The biochemical assessment of edible wild and cultivated figs (*Ficus carica* L.) from Eastern Iran

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Abstract

Fig fruits are well-known for their significant nutritional and medicinal benefits. In this research, the phytochemical compounds present in 18 local and wild fig accessions from the South Khorasan region, east of Iran, were extracted and compared with the three well-known Iranian fig cultivars (Shah Anjir, Siah, Sabz). The results indicated that the studied genotypes exhibited significant differences in various biochemical traits, including total acidity, vitamin C, total antioxidant capacity, total phenols, anthocyanin, soluble solids, pH, quercetin, and catechin. However, there was no significant variation in flavonoid content among the genotypes. Accession 2 had the highest total acidity while Accession 20 had the lowest. The fruits of Accession 36 contained the highest levels of vitamin C, whereas the highest phenol content was found in the fruits of Accession 13. The fruits collected from Accession 4 displayed the highest sugar content while Accessions 1 and 35 were identified as rich sources of quercetin and catechin, respectively. Following factor analysis, it was revealed that, among the 11 factors analyzed, factor 1 accounted for 97% of the variation in biochemical traits. Finally, the cluster analysis categorized these fig accessions into three groups. Accessions 4,5,10,50, and 51 formed a subgroup along with the well-known, commercial cultivars of Estehban (Fars Province), indicating that these genotypes have potential for planting and further evaluation. The unique compounds found in these genotypes may be used to identify health benefits. Additionally, the findings may contribute to the conservation of these valuable genetic resources and enhance breeding programs focused on enhancing the nutritional quality of commercial fig cultivars.

Keywords: catechin, diversity, fig, quercetin, wild trees

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Introduction

The fig tree is among the earliest plants to be domesticated (Mijit et al., 2017). Figs are highly nutritious and possess medicinal properties, being rich in sugars and essential minerals like potassium, magnesium, calcium, and phosphorus, as well as vitamins A, B, C, and fiber. This tonic fruit is often recommended for patients who have been ill for an extended period, as it helps to rejuvenate their strength. Additionally, figs are significant sources of phenolic compounds, antioxidants,

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vitamins, and amino acids (Tanriver, 2019). The primary bioactive compounds in figs are flavonoids. In ancient Greece, figs were taught to physicians as a remedy for various ailments (Abdelsalam et al., 2019). They are widely utilized in the traditional medicine of many countries, with all parts of the fig plant being employed to treat and prevent various health issues.

Additionally, fig leaves contain polyphenols with antioxidant properties that may be beneficial for human health. Traditionally, fig leaves have been used to manage diabetes and liver disorders (Gani et al., 2018). Figs have a long history of use in traditional medicine for treating cardiovascular and respiratory diseases, acting as an anti-spasmodic and anti-inflammatory agent(Shahrajabian et al., 2021). Bioactive compounds found in fig leaves and roots are employed to address a variety of conditions, including gastrointestinal issues such as colic, indigestion, loss of appetite, and diarrhea, as well as respiratory problems like sore throat, cough, bronchial difficulties, and inflammatory and cardiovascular diseases (Shiraishi et al., 2023). Both fresh and dried figs along with fig syrup have been recognized for their valuable laxative properties (Sandhu et al., 2023). Additionally, fig latex is commonly used to treat skin warts. Ishnaiwer (2023)reported that figs possess anti-cancer, antioxidant, anti-diabetic, anti-fungal, and anti-mutagenic properties.

Iran is recognized as a significant center for plant genetic diversity and is one of the primary origins of figs (Sayadi et al., 2022). Fig trees are commonly found in various regions across Iran, often growing wild. Numerous efforts have been made to study and identify fig populations in the country, with a majority of these initiatives taking place in Fars province, which has the largest area dedicated to fig cultivation and production in Iran (Fatahi et al., 2017). Attention has also been given to the western provinces, including West and East Azerbaijan, Kermanshah, Ilam, and Lorestan.

In various areas of Khorasan Razavi, wild figs are found scattered across the mountains and steep slopes, often in groups comprising several trees that have thrived for centuries (Fig.I). The city of Bardaskan boasts 200 hectares of commercial fig orchards, producing over 2,400 tons of fresh figs, making it a key center for fig production in Khorasan Razavi. Approximately 80% of the figs produced are consumed fresh while the remaining 20% are processed into dried figs. The organic nature of Bardaskan figs, characterized by minimal use of pesticides and chemical fertilizers, highlights the advantages of this product in the region (Personal interview).

In the present research, a field survey was conducted in the southern cities of Khorasan Razavi, specifically Gonabad, Bejestan, and Bardeskan cities, focusing on wild edible figs. The study involved morphological as well as biochemical evaluations of 18 wild fig populations alongside 7 domestic and local fig cultivars. As a result, the morphological data has recently been published by Alizadeh et al. (2023), and this report focuses on the biochemical evaluation of these genotypes. The data collected from these genotypes were compared with three notable fig varieties from Fars Province: Shah Anjir, Green, and Black figs. This study represents the first comprehensive evaluation of both wild and cultivated figs in the South Khorasan Razavi region. The findings are significant for emphasizing the potential of genetic resources in the area, promoting the conservation and maintenance of these valuable genetic assets, and supporting breeding programs for edible fig cultivars.

