INTRODUCTION

Although jujube (Ziziphus jujuba Mill., the Rhamnaceae family) is mainly adapted to temperate and subtropical regions and naturally to areas with cold winters and hot summers, it is widely distributed in dry climates (Gao et al., 2011). Jujube fruit is rich in vitamins A, B, and C, as well as minerals and various compounds such as alkaloids, flavonoids, sterols, tannins, saponins, and fatty acids. Jujube also has significant antioxidant properties that can neutralize the activity of free radicals, so its fruit is involved in traditional medicine (Tatari et al., 2016). The flesh of jujube fruit contains protein, fat, carbohydrates, calcium, phosphorus, and iron (Karakaya et al., 2020; Ozturk et al., 2021). Jujube fruits are consumed worldwide as food and herbal medicine because of their impact on human health and benefits (Chen et al., 2017). Different parts of jujube are rich in medicinal properties such as antiseptic, analgesic, and antidiabetic.
Jujube seeds are used because of their effect on reducing insomnia and anxiety. Jujube is used as a blood purifier, nerve sedative, stomach tonic, laxative, and antitussive (Gao et al., 2011).

Genetic diversity is the basis of agricultural programs and development. Genetic resources are the primary basis for creating promising improved cultivars, which today are considered to be the most valuable national resources and primary resources of any country (Behera et al., 2008). Gene banks are created to collect genetic material to examine genetic diversity and long-term protection. Materials collected in terms of population, species, and gene pool need to be diverse. In any country, it is essential to study the genetic diversity of plant species to use them in breeding, conservation, management, and establishment of plant species (Ghazaeian, 2015). Iran is one of the richest countries in the world in terms of plant genetic resources. The country has an advantage in terms of plant diversity, which is part of the existing biological richness, due to exceptional ecological characteristics (Khadivi, 2018).

Morphological characterization is one of the first steps to identify plant genetic resources. Evaluation of morphological traits, genetic resources, and the collection of desirable traits in one cultivar is one of the important breeding goals in plants (Khadivi-Khub & Anjam, 2014). Also, knowledge about the chemical properties of a plant species can help the food and pharmaceutical industries. Superior accessions can be used to produce different food, pharmaceutical, and antioxidant products (Halliwell & Gutteridge, 1990). The present research aimed to investigate the phenotypic and biochemical characteristics of jujube (Z. jujuba) and then to select superior accessions for cultivation in the orchards as well as use in future breeding programs.

2 | MATERIAL AND METHODS

2.1 | Plant material

In the present study, 100 local accessions of jujube (Z. jujuba) in a collection site from Tootkan area in Lorestan province/Iran were selected. The sampled accessions were chosen randomly based on their health and yield. Tootkan area is located at 32°54′57″N latitude, 49°39′31″E longitude, and 2025 m height above sea level (Figure 1).

2.2 | Morphological and pomological analysis

Phenotypic diversity of the accessions studied was investigated using 39 morphological traits according to the International Plant Genetic Resources Institute (IPGRI) guideline (Saha, 1997). The 50 mature leaves and 50 mature fruits in each accession were used to record the related characters. The length and width of leaf, fruit, and stone were measured using a digital caliper. Also, fresh fruit weight, dry fruit weight, and stone weight were measured using an electronic balance with 0.01 g precision. Furthermore, the qualitative characters were estimated based on rating and coding (Table 2) (IPGRI, Saha, 1997).

2.3 | Chemical analysis

2.3.1 | Total phenolic content

For extraction, samples (1.00 g) were homogenized using 10.00 ml of 80.00% methanol, and the mixtures were centrifuged at 4472 g (revolutions per minute) for 10 min. Supernatants were collected and analyzed for total phenolic content and antioxidant activity assays. Total phenolic content of fruit extracts was measured using the Folin–Ciocalteu reagent method with spectrophotometry (Singleton & Rossi, 1965). Briefly, 400 μl of the extract was combined with 2.00 ml of 10-fold diluted Folin–Ciocalteu reagent and 1.60 ml of sodium carbonate 7.50% and then placed at room temperature for 30 min. The absorbance was estimated at 756 nm. The concentration of total phenolic content was read in mg gallic equivalents per g fruit weight (FW) using a calibration curve prepared with gallic acid.

2.3.2 | Total flavonoid content

For determination of total flavonoid content, the method described by Grzegorczyk-Karolak et al. (2015) was adopted so that the 2 ml of fruit extracts was mixed with 2 ml of 2.00% aluminum chloride (AlCl3) and the reaction mixture was allowed to stand for 15 min at room temperature. The absorbance was measured at 415 nm, and the findings were expressed as mg quercetin equivalents per g FW (mg QE/g FW) for total flavonoid content.

2.3.3 | Total anthocyanins

Total anthocyanins in fruits were extracted with mixing 0.50 g of fresh materials with 10 ml of acidified methanol containing 1% HCl (v/v). The extract was centrifuged at 4472 g for 10 min and the absorbance of supernatants was recorded at 530 nm (Nogues & Baker, 2000). The content of anthocyanins in fruit samples was calculated using the extinction coefficient of cyanidin-3-glucoside (cyd-3-glu) and expressed as mg Cyd-3-glu equivalents.

