Turkish Journal of Agriculture and Forestry

Volume 47 | Number 4 Article 14

8-28-2023

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Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2023) 47: 590-601
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doi:10.55730/1300-011X.3111

Multivariate analysis for agromorphological and cooking properties in chickpea (*Cicer arietinum L.*) germplasm

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Received: 11.01.2023 • **Accepted/Published Online:** 08.06.2023 • **Final Version:** 28.08.2023

Abstract: The objective of the study is to reveal diversity among some chickpea germplasms and selection criteria for agromorphological and cooking properties using multivariate techniques for improving new cultivars. The experiment was arranged in augmented block design with 65 chickpea germplasms and 2 check cultivars during 2020/2021 and 2021/2022. Positive correlations of seed yield per plant were found with primer branches per plant, biological yield per plant, harvest index, pods per plant, and seeds per plant. The first four principal components (PCs) accounted for 88.8% of total existing variation for agromorphological traits. Seed dry weight showed positive and significant association with wet seed weight, hydration capacity, and swelling capacity. The first two principal components (PC_s) explained 83.64% of the total variation observed among the genotypes for cooking properties. Hierarchical cluster analysis revealed that there were wide variability among the studied chickpea germplasms for contributing yield components and cooking properties. This variation among the chickpea germplasms can be used to improve new cultivars.

Key words: Chickpea, cooking quality, correlation, morphological traits, multivariate analysis

1. Introduction

Chickpea (*Cicer arietinum* L.) is one of the major pulses used by canning, boiling, or roasting in human diet. It has high amount of protein, mineral, dietary fiber, carbohydrate, and vitamins. Chickpea, as in other legumes, can fix air nitrogen through rhizobia to the soil and it also contributes to the increase of soil fertility. (Jensen ES, Hauggaard-Nielsen H (2003). Its cultivation is widespread in the world and it is the second most important grain legume crops after dry bean for planting area in the worldwide. Chickpea plays an important role in cultivation of arid and semiarid regions and is also successfully grown in winter in crop rotation with cotton and maize in temperate climate conditions. However, Ascochyta blight is a serious problem for winter-sowing chickpea production because of warm and rainy climate conditions, and the disease causes excessive yield loss. In Mediterranean climate conditions, chickpea is grown traditionally in spring and yield is limited due to low rainfall in this stage, but grain yield can be increased greatly if cultivars tolerant to Ascochyta blight are grown as a winter season crop (Toker and Çağıran, 1998; Yucel and Anlarsal, 2008; Ton and Anlarsal, 2016). Therefore, winter chickpea cultivars with high yield capacity and that are appropriate for regional conditions should be improved. Therefore, it is important to select from starting material to develop new chickpea cultivars (Vus et al., 2020). It is a basic prerequisite to exhibiting genetic variation of agromorpohologic and cooking properties to improve for new variety (Munıraja et al., 2011). Magnitude of genetic diversity in the various traits of studied genotypes is needed for successful breeding programs. Genetic diversity among the chickpea genotypes can be explained by cluster analysis and principal component analysis (PCA) and these analyses are called multivariate statistical techniques.

These methods exhibit disparities and similarities among the genotypes for characters and some promising lines for specific features (Vural and Karasu, 2007; Malik et al., 2014; Manivannan et al., 2016; Parveen et al., 2020). Many studies on determining diversity of agromorphological and cooking properties were carried out in chickpea genotypes (Cinsoy et al., 1997; Kaur et al., 2005; Syed et al; 2012; Johnson et al., 2015; Sharifi et al., 2018; Shivwansi and Babbar, 2017; Sofi et al., 2018; Cin and Topal, 2021; Kumar et al., 2021; Sayılğan and Kara, 2022).

The objective of the study is to evaluate the diversity among some chickpea germplasms and selection criteria for agromorphological and cooking traits using multivariate techniques to improve new cultivars with high yielding capacity in the temperate climate conditions.

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2. Materials and methods

2.1. Experimental conditions

This study was conducted in the research area of Field Crops Department of Agricultural Faculty, Çukurova University for a 2-year period during the 2020/2021 and 2021/2022 growing seasons under rainfed conditions in Adana. The annual total precipitation of location was 625 mm and the mean temperature 18.7 °C according to long-term meteorological data. The texture of research soil was silty clayey loam. The values of pH, salt content, organic matter content and lime content were 7.25 and 0.25 mmhos cm^{-1}, 1.19%, 36.8%, respectively.

2.2. Plant material

In the present study, 65 chickpea germplasms provided by gene bank of ICARDA (International Center for Agricultural Research in the Dry Area) and Hasanbey and Seçkin (check cultivars) were used as plant material. The list of chickpea genotypes is exhibited in Table 1.

The experiment was arranged in augmented block design with two standard check cultivars. The experiment had 5 blocks and each block had 2 check cultivars (Seçkin, Hasanbey) and 13 germplasms. Each plot was sown in 2 rows of 4-m length with an interrow spacing of 45 cm and intrarow spacing of 7 cm. Fertilization was applied at a rate of 30 kg N ha^{-1} and 76 kg P_2O_5 ha^{-1} before sowing (18–46). The experiment was established on 20 November 2020 and on 24 November 2021. Field emergences were recorded on 3 December 2020 and on 6 December 2021. The plots were harvested on 10 June 2021 and on 21 June 2022.