Materials and Methods

Plant materials

In the current research, fruits from 18 local and wild fig accessions were collected from cities in Gonabad, Bejestan, and Bardeskan in the southern region of Khorasan Razavi Province, eastern Iran (Table 1). Additionally, fruits from two nationally recognized fig cultivars were obtained from the Fig Research Station in Estehban, Fars Province, Iran. The fruits were harvested according to the commercial maturity index applicable to each region. Subsequently, the collected fruits were oven-dried at 55 °C and utilized for measuring various biochemical characteristics. The biochemical traits assessed included total soluble solids, titratable acidity, pH of fruit juice, flavonoid

Table 1
Characteristics of locations and fig habitats in Khorasan Razavi and Fars provinces, Iran

Sr. No.	Accession No.	Province	County	Site	Latitude	Longitude	Height MSL	Fig local Name	Fig type
1	1	Khorasan Razavi	Gonabad	Kandal Olya	˜56.314′36 ˚58	˜9.137′80ϑ34	1772	Kouhi	Smyrna
2	2	-do-	Gonabad	Kandal Olya	˜52.157′36 ˚58	˜9.329′80ϑ34	1767	Kouhi	Smyrna
3	4	-do-	Gonabad	Kandal Wosta	˜12.64′37 ˚58	˜7.807′83ϑ34	1669	Lowlak	Smyrna
4	5	-do-	Gonabad	Kandal Wosta	˜14.138′37 ˚58	˜9.606′83ϑ34	1648	Zard	Smyrna
5	6	-do-	Gonabad	Kandal Sofla	˜22.582′37 ˚58	˜6.614′85ϑ34	1613	Gholoumi	Smyrna
6	10	-do-	Gonabad	Pachk	˜03.152′37 ˚58	˜9.352′70ϑ34	1802	Kouhi	Smyrna
7	12	-do-	Gonabad	Pachk	˜17.171′37 ˚58	˜6.3527′72ϑ34	1779	Kouhi	Smyrna
8	13	-do-	Bardaskan	Sir	˜2.704′43 ˚58	˜07.362′23ϑ35	1779	Kouhi	Smyrna
9	20	-do-	Gonabad	Mahabad	˜39.608′48 ˚58	˜6.701′54ϑ34	1555	Kouhi	Smyrna
10	22	-do-	Gonabad	Kakhk	˜57.605′37 ˚58	˜5.182′90ϑ34	1584	Tortoshi	Smyrna
11	23	-do-	Bardaskan	Bardaskan	˜13.597′59 ˚57	˜3.647′15ϑ35	990	Sabzak	Smyrna
12	34	Fars	Estahban	Fig Research Station	˜4.25′8 ˚54	˜6.49′12ϑ9	1767	Shahanjir	Smyrna
13	35	Fars	Estahban	Fig Research Station	˜4.25′8 ˚54	˜6.49′12ϑ9	1767	Siah	Smyrna
14	36	Fars	Estahban	Fig Research Station	˜01.35′00 ˚58	˜42.785′28ϑ34	1767	Sabz	Smyrna
15	50	Khorasan Razavi	Bajestan	Motrabad	˜35.335′00 ˚58	˜43.177′28ϑ34	1368	Khodroo	Smyrna
16	51	-do-	Bajestan	Motrabad	˜35.579′00 ˚58	˜49.089′28ϑ34	1378	Siah	Smyrna
17	53	-do-	Bajestan	Motrabad	˜41.006′48 ˚58	˜50.087′05ϑ34	1359	Sabz	Smyrna
18	55	-do-	Gonabad	Mahabad	˜56.314′36 ˚58	˜9.137′80ϑ34	1527	Kouhi	Smyrna

content, total sugars, fruit anthocyanin, total antioxidant capacity, total phenols, vitamin C, quercetin, and catechin levels.

Two grams of dried figs were weighed and then pounded in 20 ml of distilled water. The resulting mixture was filtered through filter paper to obtain the extract, which was used to measure pH, total soluble solids (TSS), and titratable acidity. A digital refractometer was utilized to measure TSS (Cherng and Ouyang, 2003) while a pH meter was employed to measure pH. Total acidity was determined according to the procedure outlined by Fallahi (1990) and expressed as a percentage of citric acid, which is the predominant organic acid in figs. The sugar content was assessed using the method of Génard and Souty (Génard and Souty, 1996) with results expressed in terms of mg glucose per gram dry weight of the fruit.

Preparation of methanolic extract

The method of Ebrahimzadeh et al. (2008)was used to measure flavonoid, phenol, and total antioxidant capacity. For this purpose, methanolic extract was first prepared. To prepare the methanolic extract, one gram of each sample was weighed and then pounded with a mortar. While pounding, a small amount of 10 ml of 80% methanol intended for each sample was added to the mortar and then poured into McCarthy jars and the remaining 10 ml of methanol was added. After preparing all the samples, they were placed on a shaker at room temperature for 24 hours and then passed through filter paper. The prepared extracts were used to measure flavonoid, phenol, and total antioxidant capacity.

Measurement of antioxidant capacity

To measure the total antioxidant capacity, 1 ml of methanolic extract was mixed with 1 ml of DPPH reagent and then kept in the dark for 30 min. Then, the absorbance of the samples was read in a spectrophotometer at a wavelength of 517 nm (Ebrahimzadeh et al., 2008). The obtained number (Y) was put in the following formula to obtain the

total antioxidant capacity in terms of the relative percentage of DPPH:

Antioxidant capacity (DPPH relative percentage) = 100 x (Y-absorption control)/(absorption control)

Flavonoids

In order to measure flavonoids, 0.5 ml of methanolic extract was mixed with 1.5 ml of pure methanol, 0.1 ml of aluminum chloride, 0.1 ml of one molar potassium acetate and 2.8 ml of pure distilled water. The composition and absorbance of the obtained solution were read in a spectrophotometer at a wavelength of 410 nm. The obtained amount (Y) was put in the Y=7.939X - 0.0377 formula to obtain the amount of flavonoid (X) in terms of milligrams per gram (dry) weight (Ebrahimzadeh et al., 2008).

