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Combined effect of drying techniques and variety on physiochemical characteristics, phytochemical contents and quality of dried figs (*Ficus carica* L.)

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Abstract

Figs are highly nutritious fruits but at same time they are highly perishable with very short span for fruit availability. So, fruit preservation is needed to meet food security issues. Drying is a practical preservation technology that helps maintain quality and makes figs available year-round. This study evaluated the effects of three drying techniques (Sun Drying, Solar Drying, Electric Hot Air Drying) on the physicochemical and Phytochemical characteristics of two local varieties Black Ball and Pink Rose. The experiment was laid out according to Completely Randomized Design (CRD) under factorial arrangement. Results indicated that Pink Rose dried through solar drying outperformed other techniques with respect to maximum fruit weight (14.53 g), largest fruit area (1392 mm²), and highest dried fruit recovery (36.36%). Electric hot-air drying required the shortest drying time (72.33 h), while sun drying needed the longest (167.9 h). Pink Rose subjected to solar drying preserved the highest levels of total soluble solids (25.50%), total sugars (28.10%), and ascorbic acid (12.53 mg/100 g). Black Ball exhibited the highest antioxidant activity (110.53 mg/100 g), whereas Pink Rose showed the highest phenolic content (132.63 mgGAE/100 g) when processed by solar and electric hot-air drying, respectively. Overall, solar drying offers substantial advantages over conventional sun drying by minimizing the drying time, increasing microbial protection, enhancing retention of bioactive substance, thereby providing a more efficient approach to preserving figs.

Keywords: Antioxidant, Drying time, *Ficus carica* L., Fruit preservation, Solar drying, Total phenolics

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Introduction

Fig (*Ficus carica L)* belongs to family Moraceae, native to Southwest Asia and the Eastern Mediterranean. As one of the largest genera in the Moraceae family, Ficus comprises over 800 species. This ancient fruit has been cultivated for more than 5,000 years. Cultivation of this species dates back more than five millennia (Soni et al., 2014). Globally, fig production reached approximately 1.30 million tonnes in 2023. Turkey remains the leading producer, contributing about 356,000 tonnes (27.3% of global production), followed by Egypt (193,058 tonnes), Morocco (119,167 tonnes), Algeria (116,183 tonnes), and Iran (73,483 tonnes). Other important fig-producing countries include Afghanistan, Syria, Spain, Brazil, and the United States. These countries collectively account for a major share of global fig production and trade (FAOSTAT, 2025). In Pakistan, fig cultivation is limited and primarily confined to arid and semi-arid regions. Despite its favorable agro-climatic conditions for fig cultivation, the crop remains underutilized, highlighting considerable potential for expansion and improvement through the adoption of improved cultivars and modern orchard management practices. The total area under fig cultivation in Pakistan is around 146 hectares with a yield of 233 metric tons (FV&C, 2022-23).

Figs play an important part in the Mediterranean diet in fresh, dried or jam form. These fruits have certain health benefits such as dietary fiber assists in maintaining normal digestive system functioning; alkalinity of these fruits ensures balance of tissue pH; calcium strengthens bones and certain chemicals like flavones contribute towards heart protection. Figs also provide vitamin A, C and E (antioxidants) that ensure deficiency of such nutrients does not occur and protect macula of eye from macular degeneration. Some of the traditional medicinal benefits include laxative properties and use to treat skin disorders like boils (Wang et al., 2017). Fresh ripe figs are very perishable because of rapid senescence, fermentation and decay, which significantly curtails their shelf life after harvesting (Michailides et al., 2008). With the use of refrigeration (0 degrees Celsius and 90 percent relative humidity), fresh figs remain in good condition for up to one week. Unlike fresh figs, dried figs can be stored for 6 to 8 months at room temperature without refrigeration (Aksoy, 2021).