Individual five plants were randomly selected from each plot. Plant height (cm) was measured from ground level to the tip of main stem. Primer branches from main stem were recorded. Number of seeds, number of pods per plant, the first podding height (cm), biological yield (g $plant^{-1}$), seed yield per plant (g), and harvest index per plant (%) were estimated from the same five plants. The 100 seed weight (g) was recorded from randomly selected samples of 100 grains from each plot. Seed volume (mL $seed^{-1}$), hydration capacity (g $seed^{-1}$), swelling capacity (mL $seed^{-1}$), and cooking time (min) were found by the methods used by other workers (Williams et al., 1986; Gülümser et al., 2008; Karaman, 2019; Özaktan, 2021).

Table 1. List of chickpea genotypes.

No	Genotypes	No	Genotypes	No	Genotypes
1	FLIP14-61C	24	FLIP14-36C	47	FLIP13-243C
2	FLIP14-35C	25	FLIP14-02C	48	FLIP13-352C
3	FLIP14-06C	26	FLIP14-11C	49	FLIP13-113C
4	FLIP14-34C	27	FLIP14-60C	50	FLIP13-353C
5	FLIP14-94C	28	FLIP14-28C	51	FLIP13-187C
6	FLIP14-10C	29	FLIP14-88C	52	FLIP13-233C
7	FLIP14-72C	30	FLIP14-16C	53	FLIP13-199C
8	FLIP14-85C	31	FLIP88-85C	54	FLIP13-238C
9	FLIP14-40C	32	FLIP14-124C	55	FLIP13-236C
10	FLIP14-13C	33	FLIP13-278C	56	FLIP13-368C
11	FLIP14-08C	34	FLIP93-93C	57	FLIP13-02C
12	FLIP14-65C	35	FLIP13-330C	58	FLIP13-316C
13	FLIP14-81C	36	FLIP13-227C	59	FLIP13-372C
14	FLIP14-74C	37	FLIP13-250C	60	FLIP13-158C
15	FLIP14-70C	38	FLIP13-308C	61	FLIP13-328C
16	FLIP14-83C	39	FLIP13-154C	62	FLIP13-361C
17	FLIP14-04C	40	FLIP13-369C	63	FLIP13-319C
18	FLIP14-03C	41	FLIP13-70C	64	FLIP13-318C
19	FLIP14-12C	42	FLIP13-277C	65	FLIP13-38C
20	FLIP14-63C	43	FLIP13-261C	66	Hasanbey
21	FLIP14-62C	44	FLIP13-13C	67	Seçkin
22	FLIP14-25C	45	FLIP13-149C		
23	FLIP14-59C	46	FLIP13-191C		

Swelling capacity is the increase in volume of a seed after 16 h of soaking. The seeds placed in boiling water were checked after 40 min and the cooking time was recorded. Hydration capacity and swelling capacity was calculated using the following equations (Williams et al., 1986).

Hydration capacity (g seed^{-1}) =(B-(A-(A/100)*N2)/(N1-N2)

B: Wet weight
A: Dry weight
N1: Original number of seeds
N2: Number of unhydrated seeds

Swelling capacity (mL/seed) = (B1-B2)-(A1-A2)-(A1-A2)/N1)*N2)/(N1-N2)

B1: Volume of water + hydrated seeds
B2: Volume of water added to hydrated seeds
A1: Volume of water + dry seeds
A2: Volume of water added to dry seeds
N1: Original number of seeds
N2: Number of unhydrated seeds

2.3. Statistical methods

Statistical analysis was performed over 2 years according to augmented block design. Data obtained from both years were also evaluated to calculate basic statistical parameters such as mean, minimum and maximum values, standard deviation, coefficient variation, correlation coefficients, principal component analysis, cluster analysis, and biplot graphing using JMP (pro 16).

3. Results and discussion

3.1. Basic statistical parameters

Basic statistical parameters according to mean values of 2 years for agromorphological and cooking properties of 67 chickpea genotypes are given in Tables 2 and 3. As shown in Table 2, great variation was observed in pods per plant (21.9–59.1), seeds per plant (29.1–70.4), seed yield per plant (12.2–24.6 g), and biological yield per plant (27.8–54.2 g). Wide ranges in the mentioned traits may be used for improving cultivar in breeding programs of chickpea. Similar to the present study, previous studies also revealed wide variability for the same traits in chickpea (Farshadfar and Farshadfar, 2008; Syed et al., 2012; Parveen et al., 2020). However, in the present study, lower variability was found for days to flowering (107.0–119.0), plant height (56.0–76.2 cm), first podding height (26.6–44.0 cm), primer branches per plant (2.7–5.2), harvest index (40.9%–51.8%), and 100-seed weight (32.3–50.7 g). In contrast to

Table 2. Basic statistical parameters for some agromorphological characters in chickpea genotypes.

Traits	Min	Max	Mean	SD	CV (%)
Days to %50 flowering	107	119	113	4.41	3.91
Plant height (cm)	56.0	76.2	64.2	3.94	6.14
First podding height (cm)	26.6	44.0	33.5	3.95	11.8
Branches per plant	2.7	5.2	3.6	0.66	18.3
Biologic yield per plant	27.8	54.2	37.1	9.5	25.8
Harvest index (%)	40.9	51.8	46.1	3.9	8.63
Pods per plant	21.9	59.1	37.4	9.7	25.9
Seeds per plant	29.1	70.4	43.2	12.2	28.3
Seeds yield per plant (g)	12.2	24.6	16.9	4.83	28.5
100-seed weight (g)	32.3	50.7	40.6	2.02	4.97

Table 3. Basic statistical parameters for cooking properties in chickpea genotypes.