Total phenols

To obtain the total amount of phenols, 100 µl of Folin and 300 µl of sodium carbonate was added to the prepared solution containing (20 µl of methanolic extract + 1.25 mL of distilled water) inside the polyethylene tubes and then covered with aluminum foil. It was then placed in a water bath at a temperature of 40 °C for 30 min. The samples were then read by a spectrophotometer at a wavelength of 760 nm. The total phenol content of the samples was obtained using the Y = 0.0025 – X 0.0024 formula (Ebrahimzadeh et al., 2008). In this formula, Y is the read absorption number and X is the amount of phenol in mg of gallic acid per gram dry weight.

Anthocyanin

To measure the amount of anthocyanin in the fruit, 0.5 g of fresh fruit was ground with 5 ml of methanol and then stored in the refrigerator at 4 °C for 24 hours (Ghasemi et al., 2011). The resulting mixture was centrifuged at 4000 rpm for 10 minutes, and the supernatant was collected for anthocyanin determination. The absorbance of the samples was measured using a spectrophotometer at a wavelength of 520 nm, and the concentration of anthocyanin was calculated using the following equation:

$$A = £bc$$

(A: absorbed value (read), £: coefficient equivalent to 3300 mM cm^{-1}, b: width of measuring cuvette equal to 1 cm, c: amount of anthocyanin in moles per gram dry weight).

Vitamin C

The titration method was employed to measure vitamin C contents of the fruit. In this process, 2.5 ml of the aqueous extract was combined with 17.5 ml of distilled water in an Erlenmeyer flask, followed by the addition of 1 ml of 0.5% starch. The resulting solution was then titrated with pure hydrochloric acid, and the volume of acid consumed was recorded. The amount of vitamin C in each sample was calculated using the equation provided by Skinner (1997):

C (milligrams per 100 g of sample weight) = (2 × 10 × sample consumption volume × extract volume obtained) / (standard for consumption volume × sample weight).

The volume used for the standard: 19; the volume of the obtained extract = the weight of the sample + the amount of water added to it.

Evaluation of fruit quercetin and catechin content through HPLC

For this purpose, the method described by Eftekhari et al. (2012)was utilized with minor modifications. The extraction phase was carried out as follows:

The dried figs were first ground into a powder using an electric grinder. One gram of the powdered fruit was then weighed and transferred into a 50 ml Erlenmeyer flask, to which 10 ml of 90% methanol (HPLC grade) was added. The contents of the flask were placed on a magnetic shaker for 30 minutes, after which the supernatant was removed and poured into a polyethylene tube. The residue from the previous step was placed back into an Erlenmeyer flask, and an additional 10 ml of 90% methanol was added. This mixture was then shaken on the magnetic shaker for 20 minutes. The supernatant was removed and combined with the materials of first extraction. This process was repeated thrice. All the supernatant solutions, along with the remaining materials, were transferred to a

polyethylene tube and centrifuged at 4000 rpm for 5 minutes. Subsequently, 5 ml of the supernatant was placed into a microtube and stored in a freezer for later use.

To measure quercetin and catechin, standard solutions were prepared. Initially, a stock solution of 1000 ppm was prepared, which was then used to prepare standard solutions at concentrations of 100, 50, 10, 5, 2.5, and 1 ppm.

The HPLC analysis was conducted using a Hitachi HPLC model L-7400 (Japan). To prepare the mobile phase, 49.9 ml of acetonitrile was measured into a 100 ml graduated cylinder. Next, 0.1 ml of glacial acetic acid was added using a sampler under a fume hood, followed by the addition of distilled water to achieve the final volume. This process was repeated several times until a sufficient quantity of mobile phase was obtained. The pH of the solution was measured with a pH meter and recorded as 3.3, which was considered appropriate and did not require any adjustments. The mobile phase was placed in an ultrasonic bath at a temperature of 20 °C for 20 minutes to ensure it was properly degassed. It was then filtered using a drain pump and filter paper with a pore size of 0.45 micrometers. This degassing and filtering process was repeated twice for all mobile phase solutions. The HPLC device was configured with a wavelength of 360 nm, a flow rate of 1 ml per minute, and a temperature of 25 degrees Celsius, with the machine pressure set at 135 psi. All samples were filtered using a needle filter with a pore size of 0.45 micrometers prior to injection. The areas under the curve were measured, and the amounts of quercetin and catechin in each sample were calculated using the equation of the line derived from the standard solutions (Figs. II & III). A graph of HPLC results for measuring quercetin and catechin in fig samples is shown in Fig. IV.

Data Analysis

This research was conducted using a nested design with a minimum of three repetitions. Data analysis was performed using SAS 9.4, Excel, and NTSYS software.

Fig. I. Wild figs are found scattered across the mountains and steep slopes of various regions in Khorasan Razavi, often in clusters of several trees that have thrived for centuries in Gonabad, Kakhk, Khorasan Razavi, eastern Iran.

