

Research Article

Morphological and Physicochemical Characterization of Some Exotic Fig (*Ficus carica* L.) Genotypes in Bangladesh

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This study investigated the diversity among five introduced fig (*Ficus carica* L.) germplasm in Bangladesh, focusing on their morphological and physicochemical characteristics. The primary goal was to assess morphological variations, including their genetic potential for future improvement, and to examine their biochemical properties. The findings demonstrated significant variations in plant growth attributes, leaf characteristics, fruit traits, sensory attributes, and biochemical properties among the genotypes under study. Notably, two genotypes, Khurtamoni (KH) and Brown Turkey (BT), emerged as exceptional performers based on their combined pomological and nutritional characteristics compared to Golden Riverside (GRS), Egyptian-2 (E-2), and Saudi Yellow Arabia (SYA). However, KH displayed outstanding growth characteristics, excellent fruit attributes, including a remarkable fruit yield of 65.67 fruits per plant, and exceptional nutri-medicinal properties with a total phenolic content (TPC) of 8.03 mg GAE/100 g FW, a total flavonoid content (TFC) of 31.084 mg QE/100 g FW, and an IC₅₀ value of 85.39 µg/ml. Besides, BT excelled in terms of taste, texture, juiciness, and various nutritional parameters with an ascorbic acid content of 4.4 mg/100 g, a TFC of 28.348 mg QE/100 g FW, and an IC₅₀ value of 83.685 µg/ml. The genotype ranking, taking into account both morphological and biochemical characteristics, reveals the following order: KH > BT > GRS > SYA > E-2 as per the principle component analysis. Consequently, the study identifies KH and BT as promising candidates for fig cultivation and breeding in Bangladesh due to their exceptional attributes. Furthermore, the genotype ranking offers valuable guidance for selecting germplasm for breeding programs and promoting sustainable fig cultivation in Bangladesh.

1. Introduction

Fig (*Ficus carica*) is a composite fruit called “syconium” belonging to the family Moraceae. It can be grown well in a wide range of soils such as heavy clay, loams, sandy loam, and light sand. Figs (*Ficus racemosa* and *Ficus hispida*) grow wild in Bangladesh and are tree-type plants. On the other hand, teen (exotic fig, *Ficus carica*) is an ideal shrubby plant suitable for yard garden to replace the wild tree-type figs (*Ficus* sp.) growing spontaneously in

Bangladesh [1]. The fig is recently introduced exotic fruit [2] that has been well accepted by the fruit growers and researchers due to its adaptability to subtropical and mild temperate climates, wide soil ranges having year-round fruit bearing characteristics. Historically, the fruit has its origin 2000 years ago and among 800 species of fig, *Ficus carica* L. is the most cultivated one. Having religious importance, the fruit is mentioned in The Holy Quran, Hadith, and The Bible [3]. It is a native tree of the Middle East, and its cultivation originated from the fertile valleys

of the Arabic peninsula [4] and has spread to the sub-continent in the recent years. The fruits are a good source of minerals and bioactive compounds. The fruits can be consumed in fresh or as processed forms such as dried fig, fig juice, pickles, jam, and jelly. They are considered healthy fruits because they are a rich source of minerals, amino acids, fiber, and carotenoids. Fresh figs provide a large amount of antioxidants, polyphenols, and flavonoids [5, 6]. Besides these, dried figs have sweet and chewy taste. The fruits are relished as dried fruit due to characteristic detectable flavour. It also helps to regulate blood pressure and blood cholesterol due to the presence of potassium, omega-6, and omega-3 fatty acids [7].

Being exotic, phenotypic expression of this introduced fig species is largely dependent on the genetic potentialities and environmental features of the growing areas. Therefore, characterizing germplasm diversity is a prerequisite for effective utilization of genetic resources. The evaluation of genetic variability is the first step in any breeding program, and the progress depends on the level/degree/magnitude of genetic variability present in the population. The classifications and evaluations of exotic fig have primarily focused on the phenotypic expressions such as color, shape, and other agronomical characteristics of the plants, leaves, stems and fruits which vary depending on cultivar differences, degree of maturity, and growing region [8–10]. Morphological, pomological, and biochemical characterization of germplasm is crucial for effective genetic resource management, identifying valuable plant materials, and enhancing crop resilience [11]. It provides insights into nutritional and medicinal properties, aligns genotypes with consumer preferences, and fosters sustainable agriculture, biodiversity conservation, and resilient crop varieties [12–14].

Despite ongoing global research on fig genetic resources, there is a dearth of information concerning fig genotypes in Bangladesh. The distinctiveness of this study lies in its pioneering investigation of morphological, pomological, and biochemical properties within the context of Bangladesh's environment. The study's core objective was to assess morphological diversity and genetic potential while examining the biochemical and bioactive properties of fig genotypes.

2. Materials and Methods

2.1. Plant Material, Sampling, and Experimental Design. The plant material, comprising five exotic genotypes from different regions of Bangladesh, was gathered to assess morphological and biochemical variations and ascertain the genetic potentiality for future improvement programs. Each of the collected genotypes was assigned a distinct accession number for convenience: Golden Riverside (GRS), Khur-tamoni (KH), Egyptian-2 (E-2), Brown Turkey (BT), and Saudi Yellow Arabia (SYA). The experiment was carried out at the Horticulture Research Field of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) in Salna, Gazipur, located at 24.09° North latitude and 90.26° East longitude. A randomized complete block design

(RCBD) with three replications was employed where five plants per replication were considered for evaluation. The genotype evaluation was conducted during 2020–2022 where at the start of the experiment, the plants were four years of age. Morphological assessment was performed during 2020–2021, while biochemical evaluation was performed during 2021–2022.

2.2. Morphological Assessment. A total of 45 quantitative and qualitative traits (12 plant growth parameters, 9 leaf characters, and 24 fruit attributes) were determined according to the fig descriptors prepared by IPGRI and CIHEAM [15] with some minor modifications that showed high discrimination value depending on the present study. Three replications per sample were considered where each replication comprised of five samples for plant measurements and ten samples for leaf and fruit measurements. Qualitative data were obtained through onsite observations in the experimental field, with field observations compared to fig descriptors for data consistency and accuracy. Quantitative attributes were measured using meter scale, manual slide caliper, and measuring tape. Notably, fruit traits were assessed from the main crop of the fig plants. Some of the leaf and fruit characters were estimated as per the guideline of UPOV [16] (Figure 1).

2.3. Biochemical Analysis

2.3.1. Sample Extract Preparation. Whole fruits were used in the sample preparation process. The sample was prepared by blending 20 g of fresh fruit slices with distilled water and centrifuged at 0°C for 20 minutes at a speed of 4000 rpm with a centrifuge machine (MPW-260R). The supernatant liquid was collected in a test tube and covered with foil paper. This extract was used for estimation of ascorbic acid, total sugar, and reducing sugar.

2.3.2. β -Carotene Content (Vitamin A). The analysis of vitamin A or β -carotene content was conducted through a modified ultraviolet scanning method, as described by Hagos et al. [17], and the results were expressed in terms of mg/100 g.

2.3.3. Ascorbic Acid Content (Vitamin C). Ascorbic acid content of fresh fig fruit was determined using the titration method [18] with some modifications, and the results were expressed in terms of mg/100 g.

2.3.4. Sugar. Using Bertrand A, Bertrand B, and Bertrand C standard solutions, reducing sugar (RS) and total sugar (TS) were estimated as per the procedure of Somogyi [19]; nonreducing sugar (NRS) was estimated from the difference between TS and RS, and the results were expressed in terms of mg/100 g.