Properties	Min	Max	Mean	SD	CV (%)
Dry weight (g)	33.7	49.4	41.3	3.23	7.82
Wet weight(g)	67.8	98.7	82.4	6.26	7.60
Hydration capacity (g seed^{-1})	0.334	0.498	0.410	0.032	7.78
Hydration index (%)	0.897	1.077	0.996	0.041	4.16
Swelling capacity (mL seed^{-1})	0.323	0.493	0.411	0.034	8.24
Swelling index (%)	2.11	2.63	2.31	0.09	4.09
Cooking time (min)	47.5	63.5	56.1	4.06	7.23

our finding, Farshadfar and Farshadfar (2008) found high variation for branch numbers. Malik et al. (2014) declared great variation for pods per plant, biological yield per plant, days to 50% flowering and harvest index but low variability for primer and secondary branches and seeds per pod in chickpea.

As presented in Table 3, wide ranges were observed for dry seed weight (33.7–49.4 g), wet seed weight (67.8–98.7 g), hydration capacity (0.334–0.498 g seed^{-1}), swelling capacity (0.323–0.493 mL seed^{-1}), and cooking time (47.5–63.5 min.). Great variability for the mentioned traits may be utilized for improving cooking properties in chickpea breeding. Similar to the present study, several studies explained the great differences among chickpea genotypes for similar cooking parameters (Kaya et al., 2016; Cin and Topal 2021; Özaktan, 2021). Hydration capacity was similar with the values indicated by Yalçın et al. (2018) (0.38–0.51 g seed^{-1}). However, in the present study, narrow variation was observed for hydration index (0.897%–1.077%), swelling index (2.11%–2.63%). Similarly to our study, Özaktan (2021) reported that differences among the genotypes were nonsignificant for hydration index.

3.2. Correlation analysis

The correlation coefficients among the seed yield and yield components are exhibited in Table 4. Positive correlations of seed yield per plant were observed with primer branches per plant, (0.375**), biological yield per plant (0.947**), harvest index (0.379**), pods per plant (0.871**), and seeds per plant (0.892**). Therefore, the results of the present study suggest that seed yield per plant can be developed throughout the selection of the mentioned agromorphological characters in chickpea germplasm. Similarly to our findings, significant and positive associations between seed yield per plant and abovementioned characters have been exhibited in earlier studies in chickpea (Malik et al., 2014; Johnson et al., 2015; Janghel et al., 2020). In the present study, correlations between seed yield per plant and plant height, first pod height, days to flowering, and 100-seed weight were nonsignificant. Similar relations were also reported by Malik et al. (2014).

The correlation coefficients among the cooking properties are presented in Table 5. As shown in Table 5, seed dry weight showed positive and significant association

Table 4. Correlation coefficients among agromorphological traits of chickpea genotypes.

Traits	1	2	3	4	5	6	7	8	9	10
1.DF	1.000	–0.096	–0.063	0.318**	0.127	0.053	0.089	0.140	–0.003	0.117
2.PH		1.000	0.758**	–0.215	0.140	–0.140	0.041	–0.046	0.396**	0.154
3.FPH			1.000	–0.331**	–0.137	–0.290*	–0.245*	–0.316**	0.435**	–0.154
4.BPP				1.000	0.458**	–0.139	0.410**	0.420**	–0.302*	0.375**
5.BYPP					1.000	0.109	0.900**	0.908**	–0.373**	0.947**
6.HI						1.000	0.193	0.255*	0.219	0.379**
7.PPP							1.000	0.944**	–0.532**	0.871**
8.SPP								1.000	–0.591**	0.892**
9.100 SW									1.000	–0.221
10.SYPP										1.000

DF: Days to %50 flowering; PH: Plant height; FPH: First podding height; BPP: Branches per plant; BYPP: Biological yield per plant, HI: Harvest index; PPP: Pods per plant; SPP: Seeds per plant; 100SW: 100 seed weight; SYPP: Seed yield per plant

Table 5. Correlation coefficients among cooking properties of chickpea genotypes.

Properties	1	2	3	4	5	6	7
1. Dry weight (g)	1.000	0.983**	0.939**	0.044	0.929**	–0.090	–0.076
2 Wet weight (g)		1.000	0.986**	0.162	0.957**	0.000	–0.043
3.Hydration capacity (g seed–1)			1.000	0.266*	0.955**	0.083	–0.012
4.Hydration index (%)				1.000	0.407**	0.884**	0.070
5. Swelling capacity (ml seed–1)					1.000	0.238	–0.044
6. Swelling index (%)						1.000	0.041
7.Cooking time (min)							1.000