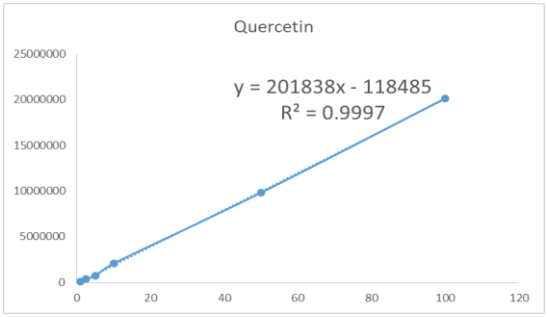

Fig. II. Equation of the line obtained from quercetin standards

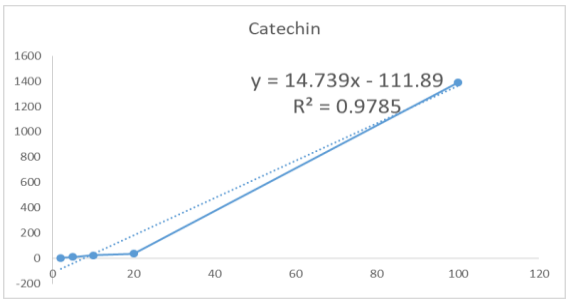

Fig. III. Equation of the line obtained from catechin standards

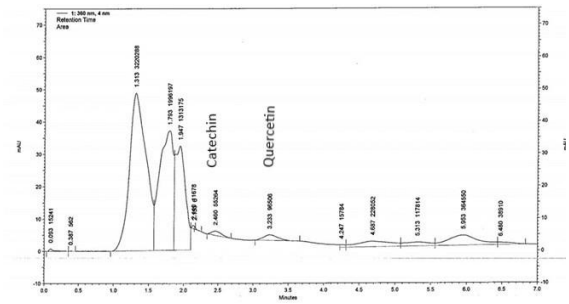

Fig. IV. Sample of HPLC results for measuring quercetin and catechin in fig fruits, Accession No. 55

Table 2.
Variance analysis for biochemical characteristics of edible figs in south Khorasan Razavi and Estehban, Fars

		Accession (Between population)	Error (Inter population)	CV (%)
Mean squares (MS)	df	17	36	-
	Total acidity	0.023*	0.0061	31.15
	Vitamin C	8855.37*	9351.93	38.54
	Flavonoid	53372.15^{ns}	12290.53	11.79
	Total antioxidant	335.5*	62.43	13.62
	Total Phenols	548135.41*	305027.9	20.73
	Anthocyanin	240.51**	16.45	18.24
	Total Sugars	1057.47*	673.89	14.53
	Soluble solids	2.86**	0.704	17.92
	pH	0.201**	0.027	4.55
	Quercetin	0.058**	0.001	4.53
	Catechin	1.01**	1.04	18.3

^{ns} not significant. *, ** indicate statistical significance at the level of 0.05% and 0.01%, respectively.

Table 3
Comparison of the average biochemical traits among fig accessions in Eastern Iran

Accession	Total acidity (%)	Vitamin C (mg/100g DW)	Flavonoids (mg/g DW)	Total antioxidant (%DDPH)	Total phenols (mg/g DW)
1	0.280 $^{a-d}$	270.18 ^{bc}	1343.5 ^{a}	44.15 ^{ef}	1912 ^{ab}
2	0.373 ^{a}	192.98 ^{c}	1056.9 $^{c-e}$	59.96 $^{c-e}$	2218 ^{ab}
4	0.210 ^{cd}	308.77 $^{a-c}$	1012.6 $^{b-e}$	65.60 $^{b-e}$	1520 ^{b}
5	0.186 $^{c-e}$	192.98 ^{c}	808.2 ^{ef}	66.21^{b-e}	1558 ^{b}
6	0.256 $^{a-d}$	192.98 ^{c}	911.1 $^{c-f}$	49.22 ^{de}	1706 ^{ab}
10	0.303 $^{a-c}$	192.98 ^{c}	867.9 $^{d-f}$	62.74 $^{c-e}$	1433 ^{b}
12	0.186 $^{c-e}$	192.98 ^{c}	763.4 ^{ef}	81.24 $^{a-c}$	1900 ^{ab}
13	0.210 ^{cd}	192.98 ^{c}	875.3 $^{d-f}$	81.219 $^{a-c}$	5873 ^{a}
20	0.070 ^{e}	192.98 ^{c}	784.3 ^{ef}	63.16 $^{c-e}$	1742 ^{ab}
22	0.373 ^{a}	192.98 ^{c}	651.4 ^{f}	93.94 ^{a}	3222 ^{ab}
23	0.350 ^{ab}	231.58 ^{bc}	758.4 ^{ef}	85.71 ^{ab}	5538 ^{ab}
34	0.233 $^{b-d}$	374.37 $^{a-c}$	1224.6 $^{a-c}$	25.33 ^{fg}	3198 ^{ab}
35	0.233 $^{b-d}$	501.75 ^{a}	1334.5 ^{a}	10.32 ^{g}	3086 ^{ab}
36	0.280 $^{a-d}$	424.56 ^{ab}	1149.0 $^{a-d}$	20.79 ^{g}	2613 ^{ab}
50	0.233 $^{b-d}$	192.98 ^{c}	881.8 $^{d-f}$	57.90 ^{de}	2422 ^{ab}
51	0.163 ^{de}	231.58 ^{bc}	662.4 ^{e}	52.07 ^{de}	2480 ^{ab}
53	0.303 $^{a-c}$	192.98 ^{c}	904.2 $^{c-f}$	55.92 ^{de}	2478 ^{ab}
55	0.280 $^{a-d}$	270.18 ^{bc}	927.6 $^{c-f}$	67.57 $^{b-d}$	3042 ^{ab}

* Means followed by the same letter in each column are not significantly different at 1%, using Duncan's test.

