor	NA
115	Balıkesir 83	Balıkesir	Stored product	NA
116	Balıkesir 84	Balıkesir	Stored product	NA
117	Batman 1	Batman	Center	E41 07 / N37 53
118	Batman 2	Batman	Center	E41 07 / N37 53
119	Bilecik 1	Bilecik	Center	E29 58 / N40 08
120	Burdur 1	Burdur	Center	E30 16 / N37 43
121	Burdur 2	Burdur	Center	E30 16 / N37 43
122	Bursa 1	Bursa	Yenice	E29 30 30 / N40 00 06
123	Bursa 2	Bursa	Yenice	E29 30 30 / N40 00 06
124	Bursa 3	Bursa	Center	E29 03 / N40 11
125	Bursa 4	Bursa	Center	E29 03 / N40 11
126	Bursa 5	Bursa	Murseller	E29 01 45 / N40 05 42
127	Bursa 6	Bursa	Center	E29 03 / N40 11
128	Bursa 7	Bursa	Orhaneli	E28 58 18 / N40 08 12

Table 1. (Continued).

129	Bursa 8	Bursa	Center	E29 03 / N40 11
130	Bursa 9	Bursa	Center	E29 03 / N40 11
131	Çanakkale 1	Çanakkale	Center	E26 25 / N40 09
132	Çanakkale 2	Çanakkale	Center	E26 25 / N40 09
133	Çanakkale 3	Çanakkale	Center	E26 25 / N40 09
134	Çanakkale 4	Çanakkale	Center	E26 25 / N40 09
135	Çanakkale 5	Çanakkale	Center	E26 25 / N40 09
136	Çanakkale 6	Çanakkale	Center	E26 25 / N40 09
137	Çanakkale 7	Çanakkale	Center	E26 25 / N40 09
138	Çanakkale 8	Çanakkale	Center	E26 25 / N40 09
139	Çanakkale 9	Çanakkale	Center	E26 25 / N40 09
140	Çanakkale 10	Çanakkale	Center	E26 25 / N40 09
141	Çanakkale 11	Çanakkale	Center	E26 25 / N40 09
142	Çanakkale 12	Çanakkale	Center	E26 25 / N40 09
143	Çanakkale 13	Çanakkale	Center	E26 25 / N40 09
144	Çanakkale 14	Çanakkale	Center	E26 25 / N40 09
145	Çanakkale 15	Çanakkale	Center	E26 25 / N40 09
146	Çanakkale 16	Çanakkale	Center	E26 25 / N40 09
147	Çanakkale 17	Çanakkale	Center	E26 25 / N40 09
148	Çanakkale 18	Çanakkale	Center	E26 25 / N40 09
149	Çanakkale 19	Çanakkale	Center	E26 25 / N40 09
150	Çanakkale 20	Çanakkale	Center	E26 25 / N40 09
151	Çanakkale 21	Çanakkale	Faba bean field	NA
152	Çanakkale 22	Çanakkale	Faba bean field	NA
153	Çanakkale 23	Çanakkale	Faba bean field	NA
154	Çanakkale 24	Çanakkale	Faba bean field	NA
155	Çanakkale 25	Çanakkale	Faba bean field	NA
156	Çanakkale 26	Çanakkale	Faba bean field	NA
157	Çanakkale 27	Çanakkale	Faba bean field	NA
158	Çanakkale 28	Çanakkale	Faba bean field	NA
159	Çanakkale 29	Çanakkale	Faba bean field	NA
160	Çanakkale 30	Çanakkale	Faba bean field	NA
161	Çanakkale 31	Çanakkale	Faba bean field	NA
162	Çanakkale 32	Çanakkale	Faba bean field	NA
163	Çanakkale 33	Çanakkale	Faba bean field	NA
164	Çanakkale 34	Çanakkale	Can	E27 02 / N40 01
165	Çanakkale 35	Çanakkale	Can	E27 02 / N40 01
166	Çanakkale 36	Çanakkale	Can	E27 02 / N40 01
167	Çanakkale 37	Çanakkale	Can	E27 02 / N40 01
168	Çanakkale 38	Çanakkale	Ezine	E26 21 / N39 43
169	Çanakkale 39	Çanakkale	Ezine	E26 21 / N39 43
170	Çanakkale 40	Çanakkale	Ezine	E26 21 / N39 43
171	Çanakkale 41	Çanakkale	Ezine	E26 21 / N39 43

Table 1. (Continued).

172	Çanakkale 42	Çanakkale	Stored product	NA
173	Çanakkale 43	Çanakkale	Stored product	NA
174	Çanakkale 44	Çanakkale	Stored product	NA
175	Çanakkale 45	Çanakkale	Güvemalan village	E26 25 / N40 09
176	Çanakkale 46	Çanakkale	Güvemalan village	E26 25 / N40 09
177	Çanakkale 47	Çanakkale	Güvemalan village	E26 25 / N40 09
178	Çanakkale 48	Çanakkale	Türkmeneli village	E26 17 / N39 47
179	Çanakkale 49	Çanakkale	Türkmeneli village	E26 17 / N39 47
180	Çanakkale 50	Çanakkale	Adatepe village	E27 07 / N40 16
181	Çanakkale 51	Çanakkale	Altınoluk	E26 39 17 / N39 33 20
182	Çanakkale 52	Çanakkale	Alçıtepe	E26 13 / N40 05
183	Çanakkale 53	Çanakkale	Ayvacık	E26 24 04 / N39 32 13
184	Çanakkale 54	Çanakkale	Bayramiç	E26 36 / N39 48
185	Çanakkale 55	Çanakkale	Bihramlı village	E26 17 13 / N40 07 34
186	Çanakkale 56	Çanakkale	Burhaniye village	E26 32 23 / N40 13 54
187	Çanakkale 57	Çanakkale	Edge	E26 27 / N40 08
188	Çanakkale 58	Çanakkale	Eskipazar	E26 30 50 / N40 09 44
189	Çanakkale 59	Çanakkale	Ecebat-Gelibolu	E26 21 / N40 11
190	Çanakkale 60	Çanakkale	Göktepe village	E27 08 / N40 13
191	Çanakkale 61	Çanakkale	Hurmaköy	E26 59 35 / N39 59 38
192	Çanakkale 62	Çanakkale	İntepe	E26 19 14 / N40 00 11
193	Çanakkale 63	Çanakkale	Karkın	E27 13 19 / N39 48 38
194	Çanakkale 64	Çanakkale	Kepez	E26 23 07 / N40 05 20
195	Çanakkale 65	Çanakkale	Kızıltepe	E27 19 10 / N39 51 24
196	Çanakkale 66	Çanakkale	Kurşunlu	E26 34 30 / N40 03 42
197	Çanakkale 67	Çanakkale	Paşaköy	E26 19 10 / N39 31 25
198	Çanakkale 68	Çanakkale	Şeddülbahir village	E26 11 49 / N40 03 09
199	Çanakkale 69	Çanakkale	Şerbetli village	E26 51 59 / N40 00 40
200	Diyarbakır 1	Diyarbakır	Center	E40 12 / N37 55
201	Edirne 1	Edirne	Center	E26 34 / N41 41
202	Edirne 2	Edirne	Center	E26 34 / N41 41
203	Edirne 3	Edirne	Center	E26 34 / N41 41
204	Edirne 4	Edirne	Alic	E26 38 27 / N41 03 41
205	Edirne 5	Edirne	Center	E26 34 / N41 41
206	Edirne 6	Edirne	Center	E26 34 / N41 41
207	Edirne 7	Edirne	Center	E26 34 / N41 41
208	Edirne 8	Edirne	Faba bean field	NA
209	Elazığ 1	Elazığ	Center	E39 13 / N38 41
210	Elazığ 2	Elazığ	Center	E39 13 / N38 41
211	Elazığ 3	Elazığ	Center	E39 13 / N38 41
212	Elazığ 4	Elazığ	Center	E39 13 / N38 41
213	Elazığ 5	Elazığ	Center	E39 13 / N38 41
214	Elazığ 6	Elazığ	Center	E39 13 / N38 41