2.3.5. Preparation of Methanolic Extract. A methanolic extract was prepared by immersing 0.5 g of fresh fruit sample in 12.5 ml of methanol, followed by a 2.5-hour of water bath

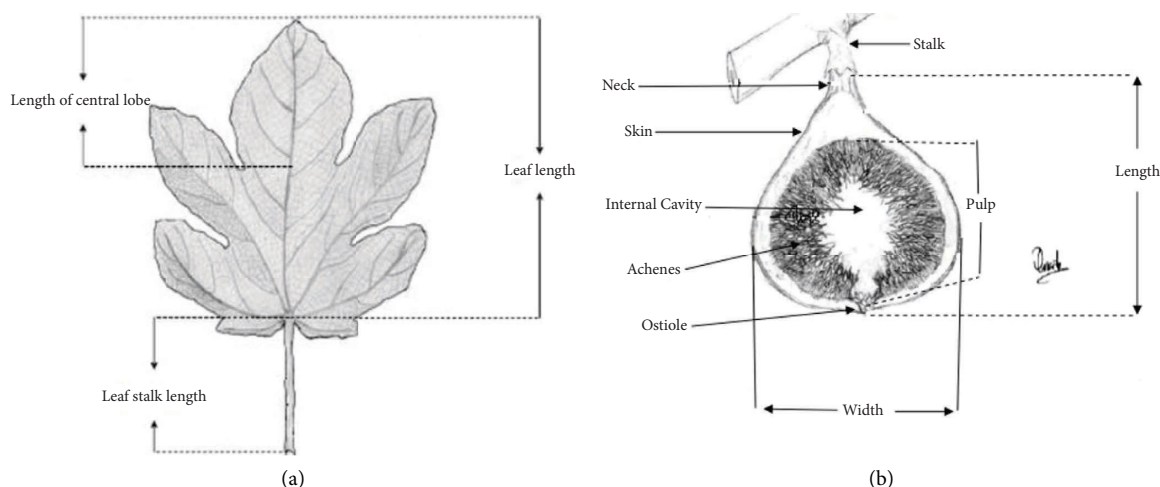


FIGURE 1: Model photographs for estimating the morphology of leaf (a) and fruit (b) as guided in UPOV [16].

at 30°C. After centrifugation and filtration, the resulting supernatant was stored at 4°C for assessing total phenolic content, total flavonoid content, and total antioxidant activity.

2.3.6. Total Phenolic Content (TPC). The total phenolic content (TPC) from fresh fig samples was estimated using the Folin–Ciocalteu procedure [6, 20] with some modification and is expressed as mg GAE/100 g FW.

2.3.7. Total Flavonoid Content (TFC). Total flavonoid content was determined by aluminum chloride colorimetric method [6, 21] with some modifications and is expressed as mg QE/100 g FW.

2.3.8. Antioxidant Activity (AA) Estimation. Antioxidant activity of the fresh fig fruit was estimated using DPPH radical scavenging assay (RSA) using the procedure of Mbondo et al. [22] with some modifications and is expressed as $\mu\text{g/ml}$.

2.3.9. Total Anthocyanin Content (TAC). The total anthocyanin content was analyzed by following the methods of Murray and Hackett [23] with slight modifications and is expressed in terms of $\mu\text{g/g}$ FW.

2.3.10. Fruit Sensory and Organoleptic Qualities. Fruit sensory and organoleptic qualities were determined through intensive observation by a panelist of five members who noted the pulp flavour and taste of fruit from each genotype. Besides, fruit firmness, flesh color, pulp texture, and juiciness were estimated by the visual observation by the researchers.

2.4. Statistical Analysis. Data were assessed with qualitative and descriptive analyses where needed, and quantitative parameters were tested through one-way ANOVA. The treatment means were separated by Fisher's least significant

difference (LSD) test, using a p value ≤ 0.05 to be statistically significant. A correlation matrix was generated using PAST software to assess the interrelationships among the variables. Qualitative parameters were scored as per fig descriptor (Table 1) before performing correlation matrix.

3. Results and Discussion

3.1. Plant Growth Attributes of Fig Genotypes

3.1.1. Qualitative Attributes. The five fig genotypes exhibited variations in terms of qualitative plant growth patterns (Table 2). Erect, semierect, spreading, weeping, and open types of growth habit were noticed where Saudi Yellow Arabia (SYA) displayed a semierect habit, while Golden Riverside (GRS), Khurtamoni (Kh), Egyptian-2 (E-2), and Brown Turkey (BT) exhibited spreading, weeping, erect, and open growth habits, respectively. High tree vigour was evident in E-2, while the other genotypes showed intermediate vigour. KH had dense branching, E-2 had sparse branching, and the remaining genotypes had intermediate branching habit. Shoot color for GRS, E-2, and SYA was brown, whereas KH and BT had grey shoots. GRS and SYA had a moderate tendency to form sucker, while KH had a high suckering tendency and E-2 showed a low suckering tendency. The study's findings on qualitative plant growth patterns, tree vigour, branching habits, shoot colors, and sucker formation align with previous research studies. Podgornik et al. [24] and Khadivi et al. [25] also observed open and spreading growth habits in fig trees, and Karaat [26] noted intermediate tree vigour in fig genotypes. Khan et al. [27] reported that the majority of fig accessions had dense branching, while Karaat [26] found that fig genotypes typically displayed brown shoots. Furthermore, the tendency for sucker formation observed in this study corresponded with Karaat's [26] findings of a medium level of sucker formation among the genotypes.

3.1.2. Quantitative Attributes. Vegetative characters for plant growth of five fig genotypes showed wide variability among them (Table 3). Plant height (PH), base girth (BG),

TABLE 1: Scoring of qualitative characters of the fig accessions.

Characters observed	Scoring
Plant growth habit (PGH)	1: erect; 2: semierect; 3: open; 4: spreading; 5: weeping
Tree vigour (TV)	5: intermediate; 7: high
Branching habit (BH)	3: sparse; 5: intermediate; 7: dense
Shoot color (SC)	2: grey; 3: brown
Suckering tendency (ST)	1: low; 2: medium; 3: high
Shape of leaf base (SLB)	3: calcarate; 4: decurrent
Leaf margin dentation (LMD)	0: no dentation (entire); 2: side dentation
Leaf venation (LV)	3: apparent
Spicule density (SD)	0: none; 3: sparse; 5: intermediate; 7: dense
Fruit shape (FS)	1: oblong; 2: globose; 3: oblate
Shape of fruit stalk (SFS)	1: variously enlarged; 2: long and slender
Fruit skin crack (FSC)	3: minute cracks
Fruit rib (FR)	0: none; 1: sparse; 2: intermediate
Fruit color (FC)	2: purple; 3: brown; 6: yellow green; 7: yellow
Fruit firmness (FF)	1: soft; 2: medium
Flesh color (FLC)	2: amber; 3: pink; 4: red; 5: dark red
Pulp texture (PT)	3: fine; 5: medium; 7: coarse
Pulp flavour (PF)	2: little flavour; 3: aromatic
Juiciness (JC)	5: little juicy; 7: juicy; 8: very juicy
Taste (Tst)	1: good; 2: very good; 3: excellent

TABLE 2: Qualitative plant growth behaviors of five fig genotypes.

Genotypes	Plant growth habit	Tree vigour	Branching habit	Shoot color	Suckering tendency
GRS	Spreading	Intermediate	Intermediate	Brown	Medium
KH	Weeping	Intermediate	Dense	Grey	High
E-2	Erect	High	Sparse	Brown	Low
BT	Open	Intermediate	Intermediate	Grey	High
SYA	Semierect	Intermediate	Intermediate	Brown	Medium

GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown Turkey, and SYA: Saudi Yellow Arabia. Here, within the replication, five samples ($n = 5$) were studied to obtain the plant growth behaviors.

TABLE 3: Quantitative plant growth characteristics of five fig genotypes.