Results

The results of the current study revealed considerable variability among the examined genotypes concerning their phytochemical constituents. The variance analysis of the biochemical traits of fig accessions is presented in Table 2. Among the studied populations, the biochemical traits assessed in 18 fig populations included total acidity, vitamin C, total antioxidant capacity, total phenols, anthocyanins, soluble solids, pH, quercetin, and catechin, all of which exhibited significant differences. However, no significant variation was found in the flavonoid content among the fig accessions.

Table 3 displays the mean data for the estimated biochemical traits in various fig genotypes. Regarding total acidity, Accessions 2 and 22 exhibited the highest values while Accession 20

Table 3 (Continued)
Comparison of the average biochemical traits among fig accessions in Eastern Iran

Accession	Anthocyanin (moles/g DW)	Total sugars (mg/100g DW)	Soluble solids (%)	pH	Quercetin (mg/100g DW)	Catechin (mg/100g DW)
1	66.07 a	187.9 b-d	3.40 de	3.35 b-d	55.09 a	6.66 d-f
2	47.74 b	172.69 cd	3.43 de	3.11 d	47.49 c	6.00 ef
4	15.92 d	154.35 d	5.03 bc	3.44 bd	32.24 gh	2.64 f
5	13.37 d	161.23 d	5.30 bc	3.83 b	52.61ab	2.93 ef
6	14.17 d	163.73 d	4.06 b-d	3.85 b	46.73 d	4.57 ef
10	24.15 cd	187.06 b-d	3.20 de	3.46 b-d	46.87 c	2.65 f
12	8.72 d	164.15 d	3.90 bd	3.57 b-d	38.76 e	5.89 ef
13	46.84 b	172.69 cd	3.00 de	3.18 cd	41.73 d	2.92 ef
20	35.98 bc	179.35 b-d	2.20 e	3.72 bc	35.52 f	10.64 c-e
22	13.40 d	177.27 cd	3.96 b-d	3.36 b-d	35.39 f	7.04 d-f
23	10.73 d	204.15 a-c	4.16 b-d	3.23 cd	29.64 h	3.47 ef
34	15.86 d	213.94 ab	7.06 a	4.85 a	31.25 h	13.55 b-d
35	19.59 d	176.65 cd	6.86 a	4.50 a	30.46 h	24.50 a
36	14.74 d	172.69 cd	6.80 a	5.05 a	30.80 h	16.74 bc
50	19.22 d	158.94 d	3.46 de	3.40 b-d	34.87 f	3.61ef
51	11.55 d	162.69 d	3.83 cd	3.70 b-d	34.24 fg	4.83 ef
53	10.81 d	179.56 b-d	6.60 ab	3.10 d	31.39 h	1.30 f
55	11.25 d	225.60 a	4.20 b-d	3.17 cd	50.90 b	18.96 ab

* Means followed by the same letter in each column are not significantly different at 1%, using Duncan's test.

Table 4
Eigenvalues of the covariance matrix for fig accessions from South Khorasan Razavi and Estehban in Fars province

Component	Eigenvalue	Difference	Proportion	Cumulative
1	3379549.66	3316012.42	0.9771	0.9771
2	63537.24	49103.87	0.0184	0.9955
3	14433.37	13795.08	0.0042	0.9997
4	638.28	366.54	0.0002	0.9999
5	271.75	59.89	0.0001	0.9999
6	211.86	208.87	0.0001	1.0000
7	2.98	2.13	0.0000	1.0000
8	0.86	0.74	0.0000	1.0000
9	0.12	0.10	0.0000	1.0000
10	0.02	0.01	0.0000	1.0000
11	0.01		0.0000	1.0000

showed the lowest value, followed by Accessions 5, 12, and 51. In terms of vitamin C content of the fruit, the highest levels were recorded in Accessions 36, 34, and 4, in that order. Conversely, the lowest vitamin C contents were found in Accessions 2, 6, 10, 12, 13, 22, 50, and 53. For total antioxidant capacity, Accessions 22, 23, 12, and 13 had the highest levels among the fig genotypes under study.

In terms of total phenols, Accession 13 exhibited the highest value while Accession 4 had the lowest. For anthocyanin content, the highest amounts were found in Accessions 1, 2, and 13, with Accession 12 showing the lowest level. When considering total sugars, Accessions 55, 23, and 34 recorded the highest amounts, whereas the lowest sugar levels were found in Accessions 4, 50, and 5. Regarding soluble solids, the highest concentrations were noted in Accessions 34, 35, 36, and 53 while the lowest was observed in the sample number 20. The highest pH of fruit juice was recorded in sample cluster 36, and the lowest was found in cluster 5. The highest quercetin levels were detected in samples 1 and 5 while the lowest amounts were in samples 23, 34, 35, 36, 53, and 50. Finally, the highest catechin concentration was measured in sample 35, and the lowest was in sample 53.