with wet seed weight, (0.983**), hydration capacity (0.939**), and swelling capacity (0.929**). Correlations between cooking time and any of the properties studied were nonsignificant. Hydration capacity was positively and significantly correlated with hydration index (0.266*) and swelling capacity (0.955**). These results support findings of earlier studies where seed dry weight was positively correlated with hydration capacity and swelling capacity, but cooking time did not associate with any of these properties (Tripathi et al., 2012; Özaktan, 2021). In contrast to the present study, significant positive correlation of cooking time with hydration capacity and swelling capacity was reported by Williams et al. (1983). Kaur et al. (2005) explained that cultivars with higher seed weight had higher swelling capacity, hydration capacity, and cooking time. Similar to our findings, Santos et al. (2018) declared that there was no correlation between cooking time and hydration capacity. Cooking time can be affected by environment conditions and seed size (Bhatty, 1984; Karasu, 1993). Cooking parameters such as swelling capacity, seed volume, and cooking time are important properties for consumers, and water absorbing capacity is associated with cell wall structure (Tripathi et al., 2012). Hydration capacity, dry weight, and swelling capacity may be considered for short cooking time in chickpea breeding.

3.3. Principal component analysis

Principal component analysis (PCA) for yield and yield components of 65 chickpea germplasms and 2 check cultivars is exhibited in Table 6 and Figure 1. The first four principal components (PCs) accounted for 88.8% of the total existing variation and these components with Eigen values of >1 (PC1, PC2, PC3, P4) contributed 44.2%, 20.1%, 13.3%, and 11.2% to total diversity. PCA analysis revealed that chickpea genotypes have a great variation for studied agromorphological characters. The results were in accordance with the findings by Sharifi et al. (2018), Parveen et al. (2020), and Janghel et al. (2020).Weight values of PCA for traits that are over $\pm$0.3 are considered to be significant (Brown,1991). In the present study, the PC1 was positively associated with biological yield per plant, pods per plant, seeds per plant, and seed yield per plant, and the PC2 was positively correlated with 100 seed weight, plant height, and first pod height. The PC3 was also positively related to harvest index and 100 seed weight and negatively associated with branches per plant and the PC4 was positively correlated with branches per plant and 100-seed weight. Traits are positively correlated if the angle between vectors is less than 90°, negatively correlated if the angle is more than 90° (Yan and Rajcan, 2002; Parihar et al., 2014). The biplot graph also exhibited

Table 6. Principle component values for agromorphological traits chickpea genotypes.

Variables	Eigenvectors									
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
DF	0.094	–0.074	–0.073	0.834	–0.519	–0.077	–0.086	0.009	–0.036	–0.018
PH	–0.064	0.654	–0.112	0.014	0.008	0.260	–0.687	–0.119	–0.026	0.026
FPH	–0.198	0.563	–0.215	0.053	–0.159	0.295	0.694	0.034	–0.007	0.003
BPP	0.268	–0.165	–0.331	0.391	0.673	0.427	0.052	–0.011	0.000	0.012
BYPP	0.437	0.220	–0.058	–0.010	0.075	–0.384	0.116	–0.262	–0.341	0.637
HI	0.113	–0.010	0.811	0.090	–0.030	0.503	0.065	–0.070	–0.162	0.181
PPP	0.449	0.126	–0.018	–0.117	–0.094	0.039	–0.052	0.856	–0.145	–0.037
SPP	0.463	0.067	0.022	–0.092	–0.158	0.075	0.038	–0.135	0.842	0.112
100 SW	–0.274	0.305	0.364	0.343	0.447	–0.446	0.042	0.282	0.311	0.075
SYPP	0.425	0.247	0.181	0.027	0.108	–0.225	0.111	–0.283	–0.168	–0.736
Eigenvalue	4.42	2.01	1.33	1.12	0.59	0.24	0.18	0.08	0.02	0.01
Cumulative Eigenvalue	4.42	6.43	7.76	8.88	9.47	9.71	9.89	9.97	9.99	10.0
Proportion of variance %	44.2	20.1	13.3	11.2	5.91	2.37	1.85	0.77	0.22	0.11
Cumulative variance %	44.2	64.3	77.6	88.8	94.7	97.1	98.9	99.7	99.9	100

DF: Days to %50 flowering; PH: Plant height; FPH: First podding height; BPP: Branches per plant; BY: Biological yield per plant, HI: Harvest index; PPP: Pods per plant; SPP: Seeds per plant; 100SW: 100-seed weight; SYPP: Seed yield per plant.