Table 1. (Continued).

215	Elazığ 7	Elazığ	Faba bean field	NA
216	Erzincan 1	Erzincan	Stored product	NA
217	Erzincan 2	Erzincan	Stored product	NA
218	Erzincan 3	Erzincan	Faba bean field	NA
219	Erzincan 4	Erzincan	Faba bean field	NA
220	Eskişehir 1	Eskişehir	Center	E30 31 / N39 46
221	Eskişehir 2	Eskişehir	Center	E30 31 / N39 46
222	Giresun 1	Giresun	Center	E38 23 / N40 55
223	Giresun 2	Giresun	Stored product	NA
224	Giresun 3	Giresun	Stored product	NA
225	Giresun 4	Giresun	Stored product	NA
226	Giresun 5	Giresun	Faba bean field	NA
227	İzmir 1	İzmir	Center	E27 10 / N38 25
228	İzmir 2	İzmir	Center	E27 10 / N38 25
229	İzmir 3	İzmir	Center	E27 10 / N38 25
230	İzmir 4	İzmir	Center	E27 10 / N38 25
231	İzmir 5	İzmir	Center	E27 10 / N38 25
232	İzmir 6	İzmir	Center	E27 10 / N38 25
233	İzmir 7	İzmir	Center	E27 10 / N38 25
234	İzmir 8	İzmir	Center	E27 10 / N38 25
235	İzmir 9	İzmir	Center	E27 10 / N38 25
236	İzmir 10	İzmir	Center	E27 10 / N38 25
237	İzmir 11	İzmir	Center	E27 10 / N38 25
238	İzmir 12	İzmir	Center	E27 10 / N38 25
239	İzmir 13	İzmir	Center	E27 10 / N38 25
240	İzmir 14	İzmir	Karşıyaka	E27 06 30 / N38 27 30
241	İzmir 15	İzmir	Karşıyaka	E27 06 30 / N38 27 30
242	İzmir 16	İzmir	Karşıyaka	E27 06 30 / N38 27 30
243	İzmir 17	İzmir	Karşıyaka	E27 06 30 / N38 27 30
244	İzmir 18	İzmir	Karşıyaka	E27 06 30 / N38 27 30
245	İzmir 19	İzmir	Karşıyaka	E27 06 30 / N38 27 30
246	İzmir 20	İzmir	Karşıyaka	E27 06 30 / N38 27 30
247	İzmir 21	İzmir	Karşıyaka	E27 06 30 / N38 27 30
248	İzmir 22	İzmir	Karşıyaka	E27 06 30 / N38 27 30
249	İzmir 23	İzmir	Karşıyaka	E27 06 30 / N38 27 30
250	İzmir 24	İzmir	Karşıyaka	E27 06 30 / N38 27 30
251	İzmir 25	İzmir	Karşıyaka	E27 06 30 / N38 27 30
252	İzmir 26	İzmir	Karşıyaka	E27 06 30 / N38 27 30
253	İzmir 27	İzmir	Karşıyaka	E27 06 30 / N38 27 30
254	İzmir 28	İzmir	Karşıyaka	E27 06 30 / N38 27 30
255	İzmir 29	İzmir	Karşıyaka	E27 06 30 / N38 27 30
256	İzmir 30	İzmir	Karşıyaka	E27 06 30 / N38 27 30
257	İzmir 31	İzmir	Karşıyaka	E27 06 30 / N38 27 30

Table 1. (Continued).

258	İzmir 32	İzmir	Faba field	NA
259	İzmir 33	İzmir	Faba field	NA
260	İzmir 34	İzmir	Faba field	NA
261	İzmir 35	İzmir	Faba field	NA
262	İzmir 36	İzmir	Faba field	NA
263	İzmir 37	İzmir	Faba field	NA
264	İzmir 38	İzmir	Faba field	NA
265	İzmir 39	İzmir	Faba field	NA
266	İzmir 40	İzmir	Threshing floor	NA
267	İzmir 41	İzmir	Threshing floor	NA
268	İzmir 42	İzmir	Threshing floor	NA
269	İzmir 43	İzmir	Threshing floor	NA
270	İzmir 44	İzmir	Kızılcaayas	E27 38 / N38 14
271	İzmir 45	İzmir	Menemen	E27 06 / N38 35
272	İzmir 46	İzmir	Kurfalliyi	E27 04 35 / N39 01 29
273	Isparta 1	Isparta	Center	E30 33 / N37 45
274	İstanbul 1	İstanbul	Center	E28 57 / N41 02
275	Kahramanmaraş 1	Kahramanmaraş	Center	E36 55 / N37 34
276	Kahramanmaraş 2	Kahramanmaraş	Center	E36 55 / N37 34
277	Kahramanmaraş 3	Kahramanmaraş	Afşin	E36 54 / N38 14
278	Kars 1	Kars	Center	E43 05 / N40 35
279	Kars 2	Kars	Center	E43 05 / N40 35
280	Kars 3	Kars	Stored product	NA
281	Kars 4	Kars	Stored product	NA
282	Kastamonu 1	Kastamonu	Center	E33 46 / N41 22
283	Kastamonu 2	Kastamonu	Center	E33 46 / N41 22
284	Kayseri 1	Kayseri	Stored product	NA
285	Kayseri 2	Kayseri	Stored product	NA
286	Kayseri 3	Kayseri	Faba bean field	NA
287	Kayseri 4	Kayseri	Faba bean field	NA
288	Kırklareli 1	Kırklareli	Faba bean field	NA
289	Kırklareli 2	Kırklareli	Faba bean field	NA
290	Kırklareli 3	Kırklareli	Center	E27 12 / N41 42
291	Kırklareli 4	Kırklareli	Center	E27 12 / N41 42
292	Kırklareli 5	Kırklareli	Akıncılar village	E27 38 28 / N41 27 15
293	Kırklareli 6	Kırklareli	Vize	E27 46 37 / N41 34 43
294	Kırşehir 1	Kırşehir	Stored product	NA
295	Kırşehir 2	Kırşehir	Faba bean field	NA
296	Kocaeli	Kocaeli	Stored product	NA
297	Konya 1	Konya	Center	E32 30 / N37 51
298	Konya 2	Konya	Center	E32 30 / N37 51
299	Konya 3	Konya	Center	E32 30 / N37 51
300	Konya 4	Konya	Center	E32 30 / N37 51