2.3.4 | Radical scavenging activity

The scavenging activity of the extracts prepared on 2,2-diphenyl-1-picyrl-hydrazyl-hydrate (DPPH) free radicals was determined. The 25 μl of the fruit extract was reacted with a 0.10 mM methanol solution of DPPH in a total volume of 3.00 ml, and the mixture was then placed in the dark at room temperature for 30 min. The absorbance was read at 517 nm. The DPPH scavenging activities were calculated based on the following formula:

\[
\text{DPPH scavenging effect (\%) = } \left( \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \right) \times 100.
\]

Where \( A_{\text{control}} \) and \( A_{\text{sample}} \) represent the control absorbance and the sample absorbance, respectively (Zhu et al., 2009). The DPPH
scavenging activity of fruits was expressed as mg ascorbic acid equivalents (ASAE) per g FW using the established ascorbic acid calibration curve.

2.3.5  Ferric reducing antioxidant power (FRAP)

The method developed by Benzie and Strain (1996) was used for the FRAP assay. The FRAP reagent comprised of 300 mM acetate buffer, 10 mM TPTZ (2,4,6-tripyridyl-s-triazine) in 40 mM HCl and 20 mM ferric chloride (10:1:1, v/v/v). To 20 µl of fruit extract was added 3.00 ml of FRAP reagent, and the reaction mixtures were placed in a 37°C water bath for 10 min. The absorbance was read at 593 nm, and antioxidant activities were determined using the prepared FeSO₄ standard curve.

3  RESULTS AND DISCUSSION

3.1  Morphological descriptions

Out of 39 morphological traits measured, nine characters, including branch color (gray in all the accessions), leaf density (high), leaf shape (ovate), leaf apex shape (obtuse), leaf upper surface color (dark green), leaf lower surface color (light green), leaf serration (present), fruit shape (oval), and fruit stone surface (coarse), had no differences among the studied accessions. Thus, they were excluded from analysis and Tables. The morphological traits without variation are more homogeneous and repeatable among the accessions, and therefore may be considered as stable traits. The remaining 30 morphological characters and also all five chemical properties had high variabilities. The highest CV (400.00%) belonged to thorn presence on annual shoot (Table 1).
The accessions showed three types of growth habit, including spreading (80 accessions), semi-erect (12), and erect (8). Tree growth vigor, tree height, canopy density, branching, and branch density were predominantly high (Table 2). In general, the higher tree growth vigor, the higher tree height, branching, and branch density, and as a result, the fruit-related traits will be more desirable, and thus the yield, fruit length, and dry fruit weight are increased (Hosseini et al., 2018).

The range of quantitative leaf-related characters was as follows, leaf length: 36.44–54.43 mm, leaf width: 18.46–28.82 mm, petiole length: 2.50–7.32 mm, and petiole thickness: 0.44–2.18 mm (Table 1). In the study of a jujube collection from the north of Iran, the ranges of leaf length, leaf width, and petiole length have been reported as 25.00–56.00 mm, 13.60–24.60 mm, and 0.20–4.10 mm, respectively (Ghazaeian, 2015).

The fruits in the majority of accessions were ripened in late-September (70 accessions). Most of the accessions (98 out of 100) showed a high yield. Fruit skin color was brown in 99 accessions, and also fruit flesh color was light green in 99 accessions (Table 2). In the study of a jujube collection from Ukraine, skin color showed strong diversity, ranging from brown-yellow to dark brown (Grygorieva et al., 2014).