Drying decreases the moisture content, thus inhibiting microbial growth and slowing down the process of adverse physical and chemical changes. Traditionally, the drying method has been used as the sole method for preserving figs owing to its cost-effectiveness and lack of dependence on refrigeration. Turkey accounts for most dried fig production. Dried figs are considered nutritious food and functional foods (Mujic et al., 2014). Sun drying is traditionally practiced. This technique has low capital requirements and needs minimal infrastructure but has some disadvantages including higher chances of Aspergillus infection and production of aflatoxins, exposure to unfavorable environmental conditions; deterioration of color, taste, and vitamin content; uneven drying causing caramelization and development of a hard outer surface (Shelar et al., 2022). In a study of dried fig processing, approximately 10% of samples were contaminated with aflatoxins and 6% with ochratoxin A, with Aspergillus spp. predominating during several processing stages (Palumbo et al., 2022).

Solar and electric dryers overcome many of the limitations associated with traditional sun drying by providing improved sanitary conditions and better control over processing parameters. These systems also increase drying rates through enhanced airflow and reduce dependence on prevailing weather conditions (Slatnar et al., 2011). However, these technologies also have certain limitations. Solar dryers remain partially dependent on solar radiation and ambient weather conditions, leading to fluctuations in drying temperature and efficiency during cloudy or humid periods. In addition, the initial investment and maintenance costs of solar drying systems may be unaffordable for small-scale producers. Hot-air drying provides greater process control and shorter drying times but is associated with high energy consumption and operational costs. Exposure to elevated temperatures may also result in undesirable changes in product quality, including shrinkage, texture hardening, browning reactions, loss of volatile compounds, and degradation of heat-sensitive nutrients and bioactive compounds. Therefore, while solar and hot-air drying offer significant advantages over traditional sun drying, optimization of drying conditions is necessary to balance drying efficiency, product quality, and economic feasibility (Onwude et al., 2022). This highlighted the need for investigation into the compositional alterations that occur during the drying process and their consequent implications for human nutrition. This study aims to assess the effects of various drying methods on the quality attributes of distinct fig cultivars to identify optimal combinations of variety and drying process that maximize preservation of desirable qualities.

Materials and Methods

Experimental site and collection of plant material

The experiment was carried out at research area of Horticultural Research Institute, Ayub Agricultural Research Institute, Faisalabad, Pakistan (Longitude 74.09 ºE, Latitude 31.42 ºN, Elevation 188 m) during 2023-2024. All trees were managed according to integrated cultivation protocols and trained as an open vase with 12 × 12 ft spacing. Fruits of two local varieties (Black Ball& Pink Rose) were harvested at proper mature stage characterized by full color development, uniform size, and optimum firmness suitable for processing. A total of 50 fruits per treatment were used and each fruit served as an experimental unit in the study. The infected, bruised, damaged and cracked fruits were manually removed, and the fruit stalks were carefully cut off with a sharp knife to avoid damaging the fruits. The fruits were then thoroughly washed to remove dirt, debris, and any latex released after stalk removal. Sugar solution was prepared by mixing known quantity (10%) of sugar in gentle boiling water and fruit of uniform size were subjected to blanching for 2-3 seconds. The purpose of this treatment was to improve flavor, maintain osmotic balance, and reduce nutrient leaching during processing. Fruits were dipped in solution of sodium benzoate (1gram/kg) for 15 minutes as a post-harvest treatment to inhibit microbial growth and extend shelf life. Sodium benzoate is widely used as a food-grade antimicrobial preservative, particularly effective in acidic food systems, and is permitted up to 0.1% in food products according to regulatory guidelines (FDA, 21 CFR 184.1733; Codex Alimentarius).

Experiment design

The experiment was conducted using a 2 × 3 factorial experimental design arranged in a Completely Randomized Design (CRD), comprising two fruit varieties (Black Ball, Pink Rose) and three drying methods (sun drying, solar drying, and electric hot-air drying), resulting in six treatment combinations. The blanched fruit placed in drying trays and subjected to drying using following drying methods/techniques.

Sun drying

Trays were placed in the drying yard, located in a sun exposed open area away from dust and potential sources of infection. Each fig was periodically turned from one side to the other until attained required moisture contents (≤ 20%).