Table 1. (Continued).

301	Konya 5	Konya	Center	E32 30 / N37 51
302	Konya 6	Konya	Center	E32 30 / N37 51
303	Konya 7	Konya	Center	E32 30 / N37 51
304	Kütahya 1	Kütahya	Threshing floor	NA
305	Malatya 1	Malatya	Stored product	NA
306	Malatya 2	Malatya	Stored product	NA
307	Malatya 3	Malatya	Faba bean field	NA
308	Malatya 4	Malatya	Faba bean field	NA
309	Manisa 1	Manisa	Center	E27 29 / N38 36
310	Manisa 2	Manisa	Center	E27 29 / N38 36
311	Manisa 3	Manisa	Center	E27 29 / N38 36
312	Manisa 4	Manisa	Center	E27 29 / N38 36
313	Manisa 5	Manisa	Center	E27 29 / N38 36
314	Manisa 6	Manisa	Center	E27 29 / N38 36
315	Manisa 7	Manisa	Center	E27 29 / N38 36
316	Manisa 8	Manisa	Center	E27 29 / N38 36
317	Manisa 9	Manisa	Center	E27 29 / N38 36
318	Manisa 10	Manisa	Center	E27 29 / N38 36
319	Manisa 11	Manisa	Center	E27 29 / N38 36
320	Manisa 12	Manisa	Center	E27 29 / N38 36
321	Manisa 13	Manisa	Center	E27 29 / N38 36
322	Manisa 14	Manisa	Faba bean field	NA
323	Manisa 15	Manisa	Faba bean field	NA
324	Manisa 16	Manisa	Faba bean field	NA
325	Manisa 17	Manisa	Kınık	E27 31 43 / N39 10 38
326	Mardin 1	Mardin	Center	E40 39 / N37 21
327	Mardin 2	Mardin	Center	E40 39 / N37 21
328	Mardin 3	Mardin	Kızıltepe	E40 35 / N37 11
329	Mersin 1	Mersin	Center	E34 38 / N36 48
330	Mersin 2	Mersin	Center	E34 38 / N36 48
331	Mersin 3	Mersin	Center	E34 38 / N36 48
332	Mersin 4	Mersin	Center	E34 38 / N36 48
333	Mersin 5	Mersin	Center	E34 38 / N36 48
334	Mersin 6	Mersin	Center	E34 38 / N36 48
335	Mersin 7	Mersin	Faba bean field	NA
336	Mersin 8	Mersin	Faba bean field	NA
337	Mersin 9	Mersin	Faba bean field	NA
338	Mersin 10	Mersin	Stored product	NA
339	Muğla 1	Muğla	Center	E28 22 / N37 13
340	Muğla 2	Muğla	Center	E28 22 / N37 13
341	Muğla 3	Muğla	Center	E28 22 / N37 13
342	Muğla 4	Muğla	Center	E28 22 / N37 13
343	Muğla 5	Muğla	Center	E28 22 / N37 13

Table 1. (Continued).

344	Muğla 6	Muğla	Center	E28 22 / N37 13
345	Muğla 7	Muğla	Center	E28 22 / N37 13
346	Muğla 8	Muğla	Center	E28 22 / N37 13
347	Muğla 9	Muğla	Fethiye	E29 08 / N36 37
348	Muğla 10	Muğla	Fethiye	E29 08 / N36 37
349	Muğla 11	Muğla	Faba bean field	NA
350	Muğla 12	Muğla	Faba bean field	NA
351	Muğla 13	Muğla	Faba bean field	NA
352	Samsun 1	Samsun	Stored product	NA
353	Samsun 2	Samsun	Stored product	NA
354	Samsun 3	Samsun	Faba bean field	NA
355	Sinop 1	Sinop	Stored product	NA
356	Sivas 1	Sivas	Stored product	NA
357	Sivas 2	Sivas	Stored product	NA
358	Sivas 3	Sivas	Stored product	NA
359	Sivas 4	Sivas	Faba bean field	NA
360	Sivas 5	Sivas	Faba bean field	NA
361	Şanlıurfa 1	Şanlıurfa	Faba bean field	NA
362	Tekirdağ 1	Tekirdağ	Center	E27 31 / N41 00
363	Tekirdağ 2	Tekirdağ	Center	E27 31 / N41 00
364	Tekirdağ 3	Tekirdağ	Center	E27 31 / N41 00
365	Tekirdağ 4	Tekirdağ	Center	E27 31 / N41 00
366	Tekirdağ 5	Tekirdağ	Faba bean field	NA
367	Tekirdağ 6	Tekirdağ	Stored product	NA
368	Tekirdağ 7	Tekirdağ	Stored product	NA
369	Tekirdağ 8	Tekirdağ	Lapseki	E26 51 36 / N40 73 51
370	Tekirdağ 9	Tekirdağ	Sarıköy	E27 01 15 / N40 38 50
371	Tekirdağ 10	Tekirdağ	Malkara	E26 55 06 / N40 51 25
372	Tekirdağ 11	Tekirdağ	Kumbağ	E27 24 46 / N40 50 33
373	Tekirdağ 12	Tekirdağ	Uçmakdere	E27 21 54 / N40 49 51
374	Tekirdağ 13	Tekirdağ	Naip village	E27 24 04 / N40 52 28
375	Tekirdağ 14	Tekirdağ	Yacı village	E27 26 24 / N41 00 03
376	Tekirdağ 15	Tekirdağ	Çerkezköy	E27 53 25 / N41 14 59
377	Tekirdağ 16	Tekirdağ	Hayrabolu	E27 19 51 / N41 03 33
378	Tekirdağ 17	Tekirdağ	Ortaca	E27 15 01 / N41 04 59
379	Tokat 1	Tokat	Faba bean field	NA
380	Tokat 2	Tokat	Faba bean field	NA
381	Tokat 3	Tokat	Faba bean field	NA
382	Tokat 4	Tokat	Faba bean field	NA
383	Tokat 5	Tokat	Faba bean field	NA
384	Tokat 6	Tokat	Faba bean field	NA
385	Urfa 1	Urfa	Ezgil	E38 18 / N37 03
386	Van 1	Van	Center	E42 58 / N38 36

Table 1. (Continued).