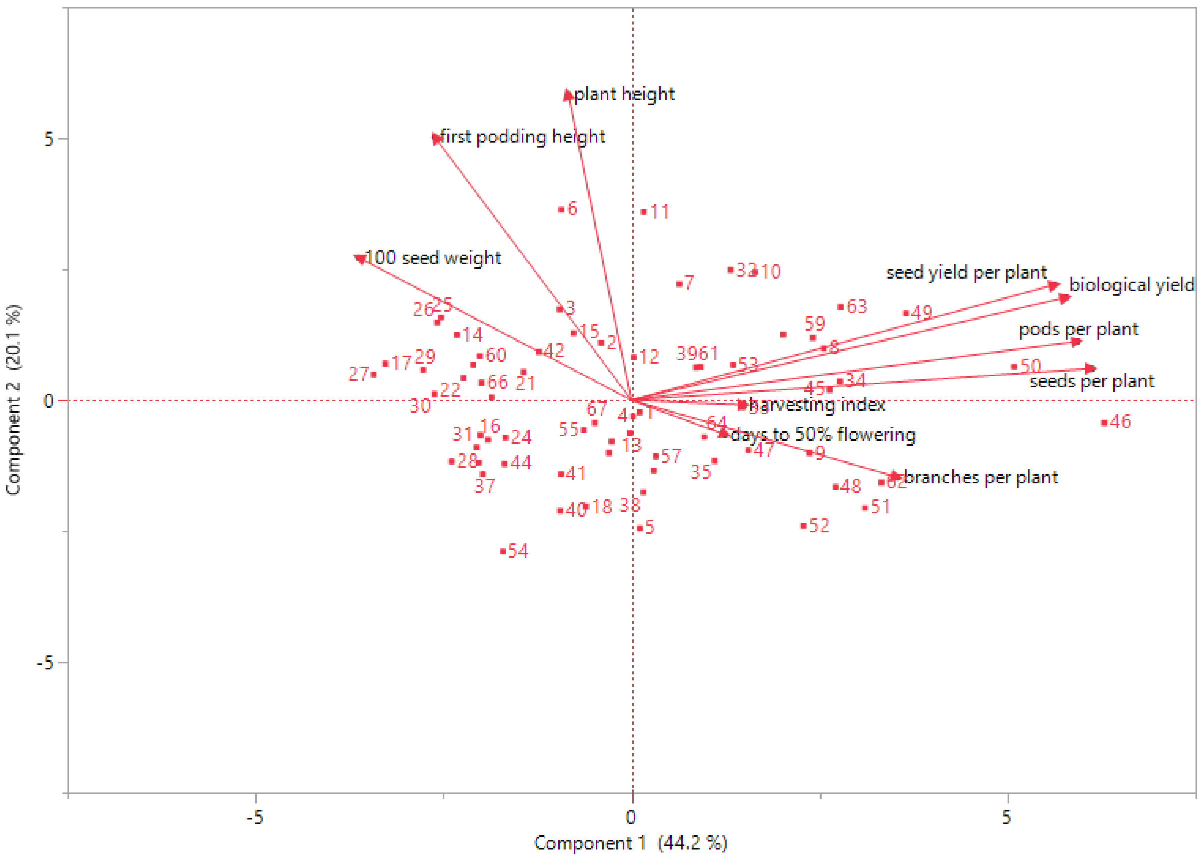

Figure 1. Biplot between PC1 and PC2 for agromorphological traits of chickpea genotypes.

that there were positive correlations among most of the agromorphological traits in PC1 and PC2 (Figure 1). The present study revealed that these traits in PC1, PC2, PC3, and PC4 can be considered for the improvement of new chickpea cultivars. Similarly to our findings, principle component analysis revealed that most of the mentioned traits greatly contributed to total variability in chickpea (Jha et al., 2015; Arora et al., 2018; Jain et al., 2021; Kumar et al., 2021). The present results support findings of Shivwanshi and Barbar (2017) that PC1 was positively correlated with pods per plant, seeds per plant, and biological yield per plant.

PCA for the cooking properties of 65 chickpea germplasms and 2 standard cultivars is demonstrated in Table 7 and Figure 2. The first two principal components (PC_s) explained 83.64% of the total variation observed among the genotypes. PC1 accounted for 56.65% and was positively related with dry seed weight, wet seed weight, hydration capacity, and swelling capacity. PC2 accounted for 27.00% of cumulative variance and was positively related to hydration index and swelling index. This variation for the mentioned cooking properties in the first two components can be utilized to improve chickpea cultivar with short cooking time. Similar to the present study, Sastry et al. (2019) indicated that the first three PCs accounted for 81.05% of total variation, and seed weight, hydration capacity, seed swelling capacity in PC1 and seed swelling index in PC2 contributed to variation in chickpea. Singh et al. (2010) also reported that principal component analysis revealed significant differences among the cultivars studied for cooking properties. Sofi et al. (2018) also reported that the first and the second principal component accounted for 98.74% of the variability for cooking properties in chickpea. In another study, PCA exhibited that PC1 and PC2 explained 49.3% and 25.79% of total variability for cooking properties respectively, and PC1 related to wet weight and water absorption while PC2 correlated with swelling capacity and swelling index (Özaktan, 2021). Also, the biplot graph exhibited that there were positive correlations among most of the cooking properties in PC1and PC2 (Figure 2).

3.4. Cluster analysis

Hierarchical cluster analysis and the mean values of agromorphological traits for each cluster are demonstrated in Table 8 and Figure 3. Cluster analysis revealed that 67 chickpea genotypes were grouped into 7 main clusters for

Table 7. Principal component values for cooking properties of chickpea genotypes.