| No. | Character                          | Abbreviation | Unit     | Min   | Max   | Mean | SD   | CV (%) |
|-----|-----------------------------------|--------------|----------|-------|-------|------|------|--------|
| 1   | Tree growth habit                 | TGH          | Code     | 1     | 5     | 1.56 | 1.21 | 77.56  |
| 2   | Tree growth vigor                 | TGV          | Code     | 3     | 5     | 4.86 | 0.51 | 10.49  |
| 3   | Tree height                       | TH           | Code     | 3     | 5     | 4.92 | 0.39 | 7.93   |
| 4   | Trunk type                        | TrTy         | Code     | 1     | 3     | 1.14 | 0.51 | 44.74  |
| 5   | Canopy density                    | CD           | Code     | 3     | 5     | 4.76 | 0.65 | 13.66  |
| 6   | Branching                         | Bra          | Code     | 3     | 5     | 4.90 | 0.44 | 8.98   |
| 7   | Branch density                    | BrD          | Code     | 3     | 5     | 4.90 | 0.44 | 8.98   |
| 8   | Branch flexibility                 | BrF          | Code     | 1     | 3     | 1.02 | 0.20 | 19.61  |
| 9   | Annual shoot length               | AnBrLe       | cm       | 11    | 105   | 19.99| 12.09| 60.48  |
| 10  | Thorn on annual shoot             | ThoBr        | Code     | 0     | 1     | 0.06 | 0.24 | 400.00 |
| 11  | Leaf length                       | LLe          | mm       | 36.44 | 54.43 | 44.11| 4.23 | 9.59   |
| 12  | Leaf width                        | LWi          | mm       | 18.46 | 28.82 | 21.13| 2.56 | 12.12  |
| 13  | Petiole length                    | PeLe         | mm       | 2.50  | 7.32  | 3.26 | 0.78 | 23.93  |
| 14  | Petiole thickness                 | PeThi        | mm       | 0.44  | 2.18  | 1.18 | 0.35 | 29.66  |
| 15  | Ripening date                     | RiDa         | Date     | Mid-Sep| Late-Sep| 2.40| 0.92 | 38.33  |
| 16  | Yield                             | Yi           | Code     | 3     | 5     | 4.96 | 0.28 | 5.65   |
| 17  | Fruit length                      | FrLe         | mm       | 21.96 | 29.45 | 24.78| 1.49 | 6.01   |
| 18  | Fruit width                       | FrWi         | mm       | 16.59 | 23.89 | 19.02| 1.09 | 5.73   |
| 19  | Fresh fruit weight                | FreFrWe      | g        | 2.72  | 6.42  | 4.54 | 0.70 | 15.42  |
| 20  | Dry fruit weight                  | DrFrWe       | g        | 0.89  | 2.57  | 1.55 | 0.31 | 20.00  |
| 21  | Fruit stalk length                | FrStLe       | mm       | 1.54  | 4.58  | 2.38 | 0.49 | 20.59  |
| 22  | Fruit stalk diameter              | FrStDi       | mm       | 0.58  | 3.33  | 1.05 | 0.30 | 28.57  |
| 23  | Fruit flesh thickness             | FrFlThi      | mm       | 4.19  | 10.09 | 5.66 | 0.77 | 13.60  |
| 24  | Color of fruit skin               | FrSkCo       | Code     | 1     | 3     | 2.98 | 0.20 | 6.71   |
| 25  | Color of fruit flesh              | FrFlCo       | Code     | 1     | 3     | 2.98 | 0.20 | 6.71   |
| 26  | Fruit flavor                      | FrFl         | Code     | 1     | 3     | 1.08 | 0.39 | 36.11  |
| 27  | Texture of fruit flesh            | FrFlTex      | Code     | 1     | 3     | 2.66 | 0.76 | 28.57  |
| 28  | Length of fruit stone             | FrStLe       | mm       | 13.41 | 19.23 | 16.12| 0.98 | 6.08   |
| 29  | Width of fruit stone              | FrStWi       | mm       | 6.91  | 11.48 | 7.56 | 0.47 | 6.22   |
| 30  | Weight of fruit stone             | FrStWe       | g        | 0.31  | 0.47  | 0.40 | 0.04 | 10.00  |
| 31  | Total phenolic content            | TPC          | mg GAE g⁻¹ FW | 1.69  | 14.05 | 5.65 | 2.38 | 42.12  |
| 32  | Total flavonoid content           | TFC          | mg QE g⁻¹ FW | 0.25  | 2.01  | 0.83 | 0.19 | 22.89  |
| 33  | Total anthocyanin content         | TAC          | µg CyE g⁻¹ FW | 5.98  | 76.32 | 46.55| 14.52| 31.19  |
| 34  | Radical scavenging activity      | DPPH         | mg AsAE g⁻¹ FW | 1.32  | 5.82  | 3.34 | 0.81 | 24.25  |
| 35  | Ferric reducing antioxidant      | FRAP         | µmol FeSO₄ g⁻¹ FW | 35.37 | 93.35 | 59.69| 13.16| 22.05  |
Fruit taste was sour-sweet in 96, and also sweet in four accesses. The range of quantitative fruit-related characters was as follows, fruit length: 21.96–29.45 mm, fruit width: 16.59–23.89 mm, fruit flesh thickness: 4.19–10.09 mm, and fruit stalk diameter: 0.58–3.33 mm. Also, fresh fruit weight varied from 2.72 to 6.42 g with an average of 4.54, while dry fruit weight ranged from 0.89 to 2.57 g with an average of 1.55 (Table 1). In the study of a jujube collection from the north of Iran, the ranges of fruit length, fruit width, and fruit have been reported as 14.60–21.30 mm, 15.30–21.60 mm, and 0.79–4.80 g, respectively (Ghazaeian, 2015). Also, the range of 0.14–6.33 g has been recorded for fruit weight in jujube from China (Liu et al., 2009).

Stone length ranged from 13.41 to 19.23 mm, stone width varied from 6.91 to 11.48 mm, and stone weighed from 0.31 to 0.47 g (Table 1). In the study of a jujube collection from the north of Iran, the ranges of stone length, stone width, and stone weight have been reported as 10.20–13.50 mm, 3.80–7.90 mm, and 0.26–1.93 g, respectively (Ghazaeian, 2015). Besides, in the study of a jujube collection from Ukraine, the ranges of stone length and stone width have been reported as 12.84–28.67 mm and 5.06–9.74 mm, respectively (Grygorieva et al., 2014). Also, the ranges of 0.28–0.65 g (Sivakov et al., 1988) and 0.06–1.90 g (Ghosh and Mathew, 2002) have been recorded for stone weight in jujube collections from different countries. The leaf and fruit’s pictures of two accessions studied of Z. jujuba are shown in Figure 2.

### Table 2

Frequency distribution for the measured qualitative morphological characters in the studied accessions of Z. jujuba

| Character                    | Frequency (no. of accessions) |
|------------------------------|-------------------------------|
| Tree growth habit – Spreading | – Spreading (80)              |
| Tree growth vigor – – – –     | – – – – (12) Semi-erect (12)  |
| Tree height – – – –           | – – Intermediate (7) High (93) |
| Tree trunk type – – – – –     | – – Single-trunk (93) Multitrunk (7) – |
| Density of canopy – – – –     | – – – Moderate (12) High (88) |
| Branching – – – –             | – – Intermediate (5) High (95) |
| Branch density – – – – – –    | – – Intermediate (5) High (95) |
| Branch flexibility – – – – –   | – – Low (99) Intermediate (1) – |
| Thorn on annual shoot – – –   | – – Absent (94) Present (6) – |
| Ripening date – – – – – – –   | – – Mid-Sep (30) Late-Sep (70) – |
| Yield – – – – – –             | – – Intermediate (2) High (98) |
| Fruit skin color – – – – – –  | – – Brown-red (1) Brown (99) – |
| Fruit flesh color – – – – – – | – – Cream (1) Light green (99) – |
| Fruit taste – – – – – – – – – | – – Sour-sweet (96) Sweet (4) – |
| Fruit flesh texture – – – – – | – – Soft (17) Firm (83) – |