Genotypes	Plant height (cm) ^X	Base girth (cm) ^X	Number of primary branch ^X	Number of sucker ^X	Canopy (m ²) ^X	Internode length (cm) ^Y	Terminal bud length (mm) ^Y	Terminal bud width (mm) ^Y
GRS	86.67 ± 0.88 ^d	2.32 ± 0.058 ^b	4.33 ± 0.29 ^a	3.57 ± 0.23 ^b	1.05 ± 0.03 ^b	5.07 ± 0.27 ^b	15.11 ± 0.58	6.65 ± 0.80
KH	111.33 ± 0.88 ^b	2.19 ± 0.058 ^b	5.00 ± 0.58 ^a	7.73 ± 0.35 ^a	1.2 ± 0.06 ^a	3.07 ± 0.35 ^d	14.80 ± 1.19	7.69 ± 0.35
E-2	65.67 ± 1.2 ^e	1.27 ± 0.063 ^c	2.33 ± 0.17 ^b	2.10 ± 0.26 ^c	0.43 ± 0.03 ^c	6.97 ± 0.22 ^a	21.47 ± 2.23	6.13 ± 0.47
BT	103.33 ± 0.88 ^c	2.31 ± 0.058 ^b	3.00 ± 0.58 ^b	7.13 ± 0.35 ^a	1.09 ± 0.06 ^b	4.17 ± 0.15 ^{bc}	15.67 ± 1.20	6.00 ± 0.58
SYA	125 ± 0.58 ^a	3.04 ± 0.33 ^a	4.67 ± 0.12 ^a	3.63 ± 0.30 ^b	1.21 ± 0.06 ^a	3.33 ± 0.27 ^{cd}	17.55 ± 2.49	6.23 ± 0.79
CV	0.49	3.35	10.15	8.81	3.42	11.07	14.15	14.6
Level of sig	**	**	**	**	**	**	NS	NS

Values (means ± SEs) with different alphabetical letters show statistically significant differences (LSD, $p < 0.05$). Variables marked with superscript "X" and "Y" had five ($n = 5$) and ten ($n = 10$) samples, respectively, per replication. NS: not significant; **Significant at 1% level of probability. CV: coefficient of variation, GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown Turkey, and SYA: Saudi Yellow Arabia.

and number of primary branch (NPB) per plant of one-year-old fig germplasm ranged from 65.67 to 125.00 cm, 1.27 to 3.04 cm, and 2.33 to 4.67 cm in E-2 and SYA genotypes, respectively. Number of suckers per plant also varied significantly being maximum in KH (7.73 per plant) having statistical parity with BT (7.13 per plant), while minimum number of suckers was counted in E-2 genotype (2.10 per plant). Canopy (Cnpy) spreading also exhibited a similar pattern, with E-2 having the smallest

canopy dimension (0.43 m²) and SYA having the largest (1.21 m²). There were significant variations in internode length (IL), terminal bud length (TBL), and terminal bud width (TBW). E-2 had the highest values for internode length (6.97 cm) and terminal bud length (21.47 mm), while KH had the lowest values (3.07 cm and 14.80 mm, respectively). KH had the widest terminal bud width (7.69 mm), while BT had the narrowest (6.00 mm). These findings align with the study conducted by Podgornik

et al. [24], who reported that the length of shoot internodes can vary within a range of 0.5 to 6 cm.

3.2. Leaf Characters of the Fig Genotypes

3.2.1. Qualitative Characters. Variations were also seen in the qualitative traits of the genotype's leaves (Table 4 and Figure 2). The findings show that Egyptian-2 (E-2) had leaves with a decurrent form at the base, whereas the other four genotypes exhibited calcarate. The leaf margin dentation is side dentate in E-2, but it is entire in the other genotypes. Degree of leaf lobation was very marked in GRS, KH, and BT while it was marked in E-2 and SYA genotypes. GRS and SYA displayed large leaf areas, whereas the remaining three genotypes had medium-sized leaf areas. Leaf venation of all five genotypes (GRS, KH, E-2, BT, and SYA) was clearly visible and apparent. Among the five genotypes, BT had no spicule density, while GRS and KH had a sparse spicule density. E-2 possessed a dense covering of leaf hairs, and SYA displayed an intermediate spicule density. The findings regarding leaf margin dentation and spicule density are in accordance with Karaat [26], while the observations related to leaf venation align with Podgornik et al. [24].

3.2.2. Quantitative Characters. Significant statistical variability was observed in the leaf parameters of the genotypes studied (Table 5). GRS exhibited the longest leaf length (LL), measuring 21.93 cm, closely followed by E-2 with a value of 21.33 cm. In contrast, BT had the shortest leaf length, measuring 16.8 cm, which was statistically similar to KH with a value of 17.9 cm and SYA with a value of 18.7 cm. Regarding leaf width (LW), GRS had the widest leaves with a value of 26.067 cm, while SYA had the narrowest with a value of 17.83 cm. Both KH and BT had the highest number of leaf lobes (Lob), each with a value of seven. In contrast, E-2 had the lowest leaf lobes with a count of three. GRS had the longest petiole with a value of 10.50 cm, followed closely by BT with a value of 10.37 cm, (Kh) with a value of 9.90 cm, and SYA with a value of 8.97 cm, with no significant differences in petiole length (PL) or leaf stalk length among these genotypes. E-2 exhibited the shortest petiole with a value of 7.07 cm, and GRS featured the longest central lobe (CLL) with a value of 20 cm, while E-2 had the shortest central lobe with a value of 11.80 cm. The observations on quantitative leaf characters align with the studies of Abdelsalam et al. [12], Rodrigues et al. [28], and Karaat [26]. The variations among the genotypes for the leaf characters might be attributed to the genetic features of the respective germplasm which expressed differently in the growing environment.

3.3. Fruit Traits of the Fig Genotypes

3.3.1. Qualitative Traits. Similarly, as plant growth and leaf characters, qualitative fruit traits also showed some distinct variations (Table 6 and Figure 3). Khurtamoni (KH), Brown Turkey (BT), Golden Riverside (GRS), and Egyptian-2 (E-2)

genotypes had oblong-shaped fruits, while Saudi Yellow Arabia (SYA) genotype displayed globose-shaped fruits. Among the studied genotypes, two distinct types of fruit stalks were identified: E-2germplasm exhibited a fruit stalk that was variously enlarged, while the other four germplasm (GRS, KH, BT, and SYA) displayed a long and slender stalk. Minute cracks on the fruit skin were noticed in all the genotypes. In case of fruit ribs, GRS and E-2 had sparse fruit ribs while KH had intermediate ribs. BT and SYA had no ribs in their fruits. Fruit color was yellow in GRS and SYA, while KH displayed brown-colored fruits, E-2 showed yellow green fruits, and BT had fruits with a purple color. Our results in case of qualitative fruit traits align with several previous studies conducted by Karaat [26], Podgornik et al. [24], Çalışkan and Polat [29], Khadiviet al. [25], Ara et al. [14], and Darjazi [30].

3.3.2. Quantitative Pomological Traits. Quantitative variations in reproductive and pomological traits of five fig genotypes varied significantly as shown in Tables 7(a) and 7(b) and Figure 4. Among the five genotypes, GRS took the longest time (D1FS), approximately 125.33 days to produce its first fruit. On the other hand, the Khurtamoni genotype (KH) achieved the quickest result, setting its first fruits in just 48.00 days after planting. The duration from the fruit set to maturity (DFSM) varied among the genotypes. SYA genotype had the longest maturation period, lasting approximately 122.33 days. Conversely, KH genotype exhibited the shortest maturation time, needing only 81.00 days. Interestingly, GRS genotype demonstrated a similar maturation period to KH, with approximately 87.33 days from fruit setting to maturity. The number of ripe fruits (Fr/pt) harvested from one-year-old plants revealed significant variations among the genotypes. SYA demonstrated the highest fruit yield, with an average of 76.67 fruits per plant. Interestingly, KH displayed a statistically similar fruit number, producing around 65.67 fruits per plant. In contrast, E-2 had the lowest fruit count of 8.67 fruits per plant, which was statistically similar to GRS genotype, measuring 18.33 fruits per plant. KH produced the heaviest fruit, weighing 51.12 g. This weight was statistically similar to both BT and E-2, which had fruit weights (FWT) of 49.87 g and 45.71 g, respectively. GRS had a fruit weight of 34.15 g, while SYA displayed the lightest fruit, weighing 22.15 g, among all the genotypes. Fruit length (FL) was highest in KH with a value of 73.42 mm, while SYA had the lowest fruit length of 38.33 mm. Fruit width (FW) was highest in E-2 with a value of 47.02 mm showing statistical similarity with KH, BT, and GRS, while SYA had the lowest fruit width of 36.50 mm. Ostiole width (OW) was highest in E-2 with a value of 11.40 mm, while SYA had the lowest ostiole width of 6.47 mm. Fruit neck length (FNL) and stalk length (FSL) were highest in KH (2.00 mm and 15.72 mm, respectively), while they were lowest in SYA (0.93 mm and 2.33 mm, respectively). KH recorded the highest flesh thickness (FT), measuring 19.88 mm, while SYA displayed the lowest flesh thickness, measuring 14.96 mm. The skin thickness (ST) of fruits varied among the five genotypes, with KH producing

TABLE 4: Qualitative variations in leaf characteristics of five fig genotypes.