Properties	PC1	PC2	PC3	PC4	PC5	PC6
Dry weight	0.476	–0.212	0.010	0.269	0.412	0.574
Wet weight	0.493	–0.136	0.031	0.037	–0.179	0.212
Hydration capacity	0.493	–0.062	0.049	–0.179	–0.720	–0.128
Hydration index	0.173	0.663	–0.046	–0.647	0.168	0.286
Swelling capacity	0.498	0.048	–0.008	–0.016	0.470	–0.726
Swelling index	0.091	0.692	–0.095	0.689	–0.172	–0.017
Cooking time	–0.023	0.107	0.993	0.041	0.032	0.000
Eigenvalue	3.965	1.890	0.991	0.111	0.042	0.002
Cumulative Eigenvalue	3.965	5.855	6.846	6.956	6.998	7.000
Proportion of variance %	56.65	27.00	14.15	1.58	0.60	0.02
Cumulative variance %	56.65	83.64	97.79	99.37	99.98	100.0

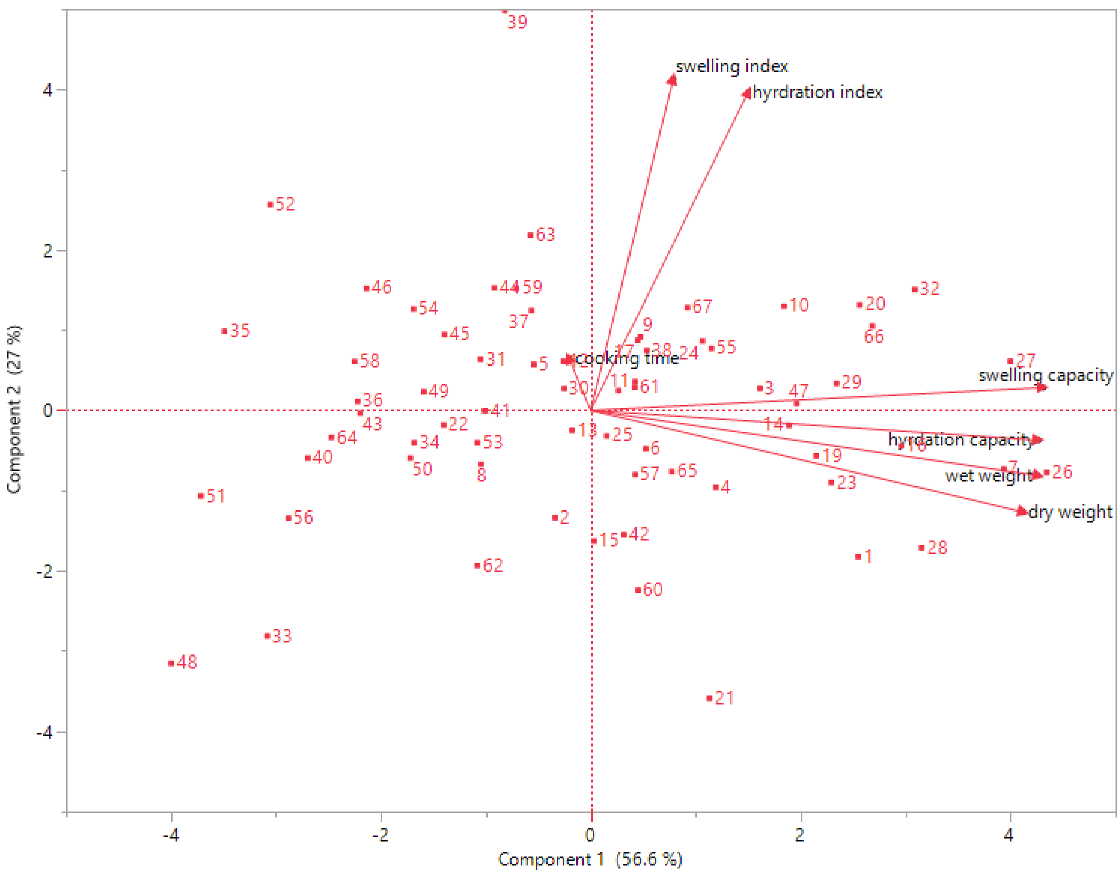

Figure 2. Biplot between PC1 and PC2 for cooking properties of chickpea genotypes.

the investigated traits. Cluster 1 included 7 germplasms and was observed to have the highest values for harvest index with 49.1%, and medium value for 100-seed weight with 41.0 g and seed yield per plant with 17.2 g. Cluster 2 consisted of 11 germplasms and 1 check cultivar (Seçkin) and showed medium values for branches per plant with 3.7, minimum value of harvest index with 44.8%, and seed yield per plant with 14.2 g. Cluster 3 contained 9 germplasms and had earliest days to %50 flowering (110), medium 100-seed weight with 42.31 and first podding

Table 8. Mean of clusters for agromorphological traits of chickpea genotypes.

Cluster	Count	DF	PH	FPH	BPP	BYPP	HI	PPP	SPP	100SW	SYPP
1	7	112	61.0	30.1	3.4	35.8	49.1	37.0	44.5	41.00	17.2
2	12	112	61.0	32.1	3.7	32.4	44.8	32.5	38.3	38.41	14.2
3	9	110	67.9	35.9	3.0	33.2	45.9	33.7	38.2	42.31	15.2
4	12	113	64.4	35.3	3.6	31.9	45.9	29.3	32.7	45.42	14.8
5	7	113	70.8	37.6	3.7	43.5	46.9	44.4	50.1	42.07	20.3
6	12	112	64.8	33.5	3.7	43.2	45.4	45.6	52.1	37.59	19.3
7	8	115	60.6	28.7	4.3	44.9	47.5	48.3	57.1	36.24	20.5

DF: Days to %50 flowering; PH: Plant height; FPH: First podding height; BPP: Branches per plant; BY: Biological yield per plant, HI: Harvest index; PPP: Pods per plant; SPP: Seeds per plant; 100SW: 100-seed weight; SYPP: Seed yield per plant.