387	Yozgat 1	Yozgat	Stored product	NA
388	Yozgat 2	Yozgat	Stored product	NA
389	G1	-	-	-
390	G2	-	-	-
391	G3	-	-	-
392	G4	-	-	-
393	G5	-	-	-
394	G6	-	-	-
395	G7	-	-	-
396	G8	-	-	-
397	FİLİZ-99	-	-	-
398	KITIK-2002	-	-	-
399	SALKIM	-	-	-

*NA:unknown

Figure 1. Collection provinces of 396 faba bean accessions used as plant material in this study.

were soaked in water for overnight and their volumes were measured. The water of the soaked seeds was filtered and weighed on a digital balance and the wet weight was measured.

2.2.2. Swelling capacity and swelling index determination

Swelling capacity (SC) and swelling index (SI) values were calculated according the protocol suggested by Elkoca and Çınar (2015).

Swelling capacity (ml/seed) = [(wet volume – 200) - (dry volume – 200)] / 100

Swelling index (%) = (wet volume – 200) / (dry volume – 200)

2.2.3. Hydration capacity and hydration index determination

Hydration capacity (HC) and hydration index (HI) were calculated according the protocol suggested by Elkoca and Çınar (2015).

Hydration capacity (g/seed) = [(wet seed weight) – (dry seed weight)] / 100

Hydration index (%) = hydration capacity / (dry seed weight / 100)

2.2.4. Cooking time (CT) determination

A total of 100 seeds were boiled in a beaker with distilled water. Boiling was continued, and samples (5–6 seeds) were withdrawn using a spatula at 5 min intervals up to 30 min and thereafter after every 2 min and tested for softness by pressing between finger and thumb. The time from the addition of seeds to the achievement of the desirable softness was recorded as the cooking time.

2.3. Statistical analysis

Augmented block design (Federer, 1956) with three standard check varieties (Filiz-99, Kıtık-2003 ve Salkım) was used for this study and the statistical inferences were derived using the online software for augmented block design developed by Rathore et al. (2004). Whole germplasm was sown in nine blocks according to augmented block design where these check varieties were used as a control group and repeated eight times. Replication of these check varieties was used to standardize the data and to calculate the adjusted means. Various parameters like minimum, maximum, mean, and standard deviation were calculated through the statistical software XLSTAT (www.xlstat.com). The same software was used to carry out the principal component analysis (PCA) and biplot analysis. Pearson's correlation coefficient and heatmap were constructed using corrplot and ggplot2 packages in R statistical software, respectively. Most stable genotypes for cooking traits were evaluated through "STABILITYSOFT" (Pour-Aboughadareh et al., 2019).

3. Results

A good range of variations for studied traits was observed in studied faba bean germplasm. Cooking traits like swelling capacity, hydration capacity, cooking time, swelling index, and hydration index ranged from 0.45 mL/seed to 1.72 mL/seed, 0.59 g/seed to 2.07 g/seed, 51.04 min to 288.41 min, 0.50 to 2.59, and 1.30 to 5.35 with a mean value of 1.05, 1.02, 114.16, 1.08 and 2.24, respectively (Table 2). Minimum swelling capacity and minimum hydration capacity were observed with landrace from Artvin. Maximum swelling capacity and maximum hydration capacity were observed with Tokat6 and Balıkesir11, respectively. Maximum and minimum cooking times were observed with Manisa16 and İzmir10, respectively.

During this study, accessions from 45 provinces of Turkey were used as plant material (Table 3). Accessions belonging to Şanlıurfa were found superior in swelling capacity and cooking time (Figure 2). Correlation coefficients among the cooking traits are provided in Figure 3. Swelling capacity reflected a highly significant and positive correlation with hydration capacity (0.65**) and swelling index (0.3**0). Hydration capacity showed a significant and positive correlation with the hydration index.

Principal component analysis was computed for cooking traits for faba bean germplasm. The first five components accounted for a total of 100.00% (Table 4). The first PC accounted for 37.93% of the variation with the highest contribution from SC. The second component showed a 25.08% variation and the swelling index was the highest variation contributing trait. The third component showed 19.56% variation and cooking time was the highest variation contributing trait. Similarly, the fourth and fifth components revealed 0.76% and 0.12% of the variation with the highest contribution from hydration index and hydration capacity, respectively.

Biplot analysis explained nearly 63.02% of the total trait variation considering the first two PCs (Figure 4). Biplot analysis distinguished the faba bean genotypes based on their cooking traits. Heatmap was developed for studied traits and divided the germplasm into two populations (Figure 5). Population A was found smaller than population B. Cooking time showed higher variations among studied traits.

4. Discussion

Cooking and quality traits are very important for legumes as they largely influence consumer preference. As legumes are consumed mostly after cooking, the breeders need to develop cultivars keeping in mind the consumer's

Table 2. Cooking traits variations in studied faba bean germplasm.

Traits	Minimum	Maximum	Mean	Std. deviation
Swelling capacity (mL/seed)	0.45	1.72	1.05	0.18
Hydration capacity (g/seed)	0.59	2.07	1.02	0.17
Cooking time (min)	51.04	288.41	114.16	36.64
Swelling index	1.30	5.35	2.24	0.25
Hydration index	0.50	2.59	1.08	0.12

Table 3. Variations of cooking traits at the province level.