Genotypes	Shape of leaf base	Leaf margin dentation	Degree of leaf lobation	Leaf area	Leaf venation	Spicule density
GRS	Calcarate	Entire	Very marked	Large	Apparent	Sparse
KH	Calcarate	Entire	Very marked	Medium	Apparent	Sparse
E-2	Decurrent	Side dentate	Marked	Medium	Apparent	Dense
BT	Calcarate	Entire	Very marked	Medium	Apparent	None
SYA	Calcarate	Entire	Marked	Large	Apparent	Intermediate

GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown Turkey, and SYA: Saudi Yellow Arabia. Here, within the replication, ten samples ($n = 10$) were studied to confirm the qualitative leaf characteristics of the fig genotypes.

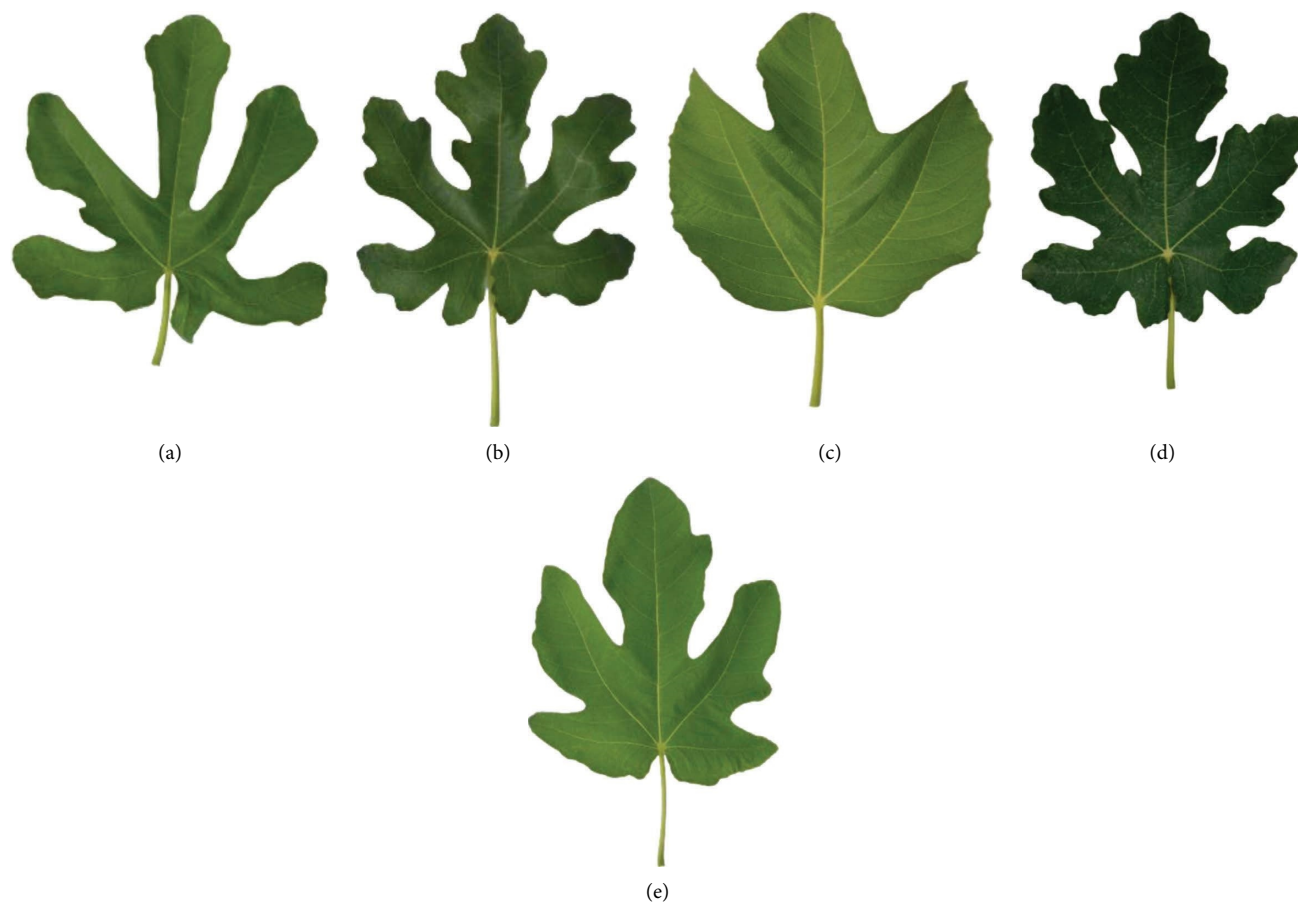


FIGURE 2: Leaves of five fig genotypes: (a) Golden Riverside; (b) Khurtamoni; (c) Egyptian-2; (d) Brown Turkey; (e) Saudi Yellow Arabia.

TABLE 5: Quantitative variations in leaf characteristics of five fig genotypes.

Genotypes	Leaf length (cm)	Leaf width (cm)	Number of leaf lobe	Leaf stalk length (cm)	Length of central lobe (cm)
GRS	21.93 ± 1.15 ^a	26.07 ± 1.15 ^a	5.67 ± 1.45 ^b	10.50 ± 0.29 ^a	20.00 ± 1.73 ^a
Kh	17.9 ± 1.45 ^b	18.83 ± 1.73 ^b	7.00 ± 1.15 ^a	9.90 ± 0.3 ^a	16.00 ± 0.92 ^b
E-2	21.33 ± 0.88 ^a	19.2 ± 0.88 ^b	3.00 ± 1.15 ^c	7.07 ± 0.32 ^b	11.80 ± 0.61 ^c
BT	16.8 ± 0.88 ^b	17.93 ± 0.58 ^b	7.00 ± 0.58 ^a	10.37 ± 1.02 ^a	16.40 ± 0.64 ^b
SYA	18.7 ± 1.15 ^{ab}	17.83 ± 1.20 ^b	5.00 ± 1.15 ^b	8.97 ± 0.03 ^a	13.37 ± 0.65 ^{bc}
CV	7.66	6.1	9.33	9.39	11.04
Level of sig	*	**	**	**	**

Values (means ± SEs) with different alphabetical letters show statistically significant differences (LSD, $p < 0.05$); *, ** Significant at 5%, 1% level of probability. CV: coefficient of variation, GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown Turkey, and SYA: Saudi Yellow Arabia. Here, within the replication, ten samples ($n = 10$) were studied to confirm the quantitative leaf characteristics of the fig genotypes.

TABLE 6: Qualitative variations in fruit traits of five fig genotypes.

Genotype	Fruit shape	Shape of fruit stalk	Fruit skin cracks	Fruit ribs	Fruit color
GRS	Oblong	Long and slender	Minute crack	Sparse	Yellow
KH	Oblong	Long and slender	Minute crack	Intermediate	Brown
E-2	Oblong	Variously enlarged	Minute crack	Sparse	Yellow green
BT	Oblong	Long and slender	Minute crack	None	Purple
SYA	Globose	Long and slender	Minute crack	None	Yellow

GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown Turkey, and SYA: Saudi Yellow Arabia. Here, within the replication, ten samples ($n = 10$) were studied to confirm the qualitative fruit traits.