Table 5
Principal Component analysis based on biochemical traits of fig accessions in South Khorasan, Razavi, and Estehban Fars

Principal component / Biochemical traits	Prin.1	Prin.2	Prin.3	Prin.4	Prin.5	Prin.6
Total acidity	0.000650	0.000340	-0.000055	0.000445	0.001076	0.019167
Vitamin C	-0.006960	-0.370372	0.858640	-0.086112	0.343284	-0.011304
Flavonoid	-0.000054	0.001738	-0.006023	0.000527	-0.010504	0.077405
Total antioxidant	0.013516	0.905539	0.418075	0.015498	-0.063565	0.024962
Total Phenols	0.999838	-0.013671	-0.001394	0.005220	0.010362	0.001059
Anthocyanin	0.000048	-0.000098	-0.003203	0.007400	0.006808	-0.044536
Total Sugars	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Soluble solids	-0.000803	-0.033621	0.011020	-0.046095	-0.041735	0.988533
pH	-0.000173	-0.016515	0.002979	-0.010883	-0.012913	0.094930
Quercetin	0.000942	0.086268	-0.127167	0.775833	0.607958	0.067612
Catechin	0.001995	-0.183819	0.267577	0.622979	-0.711568	-0.011143

Table 5 (Continued)

Principal component / Biochemical traits	Prin.7	Prin.8	Prin.9	Prin.10	Prin.11
Total acidity	0.02550	-0.04907	0.17967	0.98198	0.00000
Vitamin C	0.01073	-0.00295	0.00045	-0.00045	0.00000
Flavonoid	0.99075	0.10586	0.02091	-0.02566	0.00000
Total antioxidant	-0.00287	0.01033	0.00329	0.00073	0.00000
Total Phenols	0.00009	0.00006	0.00127	-0.000072	0.00000
Anthocyanin	-0.01562	-0.05293	0.980894	-0.180851	0.00000
Total Sugars	0.00000	0.00000	0.00000	0.00000	1.00000
Soluble solids	-0.06767	-0.1056	0.033457	-0.028857	0.00000
pH	-0.11314	0.98597	0.063054	0.038842	0.00000
Quercetin	-0.00134	0.012148	-0.006868	-0.000475	0.00000
Catechin	-0.00443	-0.00581	0.000304	0.000563	0.00000

In this study, the correlations between the measured biochemical traits were analyzed using Pearson's correlation coefficient, with the results displayed in Table 6. It is evident that total acidity, total phenols, and total sugars did not show a significant correlation with any of the traits measured. In the analysis of various biochemical traits (Table 6), it was observed that the level of vitamin C displays a significant positive correlation with soluble solids, pH, and catechin while showing a negative correlation with total antioxidant properties. Conversely, total antioxidant content was significantly positively correlated with soluble solids and negatively correlated with vitamin C, pH, and catechin. Additionally, anthocyanin content had a significant positive correlation with quercetin levels, but a negative correlation with soluble solids. Soluble solids exhibited a significant positive correlation with vitamin C, pH, and catechin while negatively correlating with total antioxidant properties, anthocyanin, and quercetin. Furthermore, quercetin content was significantly positively correlated with anthocyanin content while negatively correlating with soluble solids and pH. In summary, as anthocyanin levels increase, quercetin levels also rise, whereas soluble solids and pH decrease. Catechin levels demonstrate a significant positive correlation with vitamin C, soluble solids, and pH, but a negative correlation with total antioxidant values.

In the cluster analysis of biochemical traits (Fig. V), fig accessions were classified into three groups. The first group comprised Accessions 1, 2, and 13. The second group was divided into two subgroups. The first subgroup consisted of Accessions 4, 5, 10, 34, 35, 36, 50, and 51. Within this subgroup, Accessions 4 and 5 were found to be similar; however, this similarity was not supported by

Table 6
Correlation between biochemical traits of edible fig accessions in South Khorasan Razavi and Estehban Fars based on Pearson's correlation coefficient

	Total acidity	Vitamin C	Flavonoid	Total antioxidant	Total phenols	Anthocyanin	Total Sugars	Soluble solids	pH	Quercetin
Total acidity	1									
Vitamin C	-0.059	1								
Flavonoid	0.263	-0.101	1							
Total antioxidant	0.096	-0.456**	0.026	1						
Total Phenols	0.123	-0.086	0.104	-0.01	1					
Anthocyanin	0.064	-0.144	-0.069	-0.131	0.537	1				
Total Sugars	0	0	0	0	0	0	1			
Soluble solids	0.1	0.389**	-0.05	0.019**	-0.092	-0.414**	0	1		
pH	-0.203	0.465**	-0.651	-0.154**	-0.051	-0.228	0	0.583**	1	
Quercetin	0.074	-0.233	0.178	-0.01	-0.207	0.465**	0	-0.411**	-0.371**	1
Catechin	-0.078	0.462**	-0.379	-0.004**	0.04	-0.062	0	0.279**	0.374**	-0.116

morphological evaluation. Additionally, within the same subgroup, Accessions 50 and 51 were assessed as similar, although this similarity was not corroborated by morphological evaluation (Bagheri et al., 2023). The second subgroup included Accessions 6, 12, 22, 23, 53, and 55. finally, the third group only included wild fig Accession 20.