Solar drying

The figs were placed in a solar dryer installed at the research area of Horticultural Research Institute. The structure is built with polycarbonate fiber sheet having 4-6 mm thickness having the ability to maintain a temperature @ 50 ± 5 °C. The dryer is fitted with a pyrometer to monitor the external surface temperature, along with internal thermocouples and hygrometers to assess internal thermal and humidity conditions. Each fig was periodically turned from one side to the other until attained required moisture contents (≤ 20%).

Electric hot air dryer

Fig trays were placed in electric hot air dryer @ 52 ± 5 °C. Dryer has capacity of 700-800 kg fruit. Each fig was periodically turned from one side to the other until attained required moisture contents (≤ 20%).

Pressing

Fig fruits were pressed in plain shape when they reached a semi-dry condition (approximately 20-30% moisture content, wet basis). Fruit samples were manually compressed using a hand-operated papad-press, with pressure applied gradually and uniformly to avoid rupture of internal tissues and prevent exudation of pulp or juice. After pressing fig fruits were further dried to reach safe moisture level (15-20%).

Parameters studied

Fruit weight (g)

Weight of fresh as well as dried fruit was recorded using digital weighing balance (SF-400).

Fruit size (mm^2)

Fruit size was measured by using Vernier caliper (Astore, 300 Germany) having capacity of 0-150 mm.

Dried fruit recovery (%)

Dried fruit recovery was calculated using following formula:

$$\text{Dried fruit recovery} = \frac{W2}{W1} \times 100$$

Where W_2 = Weight of dried fig
W_1 = Weight of fresh fig

Drying time (h)

Total time taken by the fig fruits to reach a safe moisture level was recorded in hours.

Organoleptic evaluation

Organoleptic evaluation was conducted by a panel of 10 semi-trained assessors. Sensory attributes including skin colour, taste, and texture were scored using a hedonic rating scale (Peryam & Pilgrim, 1957).

Hedonic scale assessment

Product/sample name: _______________
Variety / Strain: _______________
Date: _______________
Name of Judge: _______________
Signature: _______________

Guidelines (please read carefully):

1. This form is intended for the organoleptic evaluation of dried fig samples.
2. Use the numerical (hedonic) method to score each sample.
3. Do not alter the designated order of the samples presented.
4. Rinse your palate (e.g., with water) before assessing the next sample

Biochemical evaluation

Total soluble solids (TSS) were determined from juice obtained by diluting 100 g of figs in 500 mL of distilled water. A digital refractometer (Atago, Japan) was used to record the TSS, and results were expressed as percent (%). Acidity was measured in triplicate following standard methods described by AOAC (AOAC, 2012). Total Sugars were measured according to method described by (Lane & Eynon 1923).

Phytochemical evaluation

Total phenolic content (TPC) was measured following the procedure described by Singleton et al. (1999), using the Folin–Ciocalteu assay. Absorbance of the reaction solution was measured at 760 nm with a UV-VIS spectrophotometer. Phenolic content was expressed as mg gallic acid equivalents (GAE) per 100 g dry weight (mg GAE/100 g DW). The antioxidant activity of the dried-fig samples was assessed using the DPPH assay on a spectrophotometer (Biochrom Libra S60), with absorbance recorded at 515 nm (Du et al., 2009).

Statistical analysis

Data were subjected to statistical analysis using software (Statistics 8.1). Differences among treatment means were evaluated by two-way Analysis of Variance (ANOVA) to assess the effects of fruit variety, drying method, and their interaction followed by a post-hoc Tukey's HSD ($p \leq 0.05$) test to identify significant mean separations. Pearson correlation ($p \leq 0.05$) was studied to find the interaction between the parameters (Steel et al., 1997).