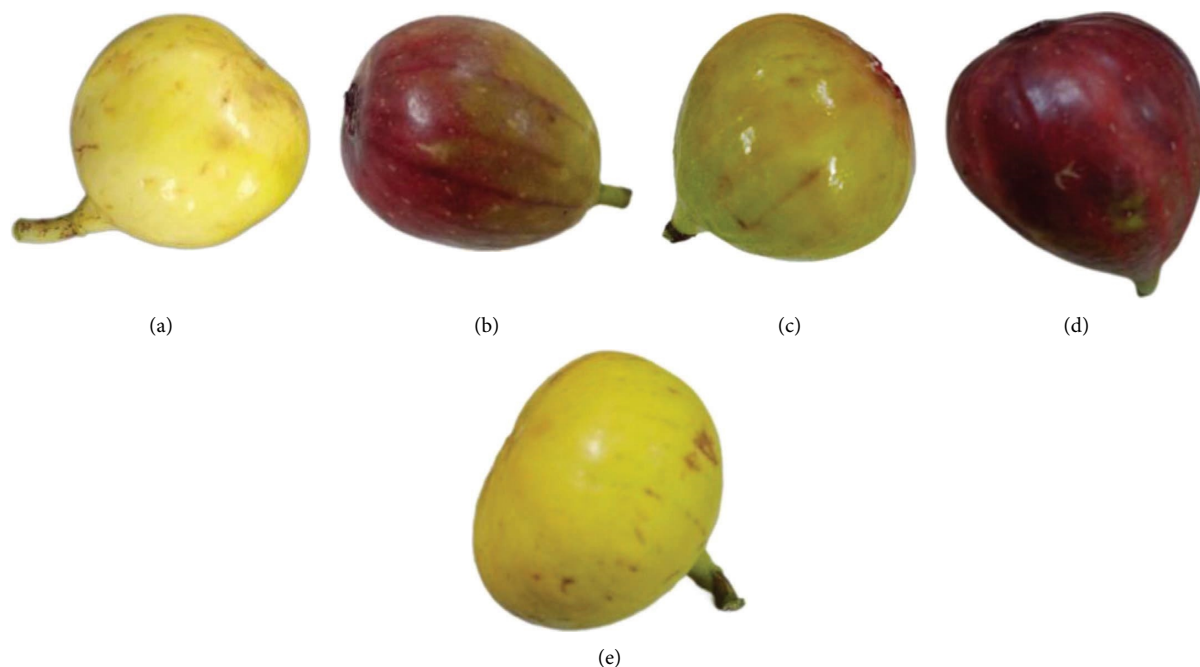


FIGURE 3: Fruits of five fig genotypes: (a) Golden Riverside, (b) Khurtamoni; (c) Egyptian-2; (d) Brown Turkey; (e) Saudi Yellow Arabia.

fruits with the thickest skin, measuring 4.69 mm, while SYA had the lowest skin thickness, measuring 2.07 mm. The total soluble solid (TSS) content in the fruits of all genotypes was statistically similar, except for SYA genotype, which had the lowest TSS content of 6.73%. Khurtamoni (KH) displayed the highest dry matter content (DM) of 14.46%, while Golden Riverside (GRS) genotype had the lowest dry matter content, measuring 8.52%. Our findings are consistent with the reported ranges from previous studies, including Abdelsalam et al. [12], Çalışkan and Polat [29], Darjazi [30], Ara et al. [14], and Mir et al. [31], concerning fruit weight. In terms of fruit length, our results align with the findings of Gaaliche et al. [8], Karaat [26], and Darjazi [30]. Fruit width findings are in agreement with those of Karaat [26] and Mehraj et al. [2]. The ostiole width is consistent with the research study of Gaaliche et al. [8] and Ara et al. [14]. Neck length aligns with the findings of Çalışkan and Polat [29] and Hssaini et al. [13]. Stalk length findings are in concordance with Ara et al. [14] and Khadivi et al. [25]. Fruit flesh thickness is consistent with Gaaliche et al. [8]. Skin thickness aligns with the research study of Hssaini et al. [13]. Total soluble solid (TSS) content corresponds with the findings of

Gaaliche et al. [8], Karaat [26], Darjazi [30], Mir et al. [31], and Mehraj et al. [2]. Dry matter content findings are in line with the study of Khadivi et al. [25].

3.4. Fruit Sensory and Organoleptic Qualities. After harvesting at a proper stage, the fruits were undergone for further evaluation and it was observed that the fig genotypes revealed some distinguishable variations in sensory and organoleptic qualities of fruits (Table 8). Among the five genotypes, the genotypes KH and BT produced soft fruits while medium soft fruits were obtained from GRS, E-2 and SYA germplasm. Amber flesh color was observed in GRS and SYA. KH displayed dark red flesh, while Egyptian-2 had red flesh and Brown Turkey showed pink flesh. Pulp texture of ripe fruits also showed some differences. Coarse textured fruits were harvested from SYA genotype, while KH and E-2 genotypes gave fine textured fruits. GRS and BT yielded with medium textured fruits. Aromatic flavoured fruits were obtained from KH and SYA germplasm, whereas the other genotypes, namely, GRS, E-2, and BT had little flavoured fruits. Fruits of KH were very juicy while juicy fruits were

TABLE 7: (a and b) Quantitative variations in reproductive and pomological traits of five fig genotypes.

(a)						
Genotypes	Days to first fruit set	Days from fruit set to maturity	Number of fruits/plant	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)
GRS	125.33 ± 5.81 ^a	87.33 ± 3.18 ^c	18.33 ± 2.03 ^{bc}	34.15 ± 2.08 ^{bc}	53.33 ± 0.88 ^c	42.67 ± 1.2 ^a
KH	48.00 ± 4.62 ^c	81.00 ± 2.31 ^c	65.67 ± 4.81 ^a	51.12 ± 2.53 ^a	73.42 ± 0.88 ^a	45.38 ± 0.33 ^a
E-2	115.33 ± 4.37 ^a	103.67 ± 3.93 ^b	8.67 ± 2.19 ^c	45.71 ± 8.07 ^{ab}	58.12 ± 1.45 ^{bc}	47.02 ± 3.06 ^a
BT	68.00 ± 6.11 ^b	98.33 ± 3.53 ^b	30.67 ± 2.03 ^b	49.87 ± 6.85 ^{ab}	61.72 ± 3.84 ^b	44.72 ± 1.67 ^a
SYA	53.33 ± 1.86 ^{bc}	122.33 ± 4.63 ^a	76.67 ± 5.93 ^a	22.15 ± 1.35 ^c	38.33 ± 1.20 ^d	36.50 ± 0.88 ^b
CV	11.08	4.75	17.54	21.58	6.18	6.69
Level of sig	**	**	**	*	**	*

(b)						
Genotypes	Ostiole width (mm)	Fruit neck length (mm)	Fruit stalk length (mm)	Fruit flesh thickness (mm)	Skin thickness (mm)	
GRS	7.00 ± 1.15	1.63 ± 1.20 ^b	9.33 ± 0.03 ^{bc}	17.44 ± 0.68	3.33 ± 0.33 ^{abc}	
Kh	10.11 ± 1.06	2.00 ± 1.20 ^a	15.72 ± 0.12 ^a	19.88 ± 0.91	4.69 ± 0.34 ^a	
E-2	11.40 ± 2.91	1.50 ± 1.89 ^{bc}	10.43 ± 0.1 ^b	19.83 ± 2.68	2.83 ± 0.44 ^{bc}	
BT	7.79 ± 0.90	1.27 ± 0.60 ^c	7.20 ± 0.07 ^c	19.56 ± 1.07	4.02 ± 0.68 ^{ab}	
SYA	6.47 ± 0.87	0.93 ± 0.33 ^d	2.33 ± 0.07 ^d	14.96 ± 1.06	2.07 ± 0.07 ^c	
CV	27.58	9.84	14.04	14.22	22.53	
Level of sig	NS	**	**	NS	*	

Values (means ± SEs) with different alphabetical letters show statistically significant differences (LSD, $p < 0.05$); NS: not significant. *, ** Significant at 5%, 1% level of probability. CV: coefficient of variation, GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown Turkey, and SYA: Saudi Yellow Arabia. Here, within the replication, ten samples ($n = 10$) were studied to confirm the quantitative fruit traits.