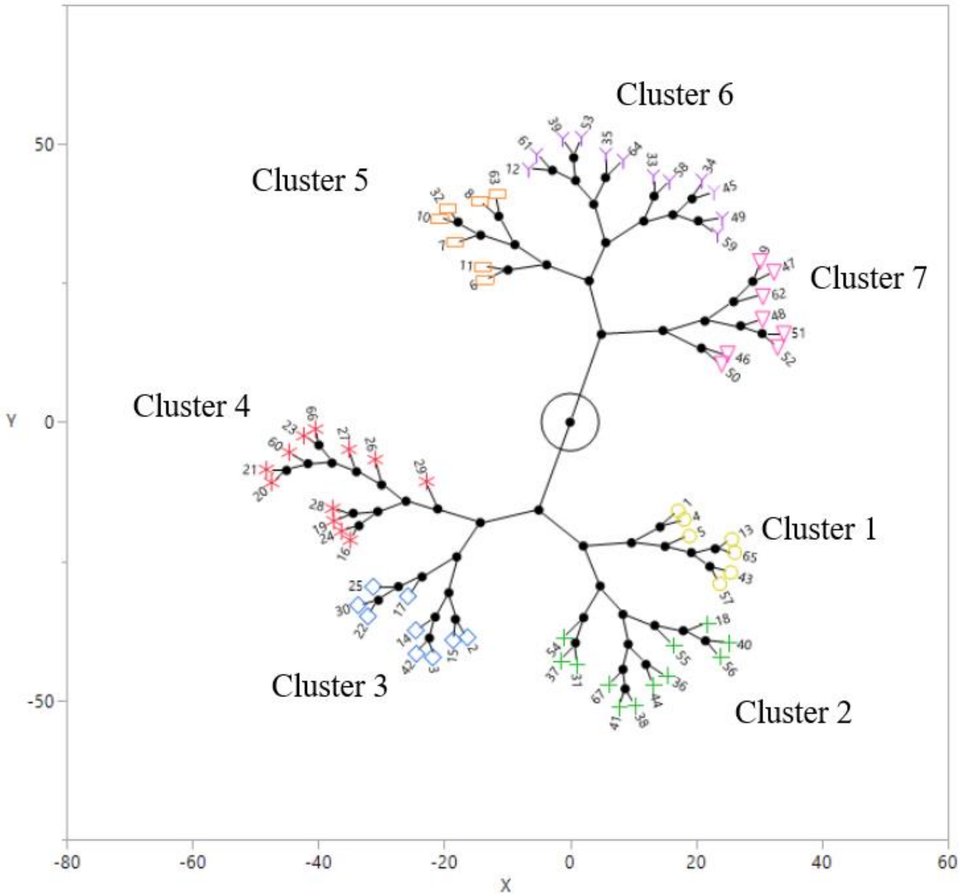

Figure 3. Hierarchical clustering analysis for agromorphological traits of chickpea.

height with 35.9, minimum value for branches per plant with 3.0. Cluster 4 included 11 germplasms and 1 control cultivar (Hasanbey) and was characterized by maximum value of 100-seed weight with 45.42 cm, the lowest biological yield per plant (31.9 g), pods per plant (29.3), and seeds per plant (32.7). Cluster 5 contained 7 genotypes and had the highest value for plant height (70.8 cm) and first podding height (37.6), high seed yield per plant (20.3 g), medium branches per plant (3.7), and seeds per plant (50.1). Cluster 6 was comprised of 12 genotypes and characterized by high seeds per plant (52.1), seed yield per plant (19.3 g), biological yield per plant (43.2 g), and pods per plant (45.6). Cluster 7 included 8 genotypes and was classified by maximum branches per plant (4.3), biological yield (44.9 g), pods per plant (48.3), seeds per plant (57.1), and seed yield per plant (20.5 g), the lowest values for plant height (60.6 cm), first podding height (28.7 cm), and 100 seed weight (36.24 g). None of the traits had highest mean values under cluster 2, cluster 3, and cluster 6. In the present study, cluster analysis exhibited wide variability among the chickpea genotypes studied for seed yield per plant and other attributing traits. Genotypes of different clusters had large divergence from each other. Similar to our findings, earlier studies demonstrated that intercluster differences were found for similar agromorphological traits in chickpea genotypes (Johnson et al., 2015; Temesgen et al., 2015; Jha et al., 2015; Samyuktha et al., 2017; Vus et al., 2020). Considerable variation among the genotypes for yield components may be utilized in further chickpea breeding (Parveen et al., 2020; Malik et al., 2014; Sharifi et al., 2018; Thakur et al. 2018). The present study revealed that selection and the hybridization among the genotypes from various clusters may ensure good cultivars in chickpea breeding**.**