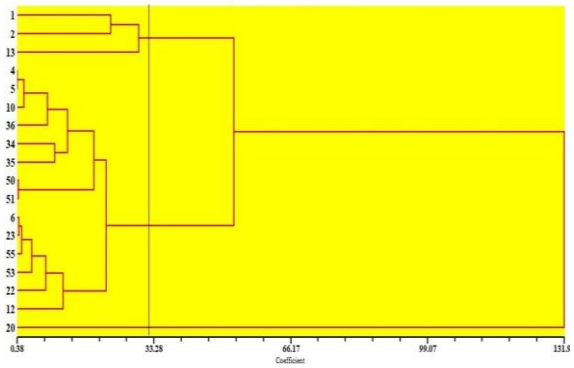

Fig. 5. Clustering of fig Accessions in South Khorasan Razavi and Estehban Fars provinces, Iran.

Discussion

Review of the literature underscores the essential biochemical properties of figs, emphasizing their nutritional advantages and potential health benefits (Gani et al., 2018). Figs are rich in a range of antioxidants, including phenolic compounds and flavonoids (Veberic and Mikulic-Petkovsek, 2016). Quercetin is a flavonoid commonly found in figs, known for its antioxidant properties, which helps protect cells from oxidative damage and may contribute to overall health(Vollmannová et al., 2024). Catechin, another flavonoid present in figs, is recognized for its role in enhancing heart health by improving blood flow and reducing blood pressure (Ciumărnean et al., 2020). The synergistic effects of quercetin and catechin, along with other phytochemicals in figs, may enhance the fruit's overall health benefits, making it a valuable addition to a balanced diet.

Pourghayoumi et al. (2016)explored the phytochemical properties of various Iranian figs and discovered that the total phenol content ranged from 1120 to 2686.8 mg / 100 g DW with an average of 1785 mg/ 100 g DW. Notably, the Kharfak variety contained significantly higher levels of total phenols as compared to other fig varieties. In another study, the amount of total phenol in figs was measured between 17.8-815 mg/100g DW (Veberic and Mikulic-Petkovsek, 2016). In a study conducted in Turkey focusing on Smyrna and San Pedro fig varieties, the total phenol content ranged from 28.6 to 211.9 mg / 100 g DW (Çalişkan and Polat, 2011). Furthermore, the total phenol levels in the dried cultivars Sari Loup and Siya Bursa were reported to be 413 and 417 mg / 100 g DW, respectively (Kamiloglu and Capanoglu, 2015).

In another study conducted in Algeria, the total phenol content was found to range from 482.62 to 644.11 mg / 100 g DW (Bey and Louaileche, 2015). Additionally, the total phenol levels in certain fig

cultivars in India were estimated to be 331.93 mg per 100 g of dry weight (Reddy et al., 2010). In the present study, the minimum total phenol content was 1430.3 while the maximum reached 5870.3, resulting in an average of 2659.3 mg/100g DW. These findings indicate that the total phenol content varied over a broader range compared to those reported by Pourghayoumi et al. (2016), Çalişkan and Polat (2011), Kamiloglu and Capanoglu (2015), as well as the results obtained in Algeria and India.

The increased total phenol content observed in this study compared to the values reported for Turkish figs, may be attributed to the hotter and drier climate in the study regions of Iran. This environmental difference is likely to lead to a higher production of secondary metabolites.

In the study conducted by Pourghayoumi et al. (2016), the total flavonoid content of various Iranian fig cultivars was found to range from 685.4 to 1171 mg/100g DW, with an average of 1.908 mg/100g DW. Siguto cultivar exhibited the highest total flavonoid levels while the Black cultivar had the lowest. Furthermore, total anthocyanin levels varied from 0.8 to 44.1 mg/100g DW, and total antioxidant capacity ranged from 37.7% to 70.2% DPPH, averaging 57.07%. The dissolved solid contents ranged between 60 and 84.8, with an average of 68.62. Notably, there was no significant difference in total antioxidant levels among most cultivars, with the exception of the Rono and Kharfak cultivars (Pourghayoumi et al., 2016).

Kamiloglu and Kapanoglu (2015) reported the flavonoid contents of various fig cultivars as 52 mg/100 g DW while total anthocyanin content was measured at 14.5 mg/100 g DW, and antioxidant content reached 104 mg/100 g DW. In another study, Bey and Louaileche (2015) found the flavonoid levels in Algerian fig cultivars to range from 24.87 to 126.55 mg/100 g. Additionally, Pourghayoumi et al. (2016) noted that the anthocyanin content was similar among the Kharfak, Rono, Shah Anjir, and Atabaki cultivars; however, it was higher in the Mati, Monbili, and Sigoto cultivars. The reported anthocyanin content in Algerian figs varied between 17.18 and 20.78 mg/100 g DW (Bey and Louaileche, 2015). In another study, the total flavonoid content was reported as 52 mg/100g, the anthocyanin content was 14.5 mg/100g, and the total antioxidant content was recorded at 104 mg/100g, expressed as the relative percentage of DDPH (Kamiloglu and Capanoglu, 2015). Differences in total phenol and total flavonoid levels may be attributed to variations among cultivars and differing weather conditions (Hoxha et al., 2015). Our findings indicated that flavonoid levels ranged from a minimum of 556.41 to a maximum of 1762.38 mg/100g, with an average of 939.55 mg/100g, which is higher than the averages reported by Pourghayoumi et al. (2016); Furthermore, the anthocyanin content in the examined accessions ranged from 8.72 to 67.66 mg/100g DW that was very different from the findings of Pourghayoumi et al. (2016) and Kamiloglu and Kapanoglu (2015).