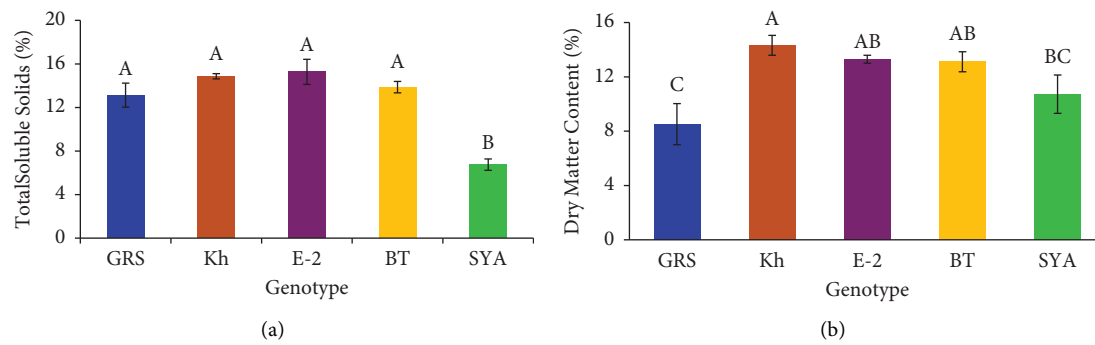


FIGURE 4: (a) Total soluble solid (TSS) content and (b) dry matter content in fruits of five fig genotypes. Values (means $\pm$ SEs) with different alphabetical letters show statistically significant differences (LSD, $p < 0.05$). GRS: Golden Riverside; KH: Khurtamoni; E-2: Egyptian-2; BT: Brown Turkey; SYA: Saudi Yellow Arabia.

TABLE 8: Sensory and organoleptic qualities of fruits of five fig genotypes.

Genotypes	Fruit firmness	Flesh color	Pulp texture	Pulp flavour	Juiciness	Taste
GRS	Medium	Amber	Medium	Little flavour	Little juicy	Good
KH	Soft	Dark red	Fine	Aromatic	Very juicy	Excellent
E-2	Medium	Red	Fine	Little flavour	Juicy	Very good
BT	Soft	Pink	Medium	Little flavour	Little juicy	Very good
SYA	Medium	Amber	Coarse	Aromatic	Little juicy	Good

GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown Turkey, and SYA: Saudi Yellow Arabia. Here, within the replication, ten samples ($n = 10$) were studied to confirm the sensory and organoleptic characters.

produced by E-2 germplasm, and the other 3 genotypes such as GRS, BT, and SYA had little juicy fruits. In terms of organoleptic test, fruits with excellent taste were obtained from KH germplasm. Two genotypes, viz., E-2 and BT obtained fruits with very good taste and other two germplasm, namely, GRS and SYA produced fruits which were good in taste. Our results align with Karaat [26], Podgornik et al. [24], and Ara et al. [14] in case of fruits sensory and organoleptic qualities.

3.5. Fruit Biochemical Attributes. *Ficus carica*, commonly known as the exotic fig, possesses intriguing biochemical attributes. After harvesting at a proper stage, the fruits were undergone for further evaluation and it was observed that the fig genotypes revealed some distinguishable variations in different biochemical parameters shown in Table 9 and Figures 5 and 6. The β -carotene content displayed statistically significant variations among the five genotypes of fruits, with Brown Turkey (BT) recording the highest value of 0.04478 mg/100 g FW, while Golden Riverside (GRS) registered the lowest value of 0.00249 mg/100 g FW. In terms of vitamin C content, both E-2 and BT had the highest values of 4.4 mg/100 g FW, showing no significant difference between them. On the other hand, GRS and SYA had the lowest values of 1.76 mg/100 g FW, with statistical similarities. Khurtamoni (KH) had the highest total sugar content of 41.20 mg/100 g, while BT had the lowest value of 35.93 mg/100 g; KH also had the highest reducing sugar content of 30.49 mg/100 g, while E-2 had the lowest value of 22.90 mg/100 g. In nonreducing sugar content, E-2 had the highest value of 14.04 mg/

100 g, while BT had the lowest value of 9.39 mg/100 g. GRS had the highest total phenolic content of 9.28 mg GAE/100 g FW, followed closely by KH with a value of 8.03 mg GAE/100 g FW, while E-2 displayed the lowest total phenolic content of 1.39 mg GAE/100 g FW. Total flavonoid content was highest in E-2 with a value of 32.703 mg QE/100 g FW, closely followed by KH with a value of 31.084 mg QE/100 g FW, while SYA displayed the lowest amount at 9.34 mg QE/100 g FW. Saudi Yellow Arabia (SYA) had the highest IC₅₀ value, indicating lowest antioxidant activity, while BT and KH showed the lowest values (83.6 μ g/ml and 85.39 μ g/ml, respectively) and highest antioxidant activity, with statistical similarities. Total anthocyanin content ranged from 38.26 μ g/g FW to 42.95 μ g/g FW across different genotypes. Saudi Yellow Arabia (SYA) had the highest pH of 5.93, while GRS had the lowest pH of 5.55, with other genotypes falling in between. Our findings were consistent with the research study of Mir et al. [31] concerning vitamin C content and total sugar content. In addition, our results aligned with Ara et al. [14] and Wojdyło et al. [32] regarding total phenolic content, and with Hssaini et al. [13], De Masi et al. [33], and Khadhraoui et al. [34] in terms of total flavonoid content. Similarly, Ara et al. [14] and Wojdyło et al. [32] presented results consistent with our findings for total anthocyanin content. In contrast to the results presented by Harzallah et al. [35], our study identified reduced antioxidant activity among different fig genotypes. These variations could be attributed to differences in experimental methodologies, environmental variables, and the genetic makeup of the fig cultivars examined.

TABLE 9: Variability in fruit biochemical composition across five fig genotypes.

Genotypes	Total phenolic content (mg GAE/100 g FW)	Total flavonoid content (mg QE/100 g FW)	DPPH scavenging activity (IC50) ($\mu\text{g/ml}$)	Total anthocyanin content ($\mu\text{g/g}$ FW)	pH
GRS	9.28 ± 10.17^a	11.02 ± 0.19^c	276.46 ± 1.85^b	38.26 ± 0.95	5.55 ± 0.058^d
KH	8.03 ± 0.7^a	31.084 ± 0.23^a	85.39 ± 0.29^d	41.68 ± 1.52	5.63 ± 0.017^c
E-2	1.39 ± 0.007^c	32.703 ± 0.41^a	144.47 ± 0.59^c	40.95 ± 0.91	5.72 ± 0.017^b
BT	4.91 ± 0.17^b	28.348 ± 0.88^b	83.6 ± 0.38^d	42.29 ± 0.99	5.58 ± 0.035^{cd}
SYA	3.49 ± 0.04^{bc}	9.34 ± 0.74^c	292.23 ± 2.69^a	40.95 ± 0.86	5.93 ± 0.017^a
CV	21.96	5.27	1.27	4.89	0.54
Level of significance	**	**	**	NS	**

Values (means $\pm$ SEs) with different alphabetical letters show statistically significant differences (LSD, $p < 0.05$); NS: not significant. **Significant at 1% level of probability. CV: coefficient of variation, GRS: Golden Riverside, KH: Khurtamoni, E-2: Egyptian-2, BT: Brown turkey, and SYA: Saudi Yellow Arabia. Here, within the replication, ten samples ($n = 10$) were studied to confirm the fruit biochemical traits.