Hierarchical cluster analysis and the mean values of cooking properties for each cluster are presented in Table 9 and Figure 4. Cluster analysis ranged 67 chickpea genotypes into 7 main clusters for cooking traits. Cluster 1 included 16 germplasms and 1 check cultivar (Hasanbey) and it had the highest value for dry weight with 45.81 g, wet weight with 91.6 g, hydration capacity with 0.458 g seed^{-1}, swelling capacity with 0.459 mL seed^{-1}. Cluster 2 consists of 13 genotypes and showed medium value of hydration index (0.966%) and high value for cooking time (58.5 min). Cluster 3 was comprised of 3 germplasms and characterized by lower value for dry weight (36.42 g), wet seed weight (70.5 g), hydration capacity (0.341 g seed^{-1}), hydration index (0.914%), swelling capacity (0.333 mL seed^{-1}), swelling index (2.17%), and cooking time (50.7 min). Cluster 4 contained 10 germplasms and was observed to have the highest hydration index (1.026%) and swelling index (2.39%). Cluster 5 had the highest cooking time (59.9 min), medium hydration capacity (0.419), swelling capacity (0.411 mL seed^{-1}), and swelling index (2.32%). Cluster 6 contained 10 germplasms and 1 check cultivar (Seçkin), cluster 7 consisted of 6 germplasms. Both clusters showed medium values for hydration capacity, hydration index, cooking time, and low values for other properties. Differences among the clusters are important to improve new chickpea cultivars for cooking quality. Similar to our results, previous studies showed that intercluster differences were found for some cooking properties (Sastry et al., 2019; Özaktan, 2021; Kaur and Prasad, 2022).

4. Conclusion

In the present study, positive correlations of seed yield per plant were observed with primer branches per plant, biological yield per plant, harvest index, pods per plant, and seeds per plant. Seed dry weight also showed positive and significant association with seed wet weight, hydration capacity, and swelling capacity. Correlations between cooking time and any of the properties studied were nonsignificant. Principal component analysis exhibited that agromorphological traits such as biological yield per plant, pods per plant, seeds per plant, seed yield per plant, plant height, 100-seed weight in the first four components and cooking properties such as hydration capacity, swelling capacity, swelling index, hydration index in the first two components can be considered for the improvement of new chickpea cultivars. Cluster analysis showed that there was wide variation among the chickpea germplasms studied for some yield components and cooking properties. As a result, new chickpea cultivars may be improve with hybridization or selection for agromorphological and cooking properties from different clusters.

Table 9. Mean values of clusters for cooking properties of chickpea genotypes.

Cluster	Count	Dry weight	Wet weight	Hydration capacity	Hydration index	Swelling capacity	Swelling index	Cooking time
1	17	45.81	91.6	0.458	1.005	0.459	2.32	55.6
2	13	38.58	75.8	0.372	0.966	0.372	2.27	58.5
3	3	36.42	70.5	0.341	0.914	0.333	2.17	50.7
4	10	37.36	75.0	0.376	1.026	0.382	2.39	57.7
5	7	41.28	83.2	0.419	0.997	0.411	2.32	59.9
6	11	39.96	80.1	0.401	1.011	0.403	2.33	52.3
7	6	43.77	85.6	0.418	0.948	0.413	2.24	53.8

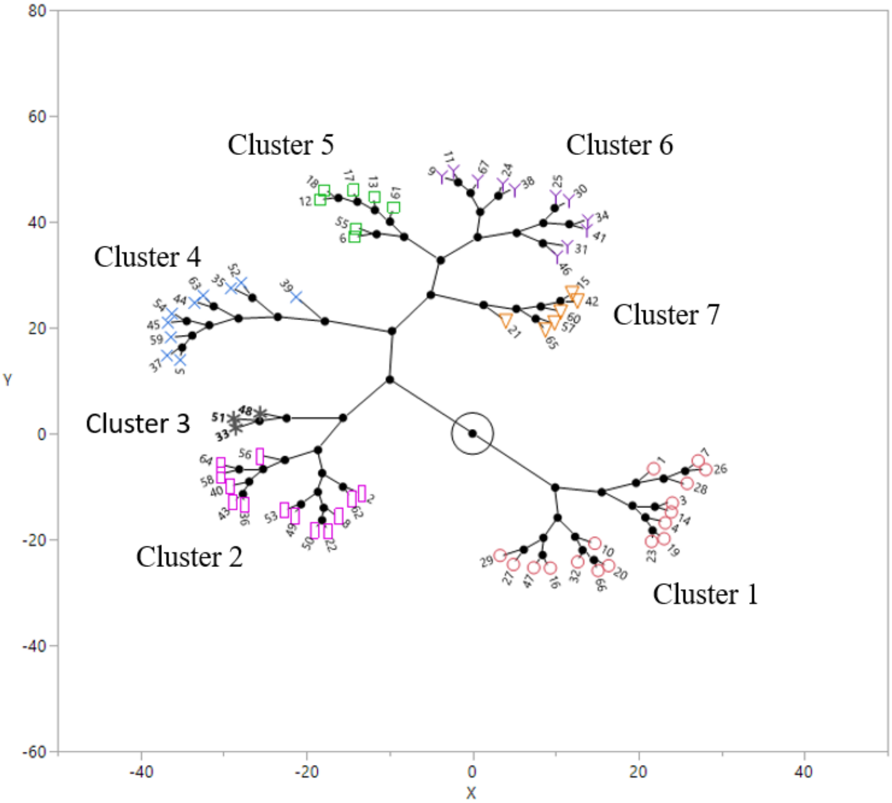

Figure 4. Hierarchical clustering analysis for cooking properties of chickpea genotypes.

Acknowledgment
Materials used in this study were provided by gene bank of ICARDA (International Center for Agricultural Research in the Dry Area). The author, Aybegün TON, would like to thank them their material support.

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