Results

Effect of different drying techniques on Physical traits of dried figs

Dried fruit weight (g)

Dried fruit weight exhibited significant difference for drying techniques and varieties. However, interaction between varietal effects and drying technique showed non-significant difference (Table 1). Pink rose dried under solar dryer got superiority over other and retained maximum weight (14.53 g) followed by Pink Rose (14 g) under electric hot air drying. Minimum fruit weight (12.66 g) was noticed in Black Ball when dried under sun drying technique. The variation in dried fruit weight across drying methods and fig varieties in this study reflects fundamental differences in how moisture is lost and how fruit structure withstands that loss. Pink Rose dried under a solar dryer retained the greatest weight (14.53 g), followed closely by hot-air drying, while Black Ball subjected to sun drying showed the lowest final weight (12.66 g).

Dried fruit recovery (%)

Dried fruit recovery possessed significant differences for varietal effect as well as drying technique. Non-significant difference was noted in case of interaction between varieties and drying techniques as illustrated in Table 1. Pink Rose possessed highest dried fruit recovery (36.36%) dried under solar dryer followed by Pink Rose (35.1%) dried under electric hot air dryer. Lowest fruit recovery (31.73%) was recorded in Black Ball using sun drying technique.

Fruit size (mm^2)

Fruit size showed significant difference for drying technique while non- significant difference for varietal effect. Conversely, non-significant difference was noted in terms of interaction between drying technique and varietal effects (Table 1). Maximum fruit size was recorded in Pink Rose dried using solar dryer (1392.3 mm^2) followed by Black Ball having (1391.3 mm^2) fruit size dried under solar dryer. The Pearson correlation analysis showed that the fruit size had negative significant correlation with drying time (Table 6). Thus, it showed that larger the fruit more time will be required for drying. Fruit size didn't exhibit any significant impact on moisture content, TSS, acidity, Total sugars, total antioxidants, phenolic content, vitamin C and organoleptic characters (Table 6).

Table 1 Effect of different drying techniques on physical traits of dried figs

Variety	Drying technique	Fresh fruit weight (g)	Dried fruit weight (g)	Fruit recovery (%)	Fruit size (mm^2)
Black Ball	Sun Drying	40a	12.66d	31.73d	1365b
	Solar Drying	40a	13.5bc	33.83c	1391.3a
	Electric Hot air Drying	40a	13.2cd	32.96cd	1387a
Pink Rose	Sun Drying	40a	13.46c	33.7c	1367.7b
	Solar Drying	40a	14.53a	36.36a	1392.3a
	Electric Hot air Drying	40a	14.03ab	35.1b	1386.7a
Effect of variety		NS	**	**	NS
Effect of drying method		NS	**	**	**
Effect of interaction		NS	NS	NS	NS
LSD		0.7	0.5	1.2	5.7

ns: Not significant, ** Highly significant ($p < 0.01$)

Effect of drying techniques on drying time and moisture contents of dried fig

Drying time (h)

Dried figs exhibit significant differences for different drying techniques. However, non-significant impact was observed for varieties and interaction between varieties and drying techniques as illustrated in Table 2. In case of drying techniques, Electric Hot air dryer takes minimum drying time (72.33 h) followed by solar dryer (95.33 h) while sun drying took maximum time (119.67 h) for drying. The Pearson correlation ($P \leq 0.05$) exhibited that the drying time is negatively significantly related with moisture content (Table 6). It is due to fact that the more moisture content in fruit will result in more drying time.

Moisture contents (%)

Data concerning moisture contents is presented in Table 2. Results exhibited significant differences for drying techniques while non-significant difference was noted in drying time. In terms of interaction between varieties and drying techniques, non-significant behavior was observed. Pink Rose exhibited higher moisture contents (20.73%) followed by Black Ball (20.63%) under electric hot air dryer. Minimum moisture contents (18.16%) were recorded in Pink Rose when dried under solar dryer.

Effect of drying techniques on biochemical traits of dried figs

Total soluble solids (Brix)

Total soluble solids showed significant difference for drying techniques as well as varieties whereas interaction effect showed non-significant difference (Table 3). Pink rose variety showed maximum total soluble solids (25.50 ºBrix) when placed in solar dryer. Minimum TSS (23.46 ºBrix) was recorded in Black Ball variety when dried in traditional sun drying method. The Pearson correlation ($p \leq 0.05$) analysis exhibited that TSS is negatively correlated with acidity, whereas, positive significant correlation found with total sugars, phenolic contents, vitamin C, taste, texture and colour of fruits (Table 6).