**FIGURE 2** The leaf and fruit’s pictures of two accessions studied of Z. jujuba

3.2 | Chemical descriptions

Total phenolic content ranged from 1.69 to 14.05 mg GAE g\(^{-1}\) FW. Total flavonoid content varied from 0.25 to 2.01 mg QE g\(^{-1}\).
FW (Table 1). Zhang et al. (2010) reported that the value of total phenolic content in Z. jujuba was 32.80 mg GAE g\(^{-1}\) DW. Phenolic compounds play an essential role in plants as primary antioxidants or free radical scavengers, and antioxidant activity is due to their redox activity, which plays a key role in the uptake and sterilization of free radicals, quenching singlet and triple oxygen, and decomposition of peroxides (Himesh et al., 2011). Phenolic compounds are a group of antioxidant agents that act as terminators of free radicals, and bioactivity may be due to their ability to chelate metals, inhibit lipooxygenases, and free radical scavenging (Lin et al., 2005; Mallavadhani et al., 2006). Phenolic compounds have also been reported to provide antimutagenic and anticarcinogenic properties in humans when approximately 1.00 g of them is consumed daily through a diet rich in vegetables and fruits (Tanaka et al., 1998).

Total anthocyanin content varied from 5.98 to 76.32 µg CyE g\(^{-1}\) FW (Table 1). Anthocyanins are mostly considered as a bioactive compound due to their antioxidant properties. The food industries have explored the potential of anthocyanins to act as natural color, as concerns about the potential side effects of synthetic colors have been increasing (Tarone et al., 2020). Radical scavenging activity ranged from 1.32 to 5.82 mg AsAE g\(^{-1}\) FW, while ferric reducing antioxidant power ranged from 35.37 to 93.35 µM FeSO\(_4\) (Table 1).

Brito et al. (2015) reported low antioxidant activity with DPPH and FRAP in Ziziphus joazeiro. The most important fruit quality-related traits and chemical properties of the selected accessions of Z. jujuba are shown in Table 3.

### 3.3 Correlations between the characters measured

There was a significant and positive correlation between tree height and tree growth vigor (\(r = .54\)) (not shown). A significant correlation was observed between leaf length and leaf width (\(r = .71\)) and agreed with the previous results in jujube (Grygorieva et al., 2014; Ivanisová et al., 2017; Khadivi et al., 2021; Mirheidari et al., 2022; Zandiehvakili & Khadivi, 2021). Fruit yield showed positive and significant correlations with tree growth vigor (\(r = .24\)). Fruit flesh thickness showed significant and positive correlations with fruit length (\(r = .47\)), fruit width (\(r = .74\)), fresh fruit weight (\(r = .47\)), dry fruit weight (\(r = .32\)), fruit stalk length (\(r = .38\)), and fruit stalk diameter (\(r = .47\)), and corresponded with the previous results in jujube (Grygorieva et al., 2014; Ivanisová et al., 2017; Khadivi et al., 2021; Mirheidari et al., 2022; Zandiehvakili & Khadivi, 2021).

Total phenolic content was significantly and positively correlated with fruit taste (\(r = .38\)), total flavonoid content (\(r = .65\)), radical scavenging activity (\(r = .48\)), and ferric reducing antioxidant (\(r = .56\)) and agreed with the previous findings in jujube (Gao et al., 2012; Zandiehvakili & Khadivi, 2021; Zhang et al., 2010). Total anthocyanin content was significantly and positively correlated with ripening date (\(r = .28\)), yield (\(r = .22\)), fresh fruit weight

### Table 3: The most important fruit quality-related traits and chemical properties of superior accessions of Z. jujuba in this investigation

| Accession | Yield | Fresh fruit weight (g) | Fruit flesh thickness (mm) | Fruit skin color | FRAP (µmol) | Total anthocyanin (µg) |
|-----------|-------|------------------------|---------------------------|-----------------|-------------|----------------------|
| Tootkan-50 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-97 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-61 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-99 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-55 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-67 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-59 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-22 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-66 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
| Tootkan-75 High | 20.43 | 6.36 | 5.29 | Soft | 2.42 | 74.26 |
TABLE 4  The fruit traits associated with chemical properties in *Z. jujuba* as revealed using MRA and coefficients

| Dependent character         | Independent character      | r    | $r^2$ | β     | t value | p value |
|-----------------------------|---------------------------|------|------|-------|---------|---------|
| Total phenolic content      | Dry fruit weight          | .377 | .142 | −.583 | −4.213  | .000    |
| Fruit flesh texture         |                           | .456 b | .208 | −.278 | −3.271  | .001    |
| Fruit taste                 |                           | .502 c | .252 | .279  | 3.097   | .003    |
| Fresh fruit weight          |                           | .545 d | .297 | .363  | 2.514   | .014    |
| Total flavonoid content     | Fruit flesh color         | .239 a | .057 | −.239 | −2.437  | .017    |
|                            | Fresh fruit weight        | .305 b | .197 | .363  | 2.514   | .014    |
| Total anthocyanin content   | Fruit flesh color         | .503 a | .173 | −.321 | 4.324   | .000    |
|                            | Dry fruit weight          | .555 b | .232 | −.285 | −2.983  | .002    |
|                            | Fruit flesh thickness     | .591 c | .263 | .245  | 2.234   | .002    |