Provinces	SC	HC	CT	HI	SI
Adana	1.00	1.01	122.99	1.08	2.19
Amasya	1.14	1.07	103.31	1.02	2.34
Antakya	0.80	0.79	117.60	0.99	2.22
Antalya	0.92	0.90	108.39	1.06	2.25
Artvin	0.45	0.59	100.33	1.08	2.25
Aydın	1.19	1.14	108.67	1.10	2.34
Balıkesir	1.04	1.05	111.27	1.11	2.26
Batman	1.14	1.08	106.26	1.12	2.31
Bilecik	1.26	1.20	81.24	1.06	2.22
Burdur	1.32	1.27	121.61	1.09	2.20
Bursa	0.99	0.94	121.69	1.06	2.25
Çanakkale	1.05	1.00	116.89	1.06	2.21
Diyarbakır	1.21	1.12	107.20	1.10	2.31
Edirne	1.24	1.13	99.45	1.15	2.34
Elazığ	1.04	1.09	111.12	1.10	2.06
Erzincan	1.14	1.09	98.69	1.12	2.25
Eskişehir	1.14	0.94	161.34	1.07	2.38
Giresun	1.06	0.98	117.42	1.14	2.41
İzmir	1.03	1.04	111.94	1.06	2.15
Isparta	0.79	0.87	96.98	1.05	1.98
İstanbul	0.92	0.93	143.40	1.05	2.16
Kahramanmaraş	0.79	0.76	95.64	1.10	2.26
Kars	1.09	1.01	85.23	1.07	2.26
Kastamonu	1.07	1.03	101.64	1.09	2.11
Kayseri	1.17	1.01	88.75	1.00	2.24
Kırklareli	1.13	1.08	126.48	1.10	2.27
Kırşehir	1.15	1.13	102.03	1.07	2.18
Kocaeli	1.10	1.09	97.14	1.07	2.25
Konya	1.06	1.02	128.27	1.11	2.25
Kütahya	1.23	1.18	93.28	1.15	2.26
Malatya	0.94	0.96	177.72	1.14	2.16
Manisa	0.98	0.93	112.29	1.09	2.24
Mardin	0.98	0.98	87.51	1.14	2.26
Mersin	1.08	1.03	123.17	1.08	2.20
Muğla	1.11	1.04	124.18	1.07	2.25
Samsun	0.95	0.89	115.31	1.14	2.81
Sinop	0.95	0.76	96.37	1.05	2.73
Sivas	0.98	0.97	87.77	1.09	2.30
Şanlıurfa	1.21	1.09	69.13	1.14	2.30
Tekirdağ	1.07	1.02	119.52	1.08	2.26
Tokat	1.16	0.93	140.33	1.04	2.50
Urfa	0.93	0.93	99.84	1.13	2.12
Van	0.87	0.94	86.72	1.08	2.30
Yozgat	1.21	1.18	111.86	1.14	2.40
Cultivars	1.18	1.17	105.68	1.12	2.25

SC: swelling capacity, HC: hydration capacity, CT: cooking time, HI: hydration index, SI: swelling index

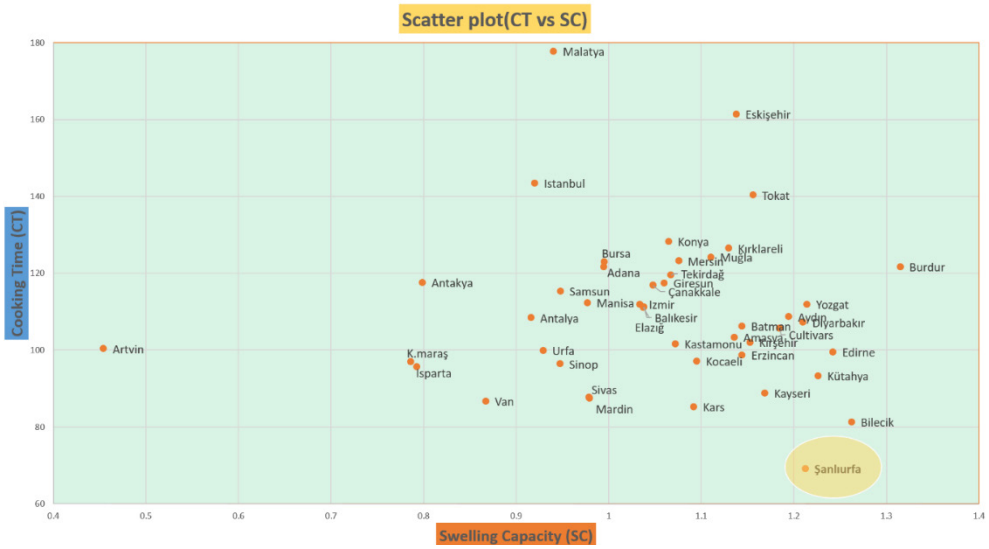

Figure 2. Scatter plot for cooking time and swelling capacity at province level.

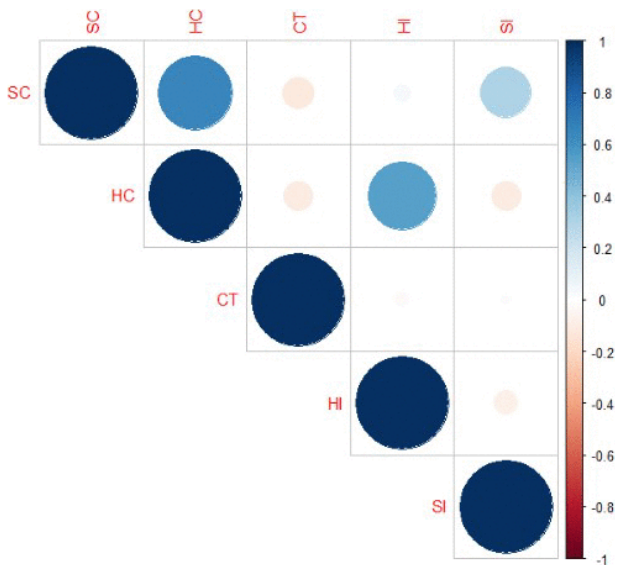

Figure 3. Correlation analysis for studied traits in faba bean germplasm.

preferences. Cooking time is one of the most important criteria used to determine the quality of seeds. It is very important to develop those varieties having less cooking time can be beneficial by saving time and energy to cook the seeds. Therefore, it is very important to develop cultivars with low cooking time. Keeping this in view, the present investigation was carried out to explore the cooking and quality traits of faba bean germplasm representing 45 provinces of Turkey. During this study, a total of five cooking traits (SC, SI, HC, HI, and CT) were studied and all studied traits reflected a good level of variation in faba bean germplasm. Mehla et al. (2001) stated that swelling capacity and hydration capacity are quality-determining traits. Swelling capacity ranged from 0.45–1.72 mL/seed with a mean of 1.05 mL/seed SC. The swelling index ranged from 1.30 to 5.356 with a mean of 2.24 SI. Balıkesir74 reflected maximum swelling capacity. The higher swelling capacity in any genotype is considered ideal in the preparation of soups, puddings, and sauces (Nciri et al., 2014). The hydration capacity indicates how much water the seed absorbs after soaking (Bewley et al., 2006). Hydration capacity depends on the chemical composition of the seed coat and cotyledons (Bewley et al., 2006). Genotypes with high hydration capacity have a shorter cooking time (Nadeem et al., 2020). Since the seeds of legumes are hard and dry, a lot of energy is spent during cooking their seeds. For this reason, the most important factor affecting the cooking quality of legumes is the cooking time (Wani et al., 2017). İzmir10 had better cooking properties due to its shorter cooking time than other cultivars. İzmir10 resulted in minimum cooking time and can be used as a candidate parent for faba bean breeding.