Table 2 Effect of drying techniques on drying time and moisture contents of dried fig

Variety	Drying technique	Drying time (h)	Moisture contents (%)
Black Ball	Sun drying	119.67a	18.4c
	Solar drying	95.33b	18.96b
	Electric hot air drying	72.33c	20.63a
Pink Rose	Sun drying	119.67a	18.16c
	Solar drying	95.33b	19.16b
	Electric hot air drying	72.33c	20.73a
Effect of variety		NS	NS
Effect of drying method		**	**
Effect of interaction		NS	NS
LSD		1.6	0.5

ns: Not significant, ** Highly significant ($p < 0.01$)

Titratable acidity (%)

Data comprised of titratable acidity of different varieties of dried figs exhibit significant differences. Non-significant difference was observed in case of drying techniques. Non-significant interaction between varieties and drying techniques was noted (Table. 3). Dried figs of Pink Rose variety showed minimum acidity (0.10%) when dried in solar dryer while maximum acidity (0.13%) in figs was noted in Black Ball variety during sun drying as well as electric hot air-drying methods. The Pearson correlation ($p \leq 0.05$) analysis exhibited that acidity has significant negative correlation with total sugars, phenolic contents, vitamin c. taste, and colour (Table 6).

Total sugars (%)

Dried figs showed significant difference between varieties while drying techniques possessed non-significant difference. However, non-significant interaction between varieties and drying techniques was observed (Table 3). The Pearson correlation ($p \leq 0.05$) analysis found that total sugars have negative significant interaction with antioxidants, whereas, positive significant correlation was observed with phenolic content, vitamin C, taste and colour (Table 6). Figs (Pink Rose) dried in Solar dryer possessed highest sugars (28.10%) followed by electric hot air dryer and sun drying method (27.66%). Lowest sugars (26.33%) were calculated in Black Ball figs during electric hot air drying.

Ascorbic acid (mg/100 g)

Ascorbic acid of dried figs depicted significant differences for varieties as well as for drying techniques. However, interaction between varieties and drying techniques were found to be non-significant (Table 3). The Pearson correlation ($p \leq 0.05$) analysis exhibited that vitamin C had positive significant correlation with phenolic content, taste, texture and colour of fig (Table 6). Pink Rose got superiority with highest ascorbic acid contents (12.53 mg/100 g) when dried under solar dryer followed by electric hot dryer (12.13 mg/100 g). Black Ball possessed lowest ascorbic acid contents (10.56 mg/100 g) dried under sun drying technique.

Table 3 Effect of different drying techniques on biochemical traits of dried figs

Variety	Drying technique	Total soluble solids (Brix^o)	Titratable acidity (%)	Total sugars (%)	Ascorbic acid (mg/100g)
Black Ball	Sun drying	23.46c	0.13a	26.73b	10.56d
	Solar drying	23.73c	0.12ab	26.73b	11.10bc
	Electric hot air drying	23.56c	0.13a	26.53b	10.93cd
Pink Rose	Sun drying	24.50b	0.11bc	27.66a	11.56b
	Solar drying	25.50a	0.10c	28.10a	12.53a
	Electric hot air drying	24.73b	0.11c	27.66a	12.13a
Effect of variety		**	**	**	**
Effect of drying method		**	NS	NS	**
Effect of interaction		NS	NS	NS	NS
LSD		0.4	0.01	0.5	0.4

ns: Non-significant, ** Highly significant (P< 0.01)

Effect of drying techniques on phytochemicals of dried figs

Antioxidants (mg/100 g)

Antioxidants exhibit significant differences for drying techniques as well as varieties. Interaction between varieties and drying techniques depicted non-significant effect (Table 4). The Pearson correlation ($p \leq 0.05$) analysis exhibited that antioxidants have significant negative correlation with phenolic content (Table 6). Black Ball exhibits highest antioxidants (110.53 mg/100g) under solar tunnel followed by electric hot air dryer with antioxidants (110.50 mg/100 g). Lowest antioxidants (108.13 mg/100 g) were observed in Pink Rose when dried under sun drying techniques.