TABLE 5  Eigenvalues of principal component axes from principal component analysis (PCA) of morphological and chemical characters in the studied accessions of *Z. jujuba*

| Character                     | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 | Component 6 | Component 7 | Component 8 | Component 9 | Component 10 | Component 11 |
|-------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Habit of tree growth          | −0.24       | 0.14        | −0.10       | 0.19        | 0.08        | 0.12        | −0.47       | 0.17        | −0.18       | 0.36        | 0.20        |
| Vigor of tree growth          | 0.32        | 0.00        | −0.09       | 0.05        | −0.44       | 0.03        | 0.11        | 0.18        | 0.58        | −0.26       | 0.25        |
| Height of tree                | 0.48        | −0.03       | −0.04       | 0.11        | −0.41       | 0.07        | 0.11        | −0.13       | 0.07        | −0.25       | 0.55        |
| Trunk type                    | −0.24       | −0.01       | −0.05       | −0.10       | 0.11        | 0.02        | −0.03       | 0.02        | 0.03        | −0.71       | 0.05        |
| Density of canopy             | 0.59        | 0.00        | −0.02       | −0.40       | −0.38       | 0.21        | 0.17        | 0.05        | 0.29        | −0.04       | −0.02       |
| Branching                     | 0.96 a      | 0.01        | −0.01       | −0.05       | −0.08       | 0.09        | 0.00        | −0.01       | −0.01       | 0.17        | −0.02       |
| Branch density                | 0.96 a      | 0.01        | −0.01       | −0.05       | −0.08       | 0.09        | 0.00        | −0.01       | −0.01       | 0.17        | −0.02       |
| Branch flexibility            | 0.13        | −0.10       | 0.23        | 0.59        | 0.06        | −0.30       | −0.06       | −0.17       | 0.16        | −0.08       | −0.14       |
| Annual shoot length           | −0.04       | 0.06        | 0.03        | 0.02        | 0.83 a      | 0.01        | 0.05        | −0.19       | 0.01        | −0.02       | −0.06       |
| Thorn on annual shoot         | −0.22       | 0.04        | 0.05        | 0.40        | 0.73 a      | −0.17       | −0.14       | 0.03        | 0.00        | −0.06       | −0.03       |
| Length of leaf                | 0.04        | 0.03        | 0.02        | −0.13       | 0.00        | 0.84 a      | 0.11        | 0.06        | 0.02        | −0.05       | 0.01        |
| Width of leaf                 | 0.10        | −0.04       | 0.12        | −0.04       | −0.14       | 0.84 a      | −0.21       | 0.02        | 0.05        | −0.01       | 0.07        |
| Length of petiole             | 0.10        | −0.06       | 0.09        | 0.11        | 0.00        | 0.83 a      | 0.10        | −0.07       | 0.03        | 0.01        | 0.00        |
| Thickness of petiole          | −0.20       | 0.14        | −0.06       | 0.03        | 0.37        | −0.07       | 0.08        | −0.46       | 0.09        | 0.47        | 0.27        |
| Ripening date                 | 0.35        | −0.27       | 0.12        | −0.35       | −0.24       | 0.15        | 0.37        | 0.42        | 0.12        | −0.16       | −0.09       |
| Yield                         | 0.03        | 0.02        | −0.01       | 0.12        | −0.08       | −0.10       | −0.09       | 0.78 b      | 0.01        | −0.12       | 0.03        |
| Length of fruit               | −0.04       | 0.31        | 0.57        | 0.01        | −0.03       | 0.20        | 0.64 a      | −0.08       | −0.02       | −0.01       | −0.01       |
| Width of fruit                | −0.17       | 0.51        | 0.70 a      | −0.06       | 0.06        | 0.06        | 0.19        | −0.13       | −0.05       | 0.07        | 0.05        |
| Weight of fruit flesh         | 0.00        | 0.04        | 0.92 b      | −0.08       | 0.03        | 0.05        | 0.09        | 0.13        | 0.06        | 0.07        | 0.07        |
| Dry fruit weight              | 0.12        | −0.02       | 0.76 a      | −0.24       | 0.03        | 0.07        | −0.01       | 0.31        | 0.09        | −0.02       | 0.11        |
| Length of fruit stalk         | 0.13        | 0.70 a      | 0.18        | −0.11       | −0.05       | 0.15        | 0.12        | 0.21        | 0.04        | −0.11       | −0.06       |
| Diameter of fruit stalk       | −0.13       | 0.82 s      | 0.12        | 0.14        | 0.11        | −0.14       | 0.11        | −0.22       | −0.08       | 0.10        | 0.06        |
| Fruit flesh thickness         | −0.14       | 0.55        | 0.60 b      | 0.14        | −0.12       | 0.21        | −0.15       | −0.18       | −0.11       | −0.20       | −0.09       |
| Fruit skin color              | −0.05       | 0.00        | 0.06        | −0.09       | 0.04        | 0.05        | −0.04       | 0.02        | 0.91 b      | −0.01       | −0.08       |
| Fruit flesh color             | 0.32        | −0.01       | 0.08        | −0.15       | −0.44       | −0.04       | −0.13       | −0.06       | −0.05       | 0.53        | −0.42       |

(Continues)
Radical scavenging activity was positively and significantly correlated with fruit taste ($r = .26$) and ferric reducing antioxidant power ($r = .87$) and corresponded with the previous findings in jujube (Gao et al., 2012; Wang et al., 2011; Zhang et al., 2010).

### PCA and HCA

The PCA showed that the first 11 components accounted for 77.38% of total variance (Table 5). Branching and branch density were found to be correlated with PC1, accounting for 9.15% of total variance. The PC2 included fruit stalk length, fruit stalk diameter, and fruit stone width, accounting for 8.83% of total variance. Four characters, including fruit width, fresh fruit weight, dry fruit weight, and fruit flesh thickness, formed the PC3, accounting for 8.74% of total variance. In the previous studies, PCA has been used to investigate phenotypic diversity within *Ziziphus* species (Baghazadeh-Daryaii et al., 2013; Soheil et al., 2014).