The mean values of all traits examined in this study were higher than in previous studies (Saharan et al., 2002; Sofi et al., 2013). In a study, it was determined that a water adsorption capacity of 1680.0 g/kg and swelling index values varied between 0.21 and 0.69 g/100 g (Sofi et al., 2013). In the study of Saharan et al. (2002), they found a hydration capacity of 0.13 g/seed, a hydration index of 0.53, a swelling capacity of 0.20 mL/seed, a swelling index of 0.61, and a cooking time of 108 min. During the present investigation, germplasm belongs to 45 provinces of Turkey. Therefore, it was important to understand

Table 4. Principal component analysis for faba bean germplasm.

	PC1	PC2	PC3	PC4	PC5
Swelling capacity (mL/seed)	0.77	0.49	0.07	–0.35	–0.19
Hydration capacity (g/seed)	0.94	–0.18	0.06	–0.17	0.23
Cooking time (min)	–0.23	–0.14	0.95	–0.16	0.00
Hydration index	0.60	–0.54	0.13	0.56	–0.13
Swelling index	0.10	0.82	0.22	0.52	0.08
Eigenvalue	**1.90**	**1.25**	**0.98**	**0.76**	**0.12**
Variability (%)	**37.93**	**25.08**	**19.56**	**15.11**	**2.31**
Cumulative %	**37.93**	**63.02**	**82.58**	**97.69**	**100.00**

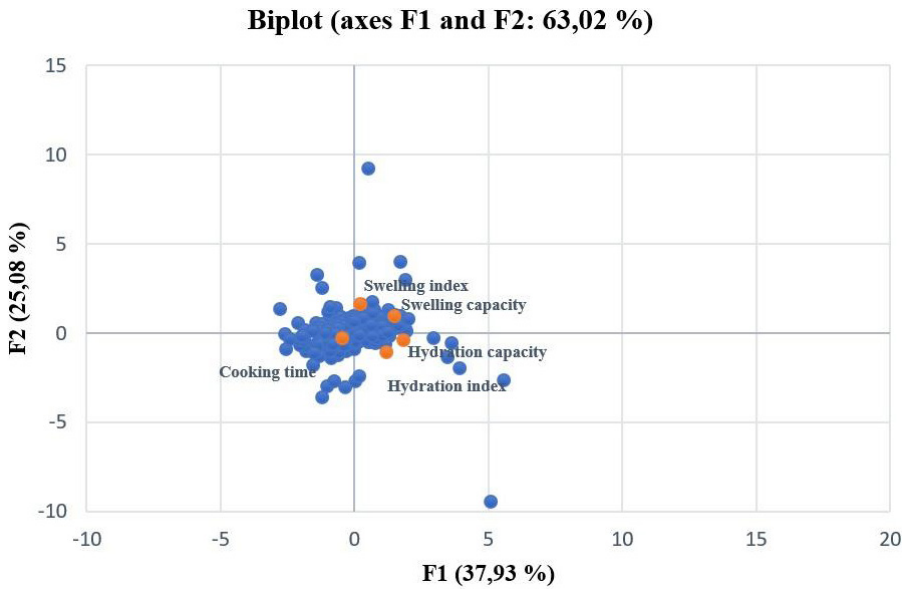

Figure 4. Biplot analysis for quality and cooking traits of faba bean germplasm.

the variation level at the province level. Landraces from Burdur reflected maximum SC and HC (Table 3). However, landraces belonging to Şanlıurfa reflected the minimum cooking time. A scatter plot was constructed between swelling capacity and cooking time, which revealed Şanlıurfa landraces as very fast cooking landraces (Figure 3). Similarly, landraces from Bilecik were also found very fast in the case of cooking. Keeping in view, landraces from both these provinces should be considered for future faba bean breeding regarding cooking and quality traits.

It was very important to investigate the effects of SC, SI, HC, and HI on cooking time and also to explore the association between studied traits. Pearson's correlation coefficient is the most trustable and widely used approach to explore the association among studied traits. If two traits show significant associations with each other, the selection of one trait will contribute to variations in the significantly associated trait through additive gene effects (Mudasir et al., 2012). Therefore, correlation analysis can be used for the determination of important traits that can be used as a selection criterion. Swelling capacity has significant positive correlations with swelling index and hydration capacity. Hydration capacity showed a highly significant and positive correlation with HI. Singh et al. (2004) reported a highly significant and positive correlation between SC, SI, HC, HI, and cooking time for Indian black gram varieties. These previous studies were found in line with our findings, as we also found a highly significant and positive correlation between SC and SI. Heatmap was developed that reflected a good level of variation in CT. Manisa16 and İzmir10 were found phenotypically distinct for cooking time. Therefore, these landraces can be used for the development of faba cultivars having low cooking time.

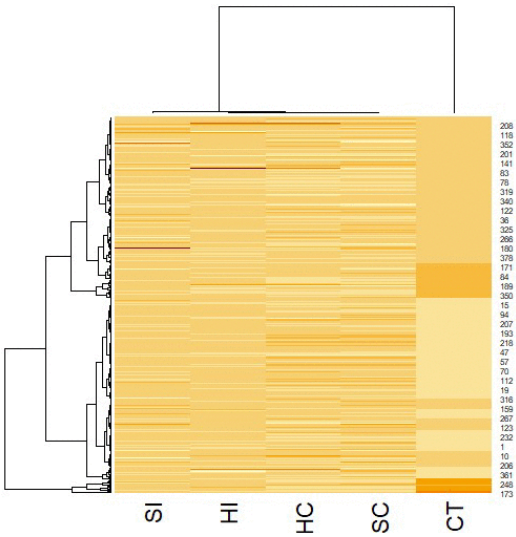

Figure 5. Heatmap for cooking traits in faba bean germplasm.