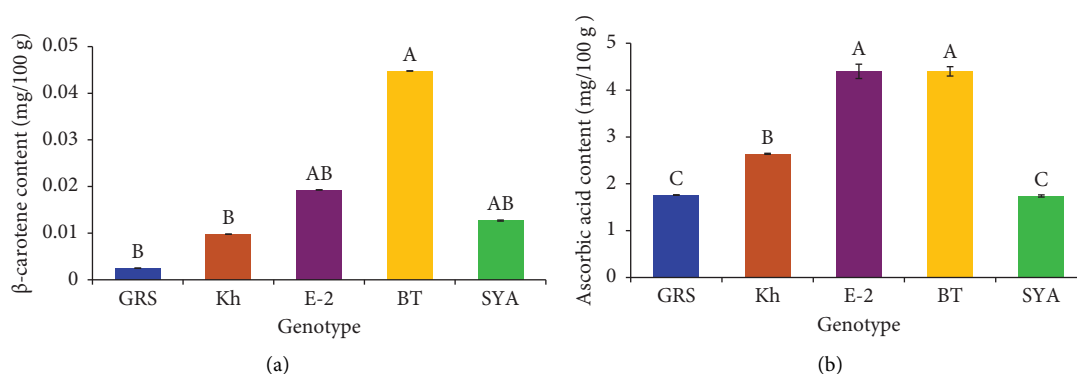


FIGURE 5: Vitamin contents in fruits of five fig genotypes: (a) β -carotene content or vitamin A and (b) ascorbic acid content or vitamin C. Values (means $\pm$ SEs) with different alphabetical letters show statistically significant differences (LSD, $p < 0.05$). GRS: Golden Riverside; KH: Khurtamoni; E-2: Egyptian-2; BT: Brown Turkey; SYA: Saudi Yellow Arabia.

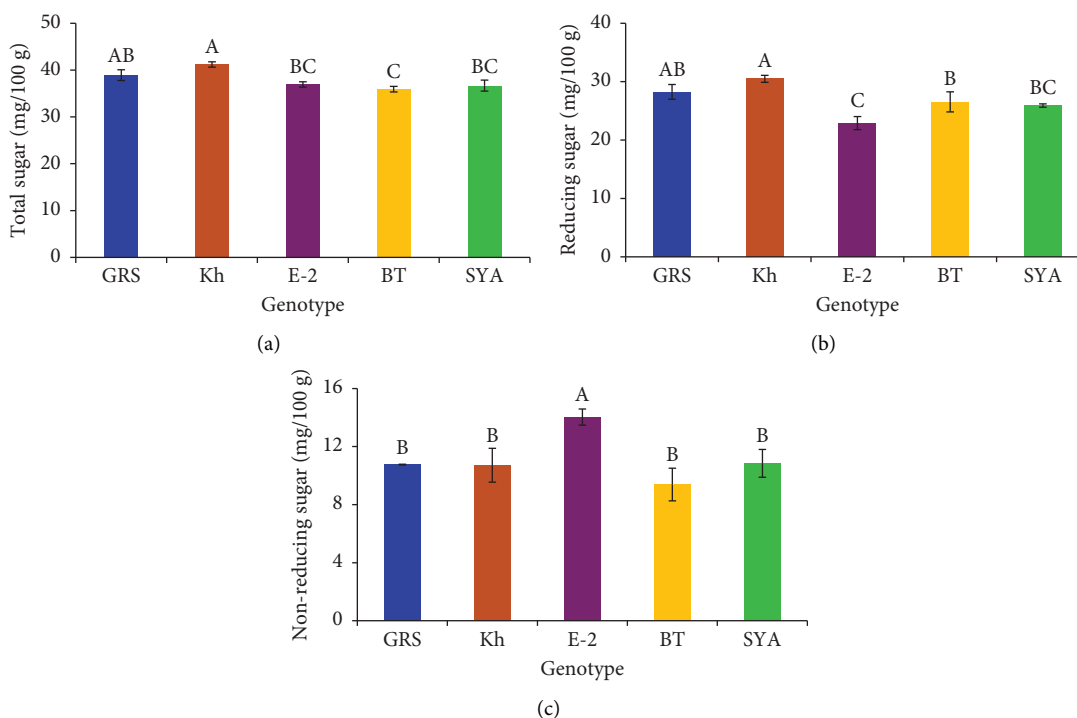


FIGURE 6: Total sugar, reducing sugar, and nonreducing sugar content in fruits of five fig genotypes: (a) total sugar content; (b) reducing sugar content; (c) nonreducing sugar content. Values (means $\pm$ SEs) with different alphabetical letters show statistically significant differences (LSD, $p < 0.05$). Here, GRS: Golden Riverside; KH: Khurtamoni; E-2: Egyptian-2; BT: Brown Turkey; SYA: Saudi Yellow Arabia.

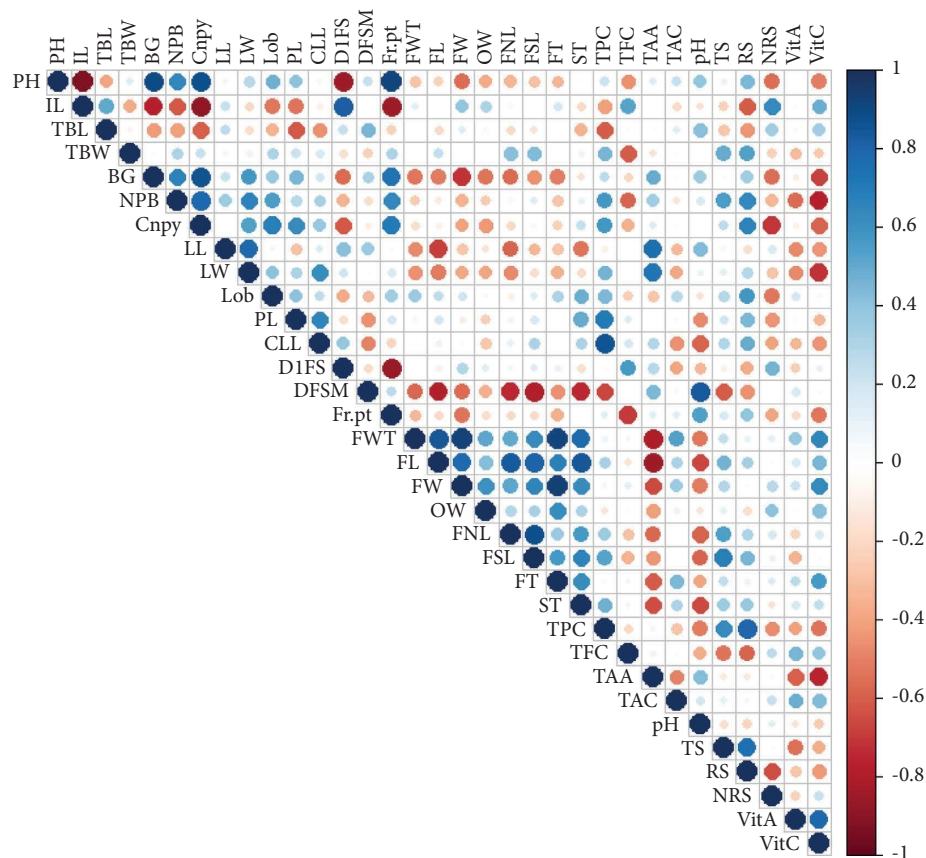


FIGURE 7: Correlation coefficients of 55 variables of five fig genotypes related to their morphological, pomological, and biochemical attributes.

3.6. Correlation Coefficient Analysis among Morphological, Pomological, and Biochemical Traits of the Fig Genotypes. Pearson's correlation was carried out to evaluate the interrelationships among the 55 morphological, pomological, and biochemical traits of the five studied fig genotypes. The correlation matrix revealed moderate to strong positive and negative correlations among the noted variables (Figure 7).