![Scatter plot for the studied accessions of Z. jujuba based on PC1/PC2/PC3 of combined data of morphological and chemical data. The “T” symbol represents the accessions of Tootkan area.](image)

3.5 PCA and HCA

The PCA showed that the first 11 components accounted for 77.38% of total variance (Table 5). Branching and branch density were found to be correlated with PC1, accounting for 9.15% of total variance. The PC2 included fruit stalk length, fruit stalk diameter, and fruit stone width, accounting for 8.83% of total variance. Four characters, including fruit width, fresh fruit weight, dry fruit weight, and fruit flesh thickness, formed the PC3, accounting for 8.74% of total variance. In the previous studies, PCA has been used to investigate phenotypic diversity within *Ziziphus* species (Baghazadeh-Daryaii et al., 2013; Soheil et al., 2014).

### Table 5 (Continued)

| Character                   | Component | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    |
|-----------------------------|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Fruit taste                 |           | -0.10 | 0.03  | -0.06 | 0.18  | 0.68* | -0.04 | 0.01  | 0.06  | -0.59 | -0.18 | 0.13  |
| Fruit flesh texture         |           | 0.16  | 0.17  | 0.25  | -0.04 | 0.03  | 0.20  | -0.53 | -0.19 | 0.22  | -0.06 | -0.31 |
| Fruit stone length          |           | 0.09  | 0.29  | 0.12  | -0.05 | 0.04  | 0.06  | 0.82* | 0.00  | 0.02  | 0.09  | 0.02  |
| Fruit stone width           |           | 0.04  | 0.91* | 0.02  | -0.07 | 0.05  | -0.09 | 0.01  | -0.02 | 0.04  | 0.11  | 0.01  |
| Weight of fruit stone       |           | 0.16  | 0.42  | -0.17 | -0.19 | 0.22  | -0.10 | 0.22  | 0.24  | 0.06  | 0.43  | 0.18  |
| Total phenolic content      |           | -0.09 | -0.07 | -0.26 | 0.59  | 0.39  | -0.39 | 0.23  | 0.00  | 0.00  | 0.08  | 0.01  |
| Total flavonoid content     |           | -0.04 | 0.02  | 0.17  | -0.06 | 0.01  | 0.06  | -0.01 | -0.06 | -0.07 | 0.04  | 0.79* |
| Total anthocyanin content   |           | -0.12 | -0.03 | 0.19  | -0.04 | -0.02 | 0.09  | 0.09  | 0.63* | 0.04  | 0.16  | -0.07 |
| Radical scavenging activity |           | -0.05 | -0.05 | -0.16 | 0.89* | 0.06  | 0.16  | -0.07 | 0.12  | -0.04 | -0.04 | -0.04 |
| Ferric reducing antioxidant |           | -0.15 | 0.06  | -0.15 | 0.88* | 0.10  | 0.03  | -0.04 | 0.04  | -0.17 | 0.12  | 0.11  |
| Total                       |           | 3.20  | 3.09  | 3.06  | 3.03  | 2.89  | 2.74  | 2.11  | 1.93  | 1.80  | 1.72  | 1.52  |
| % of Variance               |           | 9.15  | 8.83  | 8.74  | 8.65  | 8.26  | 7.82  | 6.04  | 5.50  | 5.16  | 4.91  | 4.34  |
| Cumulative %                |           | 9.15  | 17.98 | 26.72 | 35.36 | 43.62 | 51.44 | 57.48 | 62.98 | 68.13 | 73.04 | 77.38 |

*Eigenvalues ≥0.60 are significant.*
FIGURE 4  Ward cluster analysis of the studied accessions of *Z. jujuba* based on the combined data of morphological and chemical traits using Euclidean distances
The scatter plot created using PC1/PC2/PC3 showed variations among the accessions (Figure 3). Tootkan-29 accession showed high differences with other, characterized by low fresh fruit weight, dry fruit weight, and fruit flesh thickness. Also, five accessions, including Tootkan-1, Tootkan-3, Tootkan-8, Tootkan-9, and Tootkan-10, formed another group, characterized by moderate fresh fruit weight, dry fruit weight, and fruit flesh thickness. The remaining accessions were placed into the same group.

Besides, HCA with Ward dendrogram showed that the accessions were clustered into two major clusters (Figure 4). The first cluster (I) contained 49 accessions, forming two subclusters. Subcluster I-A included 14 accessions, characterized by the highest values for leaf length, leaf width, petiole length, petiole thickness, and fruit stone weight. Subcluster I-B included 35 accessions, characterized by moderate values for leaf length, leaf width, petiole length, petiole thickness, and fruit stone weight. The remaining 51 accessions were placed into the second cluster (II), forming two subclusters, characterized by low values for above characters.

4 | CONCLUSION

Genetic diversity of indigenous genotypes and their related wild accessions is the primary basis for many agricultural research programs, especially breeding programs. Therefore, it is necessary to know the characteristics and potential of these valuable resources collected to use in research programs, so that specialized experts can use them to improve the characters in their programs. The present study showed high diversity in morphological and chemical properties of some jujube accessions. Based on the traits related to fruit quality such as high fruit weight, soft fruit flesh texture, brown fruit skin color, and sweet fruit flavor, as well as in terms of chemical characteristics related to medicinal properties such as higher total anthocyanin content and higher antioxidant activity, 13 accessions, including Tootkan-50, Tootkan-97, Tootkan-99, Tootkan-61, Tootkan-55, Tootkan-59, Tootkan-67, Tootkan-22, Tootkan-96, Tootkan-66, Tootkan-75, Tootkan-49, and Tootkan-38, were superior. The commercial orchard of those best accessions should be extensively constructed to take advantage of the high yield of *Z. jujuba* as a crop and its medicinal properties.