In a study conducted by Abbasi et al. (2024). The fig tree leaves from Gorgan exhibited the highest total antioxidant levels while those from Noor had the lowest. In terms of total phenol content, the highest amounts were found in the fig leaves from the Islam region, whereas the lowest were recorded in Noor city. The total phenol levels ranged from 3.40 to 14.51 mg/100 g dry weight (DW), with the lowest value attributed to the Keshki variety and the highest to the Atabaki variety.

In a study by Bey and Louaileche (2015), the maximum antioxidant content was recorded at 45.25% in the Bunkik variety while the minimum was noted at 28.33% in the Taganimet variety. (Kebal et al., 2024). Quercetin levels in fig varieties ranged from 0.12 to 1.27 mg/100g DW, with the Keshki variety exhibiting the lowest quercetin content and the Shah Fig variety recording the highest. In a study conducted by Veberic and Mikulic-Petkovsek (2016), the quercetin content in dried fig fruits was estimated to range from 0.5 to 8.2 mg/100g dry weight (DW) while catechin levels were between 75.19 and 88.5 mg/100g DW. In our research, the highest quercetin content was observed55.09 mg/100g in Accession No. 1 while the lowest was recorded in local Accession No. 23 at 29.64 mg/100g DW. Additionally, the highest catechin content in our study was found in Accession No. 55 at 18.96 mg/100g, and the lowest was in Accession No. 53 at 1.30 mg/100g DW, which contradicted the findings of

Pourghayoumi et al. (2016). According to Kamiloglu and Capanoglu (2015), the quercetin and catechin levels in some Turkish fig cultivars were 0.7 and 2.5 mg/100g, respectively.

Among common fruits and vegetables, figs are notable for their rich anthocyanin and flavonol contents, as well as glycosides and other polyphenols that enhance the fruit's high antioxidant capacity. Fig fruits hold significant commercial value not only due to their exceptional taste and nutritional benefits but also because of the compounds recognized for promoting human health. The accumulation of phenolic metabolites in plants is significantly affected by both environmental and genetic factors (Alami et al., 2024). Generally, genotypes with black and purple skin exhibit higher total antioxidant capacity compared to cultivars with lighter skin (Çalişkan and Polat, 2011). This is attributed to the elevated concentration of phenolic compounds found in the skin of black cultivars (Abbasi et al., 2024). Factors such as climatic variations, technological practices, ripening stages, and pre-harvest and post-harvest conditions significantly influence the diversity of antioxidant activity in figs. Additionally, the antioxidant activity is affected by the characteristics of the extraction solvent and techniques, as well as the drying temperature of the figs (Mostapha et al., 2024).

Upon reviewing Table 4, it is evident that among the 11 factors, 7 factors exhibit an eigenvalue greater than one. Factor number one alone accounts for 97% of the variation associated with biochemical traits. Furthermore, the combination of factors number 1 and 2 together explains 99% of the observed changes. The primary component of factor number 1 is predominantly related to total phenol content while factor number 2 primarily relates to the total antioxidant levels. In other words, measuring just the two attributes of total phenol and total antioxidants can account for nearly 99% of the variations in diversity observed in the study. In the study of the biochemical characteristics of figs in Algeria, the first factor accounted for 79.73% of the variance after decomposition into main factors (Bey and Louaileche, 2015). In addition to biochemical traits such as total phenol, total flavonoid, anthocyanin, and total antioxidant, this factor also included five other traits.

Considering the grouping, it is clear that the Accessions in the three groups were not geographically similar. Also, Accessions 4, 5, 10, 50 and 51 were placed in a subgroup with commercial figs of Estehban. Accessions 10 and 51 are among the wild Accessions and Accessions 4, 5, and 50 are considered local fig genotypes. There is the capacity to use these Accessions to introduce for further investigations in order to be used in breeding programs and also to be used for planting in commercial gardens. It is necessary to explain that some Accessions, such as Accession No. 23, are widely used as dried figs in Bardskan city. Some Accessions, such as 4, 5, 6, 22, 50, and 53 are now cultivated sporadically as fresh figs in Gonabad and Bejestan cities. Owing to the phytochemical diversity present in these fig accessions, their potential applications in nutrition and medicine is clear.

A strong positive correlation has been established between the total phenol content and antioxidant capacity in fig fruits (Abbasi et al., 2024). In another study on fig, the correlation coefficients between total phenols and flavonoids, total anthocyanins, and total antioxidants were found to be 0.94, 0.87, and 0.90, respectively. Additionally, the correlation coefficients between total anthocyanins, total flavonoids, and total antioxidants were 0.86 and 0.93, respectively while the correlation between antioxidants and total flavonoids was 0.96 (Kamiloglu and Capanoglu, 2015). Another study on various Algerian fig cultivars revealed correlation coefficients for total phenols with flavonoids, anthocyanins, and total antioxidants of 0.88, 0.92, and 0.88, respectively. Furthermore, the correlation coefficients between flavonoids and anthocyanins and total antioxidants were measured as 0.89 and 0.87, respectively, and the correlation between anthocyanins and total antioxidants was 0.91 (Bey and Louaileche, 2015).

The findings enhance our understanding of the phytochemical diversity in these fig accessions and their possible applications in nutrition and medicine. The distinct compounds identified in

these genotypes could help pinpoint their health benefits. Furthermore, the findings may contribute to the conservation of these valuable genetic resources and enhance breeding programs focused on enhancing the nutritional quality of commercial fig cultivars.

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