Principal component analysis was performed and the first two PCs accounted for a total of 63.02% variation (Table 2, Figure 1). Among the evaluated first three PCs, HC, SI, and CT were found key variations contributing traits respectively. These results can be confirmed through correlation analysis, as there was a significant and positive correlation between these traits. Therefore, these traits are suggested to be used as selection criteria for the investigation of superior faba bean genotypes for cooking and quality traits.

5. Conclusion

The present study provided deep insight into cooking and quality trait variations in faba bean germplasm. Manisa16 and İzmir10 were found distinct for cooking time and might be used as candidate parents for faba bean breeding. A highly significant and positive correlation was present between SC and SI, HC and HI. Landraces from Şanlıurfa and Bilecik reflected the minimum cooking time. Therefore, landraces from these provinces can be used for the faba bean breeding.

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Author contributions

Methodology, TK and MAN; software, MAN, validation, TK, MAN, and YÇ; formal analysis, MAN, investigation, YÇ, NG, and MAN, resources, TK, data curation, YÇ and MAN; writing—original draft preparation, YÇ and MAN; writing—review and editing, YÇ, MAN, NG, and TK.

Data availability

All data needed to conduct this study is provided within the manuscript.

Conflict of interest

The authors confirm that this article content has no conflicts of interest.

Ethical approval

All the authors read the study and showed their willingness to the publication of this study. This manuscript does not contain any research activity involving the animals or human participants performed by any of the authors.

Consent to participate and publish

All the authors have read the manuscript and showed their willingness to publish this study.

References

Abdel-Hameed SM, Latif SS (2019). Effect of soaking and cooking on nutritional and quality properties of faba bean. Journal of Food and Dairy Sciences 10 (10): 389-395. https://doi.org/10.21608/jfds.2019.62862

Alghamdi SS, Migdadi HM, Ammar MH, Paull JG, Siddique KHM (2012). Faba bean genomics: current status and future prospects. Euphytica 186 (3): 609-624. https://doi.org/10.1007/s10681-012-0658-4

Baloch FS, Alsaleh A, Shahid MQ, Çiftçi V, De Miera LE et al. (2017). Whole genome DArTseq and SNP analysis for genetic diversity assessment in wheat from central fertile crescent. PLoS ONE 12: e0167821. https://doi.org/10.1371/journal.pone.0167821

Bewley JD, Black M, Halme P (2006). The encyclopedia of seeds: science, technology and uses. CABI, Wallingford, UK, pp 81

Chavan JK, Kadam SS, Salunkhe DK (1986). Biochemistry and technology of chickpea (*Cicer arietinum* L.) seeds. Critical Reviews in Food Science and Nutrition 25: 107–158. https://doi.org/10.1080/10408398709527449

Cottage A, Gostkiewicz K, Thomas JE, Borrows R, Torres AM et al. (2012). Heterozygosity and diversity analysis using mapped single nucelotide polymorphisms in a faba bean inbreeding programme. Molecular Breeding 30 (4): 1799-1809. https://doi.org/10.1007/s11032-012-9745-4

Dita MA, Rispail N, Prats E, Rubiales D, Singh KB (2006). Biotechnology approaches to overcome biotic and abiotic stress constraints in legumes. Euphytica 147 (1): 1-24. https://doi.org/10.1007/s10681-006-6156-9

Elkoca E, Çınar T (2015). Adaptation of some dry bean (*Phaseolus vulgaris* L.) cultivars and lines to Erzurum ecological conditions, agricultural and quality characteristics. Anatolian Journal of Agricultural Sciences 30 (2): 141-153. https://doi.org/10.7161/anajas.2015.30.2.141-153

FAO (2021). FAO statistical yearbook. Available at http://www.fao.org/docrep/017/i3138e/i3138e. Accessed 29 June 2021

Federer WT (1956). Augmented (or hoonuiaku) designs. Hawaii Plant Rec. 55, 191–208

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D et al. (2010) Food security: the challenge of feeding 9 billion people. Science 327 (5967): 812-818. https://doi.org/10.1126/science.1185383

Jensen ES, Peoples MB, Hauggaard-Nielsen H (2010). Faba bean in cropping systems. Field Crops Research 115: 203–16

Khush GS, Lee S, Cho JI, Jeon JS (2012). Biofortification of crops for reducing malnutrition. Plant Biotechnology Reports 6: 195–202. https://doi.org/10.1007/s11816-012-0216-5

Köpke U, Nemecek T (2010). Ecological services of faba bean. Field Crop Research 115:217–33. https://doi.org/10.1016/j.fcr.2009.10.012

Mehla IS, Waldia RS, Dahiya SS (2001). Variation and relationship among cooking quality attributes across the environments in 'Kabuli' chickpea (*Cicer arietinum* L.). Journal of Food Science and Technology (Mysore) 38 (3): 283-286

Mudasir S, Sofi PA, Khan MN, Sofi NR, Dar ZA (2012). Genetic diversity, variability and character association in local common Bean (*Phaseolus vulgaris* L.) germplasm of Kashmir. Electronic Journal of Plant Breeding 3 (3): 883-891

Nadeem MA (2021). Deciphering the genetic diversity and population structure of Turkish bread wheat germplasm using iPBS-retrotransposons markers. Molecular Biology Reports 48 (10): 6739-6748. https://doi.org/10.1007/s11033-021-06670-w

Nadeem MA, Çilesiz Y, Ali F, Baloch FS, Karaköy T (2020). Investigation of quality and cooking traits diversity in a global common bean germplasm. Global Journal of Botanical Science 8, 21-29

Nadeem MA, Nawaz MA, Shahid MQ, Doğan Y, Comertpay G et al. (2018). DNA molecular markers in plant breeding: current status and recent advancements in genomic selection and genome editing. Biotechnology & Biotechnological Equipment 32 (2): 261-285. https://doi.org/10.1080/13102818.2017.1400401

Nadeem MA, Yeken MZ, Shahid MQ, Habyarimana E, Yılmaz H et al. (2021). Common bean as a potential crop for future food security: an overview of past, current and future contributions in genomics, transcriptomics, transgenics and proteomics. Biotechnology & Biotechnological Equipment 35 (1): 758-786. https://doi.org/10.1080/13102818.2021.1920462

Nadeem MA, Gündoğdu M, Ercişli S, Karaköy T, Saracoğlu O et al. (2020). Uncovering phenotypic diversity and dartseq marker loci associated with antioxidant activity in common bean. Genes 11: 36. https://doi.org/10.3390/genes11010036