ACKNOWLEDGMENT

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

RESEARCH INVOLVING HUMAN PARTICIPANTS AND/OR ANIMALS

None.

INFORMED CONSENT

None.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Ali Khadivi https://orcid.org/0000-0001-6354-445X

REFERENCES

Baghazadeh-Daryaii, L., Sharifi-Sirchi, G.-R., & Samsampoor, D. (2017). Morphological, phytochemical and genetic diversity of *Ziziphus spina-christi* (L.) Des. in South and Southeastern of Iran. *Journal of Applied Research on Medicinal and Aromatic Plants*, 7, 99–107. https://doi.org/10.1016/j.jarmap.2017.06.006

Behera, T. K., Gaikward, A. B., Singh, A. K., & Staub, J. E. (2008). Relative efficiency of DNA markers (RAPD, ISSR and AFLP) in detecting genetic diversity of bitter gourd (*Momordica charantia* L.). *Journal of the Science of Food and Agriculture*, 88, 733–737.

Benzie, I. F. &., & Strain, J. J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of ‘antioxidant power’: The FRAP assay. *Analytical Biochemistry*, 239, 70–76. https://doi.org/10.1006/abio.1996.0292

Brito, S. M. O., Coutinho, H. D. M., Talvani, A., Coronel, C., Barbosa, A. G. R., Vega, C., Figueredo, F. G., Tintino, S. R., Lima, L. F., Boligon, A. A., Athayde, M. L., & Menezes, I. R. A. (2015). Analysis of bioactivities and chemical composition of *Ziziphus joaazeiro* Mart. using HPLC-DAD. *Food Chemistry*, 186, 185–191. https://doi.org/10.1016/j.foodchem.2014.10.031

Chen, J., Liu, X., Li, Z., Qi, A., Yao, P., Zhou, Z., Dong, T., & Tsim, K. (2017). A review of dietary *Ziziphus jujuba* fruit (Jujube): Developing food health supplements for brain protection. *Evidence-Based Complementary and Alternative Medicine*, 2017(3019568), 1–10.

Gao, Q., Wu, C. S., Yu, J. G., Wang, M., Ma, Y. J., & Li, C. L. (2012). Textural characteristic, antioxidant activity, sugar, organic acid, and phenolic profiles of 10 promising jujube (*Ziziphus jujuba* Mill.) selections. *Journal of Food Science*, 77(11), C1218–C1225.

Gao, Q., Wu, P., Liu, J., Wu, C., Parry, J., & Wang, M. (2011). Physicochemical properties and antioxidant capacity of different jujube (*Ziziphus jujuba* Mill.) cultivars grown in loess plateau of China. *Scientia Horticulturae*, 130, 67–72.

Ghazaeian, M. (2015). Genetic diversity of jujube (*Ziziphus jujuba* Mill.) germplasm based on vegetative and fruits physicochemical characteristics from Golestan province of Iran. *Comunicata Scientiae*, 6(1), 10–16.

Ghosh, S. N., & Matthew, B. (2002). Performance of nine ber (*Ziziphus mauritiana* Lamk) cultivars on topworking in the semi-arid region of West Bengal. *Journal of Applied Horticulture*, 4, 49–51. https://doi.org/10.37855/jah.2002.v04i01.16

Grygorieva, O., Abramova, V., Karnatovska, M., Bheja, R., & Brindza, J. (2014). Morphological characteristics of fruits, drupes and seeds in accessions of *Ziziphus jujuba* Mill. *Potravinarstvo Scientific Journal for Food Industry*, 32, 27–42.

Grzegorzcyk-Karolak, L., Kuzma, L., & Wysokinska, H. (2015). Study on the chemical composition and antioxidant activity of extracts from shoot culture and regenerated plants of *Scutellaria altissima* L. *Acta Physiologiae Plantarum*, 37, 1736. https://doi.org/10.1007/s11738-014-1736-0

Halliwell, B., & Gutteridge, J. (1990). The antioxidants of human extracellular fluids. *Archives of Biochemistry and Biophysics*, 280(1), 1–8.

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). *PAST*: Paleontological statistics software package for education and data analysis. *Paleontologia Electronica*, 4(1), 9.

Himesh, S., Sarvesh, S., Sharan, P., & Singhai, A. (2011). Preliminary phytochemical screening and HPLC analysis of flavonoid from methanolic extract of leaves of *Annona squamosa*. *International Research Journal of Pharmacy*, 2(5), 242–246.
Hosseini, A. S., Akramian, M., Khadivi, A., & Salehi-Arjmand, H. (2018). Phenotypic and chemical variation of black mulberry (Morus nigra) accessions. *Industrial Crops and Products*, 117, 260–271.

Ivanisová, E., Grygorieva, O., Abrahamová, V., Schubertova, Z., Terentjeva, M., & Brindza, J. (2017). Characterization of morphological parameters and biological activity of jujube fruit (*Ziziphus jujuba* Mill.). *Journal of Berry Research*, 7(4), 249–260.

Karakaya, O., Aglar, E., Ozturk, B., Gun, S., Ates, U., & Ocalan, O. N. (2020). Changes of quality traits and phytochemical components of jujube fruit treated with preharvest GA3 and Parka during cold storage. *Turkish Journal of Food and Agriculture Sciences*, 2(2), 30–37. https://doi.org/10.14744/turkjfas.2020.007

Khadivi, A. (2018). Phenotypic characterization of *Elaeagnus angustifolia* using multivariate analysis. *Industrial Crops Products*, 120, 155–161. https://doi.org/10.1016/j.indcrops.2018.04.050

Khadivi, A., Mirheidari, F., Moradi, Y., & Paryan, S. (2021). Identification of superior jujube (*Ziziphus jujuba* Mill.) genotypes based on morphological and fruit characterizations. *Food Sciences and Nutrition*, 9, 3165–3176.