Firstly, plant morphological attributes such as plant height, base girth, the number of primary branches, canopy size, branching habit, and suckering tendency positively augmented the fruit yield of fig under observation displaying moderate to strong positive correlations. Meanwhile, some other plant growth traits such as shoot color, internode length, leaf margin dentation, leaf length, and leaf width had very weak to negative correlations with fruit production. Such phenomena outlined that superior overall tree vigour and canopy growth, not the minute shoot and leaf qualities, had significant influence on fruit setting and yield of figs in the present studied condition. Likely, while investigating with morphoagronomic, pomological, and biochemical behaviors of fig cultivars, Hssaini et al. [13, 14] noted that healthy plant stature ultimately produced greater amount of fruits compared to bushy and smaller sized plants whereas fruit physical and biochemical traits, namely, FL, OW, FNL, FSL, FT, ST, TSS, DM, FF, FLC, PT, vitamin A, vitamin C, TS, RS, NRS, TPC, TFC, TAA, TAC, and pH demonstrated variable responses towards plant growth nature which can be

elucidated that fruit quality attributes reflects the genetic expression of genotypes. These findings have close conformity with that of Karaat [26] who observed that the twenty-five studied genotypes showed variable features in terms of their growth, yield, and fruit quality nature. Darjazi [36] demonstrated that fig accessions produced fruits of 8.0 to 43.5 g of weight. He also noticed wide variation in fruit length, fruit diameter, ostiole width, stalk length, TSS, and sugar content among the nine studied genotypes. Thus, the correlation matrix showed remarkable variations in relationships among the studied variables for fig genotypes at studied condition.

3.6.1. Principle Component Analysis (PCA). Cluster heatmap (Figure 8(a)) and PCA biplot (Figure 8(b)) display that the five fig genotypes had variable performances for their growth, yield, and fruit quality traits. However, considering their comparative expression, the genotypes fall into two distinct categories (Figure 8(a)). The genotypes KH and BT took their place in cluster 1, whereas of the rest three genotypes, GRS and SYA stood close compared to E-2 germplasm. Furthermore, PCA biplot (Figure 8(b)) demonstrates that the five genotypes were located in different positions in the quadrants. It is seen that KH and BT had their location in the right quadrant and GRS obtained its position in the left quadrant. However, SYA and E-2 were

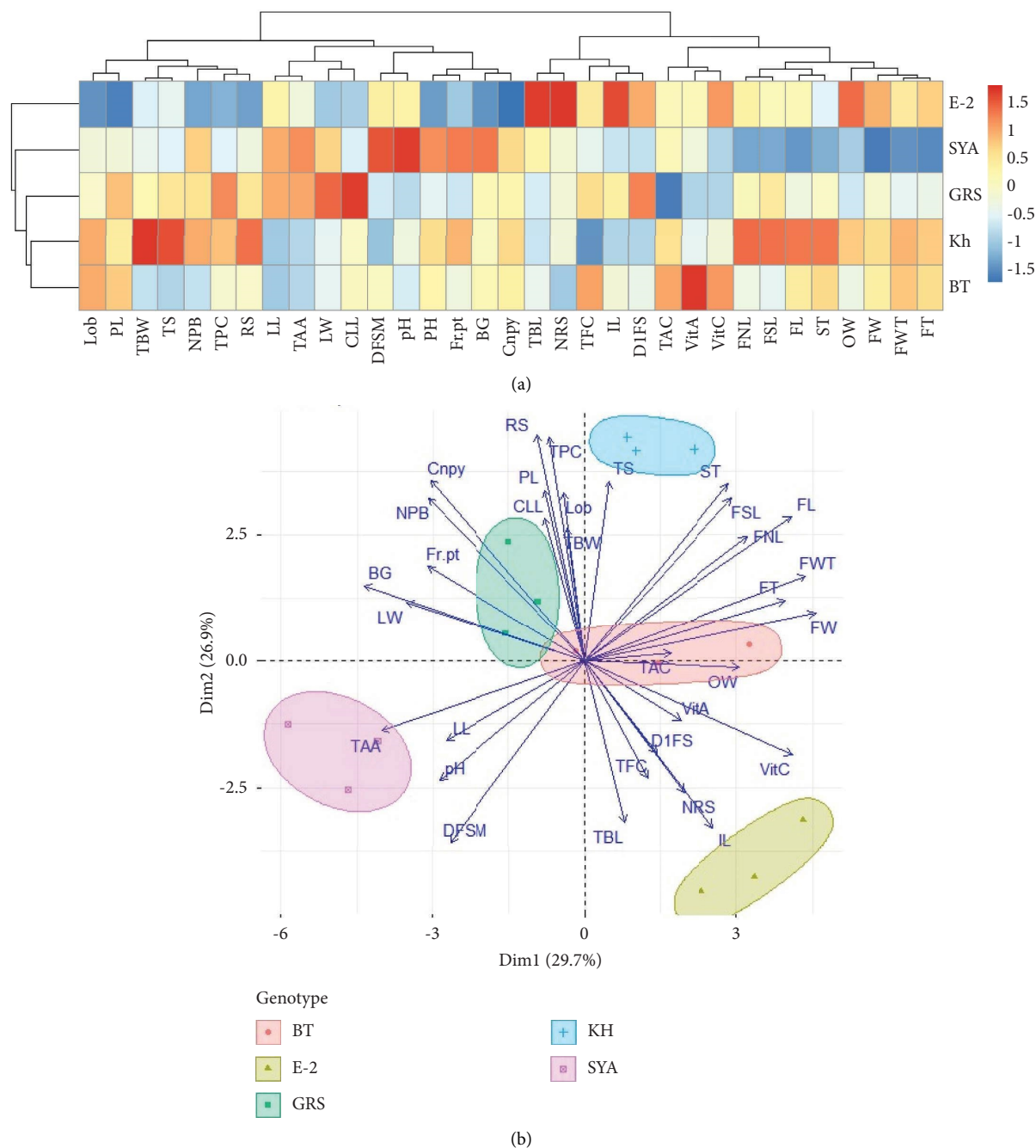


FIGURE 8: Cluster heatmap (a) and PCA biplot (b) showing the comparative performances of different fig genotypes with respect to 35 variables on growth, yield, and fruit biochemical properties.

situated below the centre. Thus, in accordance with the relative performances, all the five genotypes took position in the order of KH > BT > GRS > SYA > E-2.

In light of this analysis, breeders should prioritize the selection of parent plants with desirable traits such as increased plant height, base girth, primary branch count, and canopy size, as these factors have demonstrated a positive correlation with fruit yield. These traits should be regarded as primary breeding objectives to develop high-yielding fruit plants. Importantly, while the enhancement of fruit yield is crucial, breeders must also carefully consider the equilibrium between morphological

traits and fruit quality, which is intricately linked to nutritional values. Overemphasizing one aspect at the expense of the other should be avoided. Instead, breeding programs should strive to create plant varieties that exhibit both high yield potential and exceptional fruit quality with enhanced nutritional properties.

4. Conclusion

Among the five exotic fig (*Ficus carica* L.) genotypes tested for their morphoagronomic and pomological traits, Khur-tamoni and Brown Turkey performed better in terms of

several desirable attributes under the present subtropical rain-fed condition of Bangladesh. The Khurtamoni excelled in fruit attributes, including size, weight, and overall quality as well as demonstrated well adaptation with profound vegetative growth compared to others. Meanwhile, Brown Turkey was another standout performer, particularly in terms of fruit texture and firmness. Both of the genotypes demonstrated outstanding nutritional properties, with higher levels of total sugar, reducing sugar, total phenols, total flavonoids, and total antioxidant activity. Overall, this study provides important insights that can guide the selection of fig genotypes for breeding programs aimed at improving fruit quality and nutritional value.

Data Availability

All the data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Khadiza Akter Koly and Joydeb Gomasta have equal contribution and share the first authorship.

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