Nciri N, El-Mhamdi F, Ismail HB, Mansour AB, Fennira F (2014). Physical properties of three white bean varieties (*Phaseolus vulgaris* L.) grown in Tunisia. Journal of Applied Science and Agriculture 9: 195-200

Nemecek T, Von Richthofen JS, Dubois G, Casta P, Charles R et al. (2008). Environmental impacts of introducing grain legumes into European crop rotations. European Journal of Agronomy 28: 380–93. https://doi.org/10.1016/j.eja.2007.11.004

Peksen E (2007). Non-destructive leaf area estimation model for faba bean (*Vicia faba* L.). Scientia Horticulturae 113 (4): 322-328. https://doi.org/10.1016/j.scienta.2007.04.003

Pour-Aboughadareh A, Yousefian M, Moradkhani H, Poczai P, Siddique KH (2019). STABILITYSOFT: A new online program to calculate parametric and non-parametric stability statistics for crop traits. Applications in Plant Sciences 7 (1): e01211. https://doi.org/10.1002/aps3.1211

Rathore A, Parsad R, Gupta VK (2004). Computer aided construction and analysis of augmented designs. Journal of the Indian Society of Agricultural Statistics. Stat 57: 320–344

Rehman Z, Salariya AM, Zafar SI (2001). Effect of processing on available carbohydrate content and starch digestibility of kidney beans (*Phaseolus vulgaris* L.). Food Chemistry 73: 351-355. https://doi.org/10.1016/S0308-8146(00)00311-3

Saharan K, Khetarpaul N, Bishnoi S (2002). Variability in physico-chemical properties and nutrient composition of newly released ricebean and fababean cultivars. Journal of Food Composition and Analysis 15 (2): 159-167. https://doi.org/10.1016/0308-8146(93)90179-J

Santos CS, Carbas B, Castanho A, Bronze MR, Serrano C, Vasconcelos MW et al. (2018). Relationship between seed traits and pasting and cooking behaviour in a pulse germplasm collection. Crop and Pasture Science 69 (9): 892-903. https://doi.org/10.1071/CP18205

Shimira F, Boyaci HF, Çilesiz Y, Nadeem MA, Baloch FS et al. (2021). Exploring the genetic diversity and population structure of scarlet eggplant germplasm from Rwanda through iPBS-retrotransposon markers. Molecular Biology Reports 48 (9): 6323-6333. https://doi.org/10.1007/s11033-021-06626-0

Singh AK, Bharati RC, Manibhushan NC, Pedpati A (2013). An assessment of faba bean (*Vicia faba* L.) current status and future prospect. African Journal of Agricultural Research 8 (50): 6634-6641

Singh N, Sandhu KS, Kaur M (2004). Characterization of starches separated from Indian chickpea (*Cicer arietinum* L.) cultivars. Journal of Food Engineering 63 (4): 441-449. https://doi.org/10.1016/j.jfoodeng.2003.09.003

Sofi BA, Wani IA, Masoodi FA, Saba I, Muzaffar S (2013). Effect of gamma irradiation on physicochemical properties of broad bean (*Vicia faba* L.) starch. LWT-Food Science and Technology 54 (1): 63-72. https://doi.org/10.1016/j.lwt.2013.05.021

Stagnari F, Maggio A, Galieni A, Pisante M (2017). Multiple benefits of legumes for agriculture sustainability: an overview. Chemical and Biological Technologies in Agriculture Dec 4 (1): 1-3. https://doi.org/10.1186/s40538-016-0085-1

Suso MJ, Pierre J, Moreno MT, Esnault R, Le Guen J (2001). Variation in outcrossing levels in faba bean cultivars: role of ecological factors. The Journal of Agricultural Science 136 (4): 399-405

Tekalign E, Bajiro M, Ayana M, Tiruneh A, Belay T (2019). Prevalence and intensity of soil-transmitted helminth infection among rural community of southwest Ethiopia: a community-based study. BioMed Research İnternational https://doi.org/10.1155/2019/3687873.

Tharanathan RN, Mahadevamma S (2003). Grain legumesa boon to human nutrition. Trends in Food Science and Technology 14: 507–518. https://doi.org/10.1016/j.tifs.2003.07.002

Tilman D, Balzer C, Hill J, Befort BL (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences USA 108: 20260–20264. https://doi.org/10.1073/pnas.1116437108

Ton A, Anlarsal AE (2016). Determining correlation analysis and agro-morphological traits of some chickpea (*Cicer arietinum* L.) genotypes in Mediterranean climate conditions. Journal of the Faculty of Agriculture, Uludağ University 30 (Special Issue): 383-391.

Topçu AA, Topçu A (2001). The effect of different preparation and cooking methods on thiamine loss in cereals and legumes. Journal of Nutrition and Diet 30 (2): 55-61.

TÜİK (2014). Turkish statistical institute. http:/www.tuik.gov.tr

Urbano G, López-Jurado M, Aranda P, VidalValverde C, Tenorio E et al. (2000). The role of phytic acid in legumes: antinutrient or beneficial function. Journal Physiology and Biochemistry 56 (3): 283-294.

Vadivel V, Pugalenthi M (2009). Effect of soaking in sodium bicarbonate solution followed by autoclaving on the nutritional and antinutritional properties of velvet bean seeds. Journal of Food Processing and Preservation 33: 60-73. https://doi.org/10.1111/j.1745-4549.2008.00237.x

Vered Y, Grosskopf I, Palevitch D, Harsat A, Charach G et al. (1997). The influence of *Vicia faba* (broad bean) seedlings on urinary sodium excretion. Planta Medica 63 (03): 237-240. https://doi.org/10.1055/s-2006-957661

Vidal-Valverde C, Frias J, Sotomayor C, Diaz-Pollan C, Fernandez M et al. (1998). Nutrients and antinutritional factors in faba beans as affected by processing. Z Lebensm Unters Forsch A, 207: 140-145.

Wani IA, Sogi DS, Wani AA, Gill BS (2017). Physical and cooking characteristics of some Indian kidney bean (*Phaseolus vulgaris* L.) cultivars. Journal of the Saudi Society of Agricultural Sciences 16 (1): 7-15. https://doi.org/10.1016/j.jssas.2014.12.002

Zohary D, Hopf M, Weiss E (2012). Domestication of Plants in the Old World: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin Oxford University Press on Demand https://doi.org/10.1093/acprof:osobl/9780199549061.001.0001.

Zong X, Liu X, Guan J, Wang S, Liu Q et al. (2009). Molecular variation among Chinese and global winter faba bean germplasm. Theoretical and Applied genetics 118 (5): 971-978. https://doi.org/10.1007/s00122-008-0954-5