Khadivi-Khub, A., & Anjam, K. (2014). Morphological characterization of *Prunus scoparia* using multivariate analysis. *Plant Systematics and Evolution*, 300, 1361–1372. https://doi.org/10.1007/s00606-013-0967-7

Lin, H.-F., Traver, D., Zhu, H., Dooley, K., Paw, B. H., Zon, L. I., & Handin, R. I. (2005). Analysis of Thrombocyte development in CD41-GFP transgenic zebrafish. *Blood*, 106, 3803–3810. https://doi.org/10.1182/blood-2005-01-0179

Liu, P., Liu, M. J., Zhao, Z. H., Liu, X. Y., Wang, J. R., & Yan, C. (2009). Investigation on the characteristics of fruiting and seed development in Chinese jujube (*Ziziphus jujuba* Mill.). *Acta Horticulturae*, 840, 209–214. https://doi.org/10.17660/ActaHortic.2009.840.26

Mallavadhani, U., Sudhakar, A., Sathyarayana, K., Mahapatra, A., Li, A., & Richard, B. (2006). Chemical and analytical screening of some edible mushrooms. *Food Chemistry*, 95, 58–64.

Mirheidari, F., Khadivi, A., Saeidifar, A., & Moradi, Y. (2022). Selection of superior genotypes of Indian jujube (*Ziziphus mauritiana* Lamk.) as revealed by fruit-related traits. *Food Sciences and Nutrition*, 10, 903–913. https://doi.org/10.1002/fsn3.2721

Nogues, S., & Baker, N. R. (2000). Effects of drought on photosynthesis in Mediterranean plants grown under enhanced UV-B radiation. *Journal of Experimental Botany*, 51, 1309–1317.

Norouzi, E., Erfani-Moghadam, J., Fazeli, A., & Khadivi, A. (2017). Morphological variability within and among three species of *Ziziphus* genus using multivariate analysis. *Scientia Horticulturae*, 222, 180–186. https://doi.org/10.1016/j.scienta.2017.05.016

Norusis, M. J. (1998). SPSS/PC advanced statistics. SPSS Inc.

Ozturk, B., Yildiz, M., Yildiz, K., & Gun, S. (2021). Maintaining the post-harvest quality and bioactive compounds of jujube (*Ziziphus jujuba* Mill. cv. ‘Li’) fruit by applying 1-methylocyclopropene. *Scientia Horticulturae*, 275, 109671.

Saha, N. N. (1997). Conservation and utilization of fruit plant genetic resources: Bangladesh perspective. In M. G. Hossain, R. K. Aurora, & P. N. Mathur (Eds), *The International Plant Genetic Resources Institute*. (pp. 20–30). BARC-IPGRI.

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture*, 16, 144–158.

Sivakov, L., Georgiev, D., Ristevski, B., & Mitreski, Z. (1988). Pomological and technological characteristics of Chinese jujube (*Ziziphus jujuba*) in Macedonia. *Jugoslovensko Vocarstvo*, 22, 387–392.

Tanaka, M., Kuie, C., Nagashima, Y., & Taguchi, T. (1998). Applications of antioxidative maillard reaction products from histidine and glucose to sardine products. *Nippon Suisan Gakaishi*, 54, 1409–1414.

Tarone, A. G., Cazarin, C. B. B., & Junior, M. R. M. (2020). Anthocyanins: New techniques and challenges in microencapsulation. *Food Research International*, 133, 109092. https://doi.org/10.1016/j.foodres.2020.109092

Tatari, M., Ghasemi, A., & Mousavi, A. (2016). Genetic diversity in jujube germplasm (*Ziziphus jujuba* Mill.) based on morphological and pomological traits in Isfahan province, Iran. *Crop Breeding Journal*, 6(2), 79–85.

Wang, Y. F., Tang, F., Xia, J. D., Yu, T., Wang, J., Azhati, R., & Zheng, X. D. (2011). A combination of marine yeast and food additive enhances preventive effects on postharvest decay of jujubes (*Zizyphus jujuba*). *Food Chemistry*, 125, 835–840. https://doi.org/10.1016/j.foodchem.2010.09.032

Zandiehvakili, G., & Khadivi, A. (2021). Identification of the promising *Ziziphus spinosa-christi* (L.) Willd. genotypes using pomological and chemical proprieties. *Food Sciences and Nutrition*, 9, 5698–5711.

Zhang, H., Jiang, L., Ye, S., Ye, Y., & Ren, F. (2010). Systematic evaluation of antioxidative capacities of the ethanolic extract of different tissues of jujube (*Ziziphus jujuba* Mill.) from China. *Food and Chemical Toxicology*, 48(6), 1461–1465.

Zhu, Z., Liang, Z., & Han, R. (2009). Saikosaponin accumulation and antioxidative protection in drought-stressed Bupleurum chinense DC. plants. *Environmental and Experimental Botany*, 66, 326–333. https://doi.org/10.1016/j.envexpbot.2009.03.017

How to cite this article: Khadivi, A., & Beigi, F. (2022). Morphological and chemical characterizations of jujube (*Ziziphus jujuba* Mill.) to select superior accessions. *Food Science & Nutrition*, 10, 2213–2223. https://doi.org/10.1002/fsn3.2831