Phenolic contents (mgGAE/100g)

Results showed significant differences for different varieties while non-significant differences for drying techniques were observed (Table 4). Interaction effect between varieties and drying techniques also found non-significant. Highest phenolic contents were recorded in Pink Rose (132.63 mgGAE/100 g) figs dried under electric hot air-drying techniques while lowest phenolic contents (122.40 mgGAE/100 g) were noted in Black Ball figs under sun drying techniques. The Pearson correlation ($p \leq 0.05$) analysis exhibited that phenolic contents have significant positive correlation fruit taste, texture and colour (Table 6).

Effect of drying techniques on organoleptic evaluation of dried figs

All drying techniques and varieties showed significant difference for organoleptic assessment as illustrated in Table 5. All attributes including taste, texture and color showed good scores in solar dried figs while sun dried figs showed lowest scores. All panelists gave good assessments of solar dried figs, especially taste and texture. The Pearson correlation ($p \leq 0.05$) analysis found that the taste has significant correlation with texture and colour; similarly, texture had significant positive correlation with colour of fruit (Table 6).

Table 4 Effect of drying techniques on phytochemicals of dried figs

Variety	Drying technique	Antioxidants (mg/100 g)	Phenolic contents (mgGAE/100 g)
Black Ball	Sun drying	109.17b	122.40b
	Solar drying	110.53a	122.73b
	Electric Hot air drying	110.50a	122.40b
Pink Rose	Sun drying	108.13c	132.43a
	Solar drying	109.17b	132.60a
	Electric Hot air drying	109.23b	132.63a
Effect of variety		NS	NS
Effect of drying method		**	**
Effect of interaction		NS	NS
LSD		0.8	0.7

ns: Not significant, ** Highly significant ($p < 0.01$)

Table 5 Effect of different drying techniques on organoleptic evaluation of dried figs

Variety	Drying technique	Taste	Texture	Color
Black Ball	Sun Drying	6.7d	6.56c	5.86e
	Solar Drying	6.7d	6.86b	6.43d
	Electric Hot air Drying	6.8cd	6.6	6.46d
Pink Rose	Sun Drying	7.0b	6.9ab	7.36c
	Solar Drying	7.4a	7a	7.6b
	Electric Hot air Drying	6.9bc	6.83b	7.8a
Effect of variety		**	**	**
Effect of drying method		**	**	**
Effect of interaction		**	NS	*
LSD		0.1	0.1	0.1

ns: Not significant, ** Highly significant ($P< 0.01$)

Table 6 Pearson correlation analysis between different quality parameters of "Fig Fruit"

	Fruit size	Drying time	Moisture content	TSS+	Acidity	Total Sugars	Antioxidants	Phenolic content	Vitamin C	Taste	Texture
Drying time	-0.746*										
Moisture content	0.582	-0.943***									
TSS	0.334	-0.083	0.014								
Acidity	-0.224	0.0214	0.065	-0.739***							
Total Sugars	0.11	0.076	-0.108	0.892***	-0.654**						
Antioxidants	0.537	-0.544	0.443	-0.438	0.343	-0.607**					
Phenolic content	0.076	-0.008	0.02	0.8537***	-0.773***	0.874***	-0.664**				
Vitamin C	0.457	-0.269	0.183	0.901***	-0.751***	0.814***	-0.345	0.853***			
Taste	0.252	0.021	-0.105	0.829***	-0.613**	0.766***	-0.356	0.682**	0.758***		
Texture	0.405	0.025	-0.16	0.759***	-0.525	0.642	-0.191	0.6**	0.733***	0.762***	
Colour	0.337	-0.287	0.248	0.846***	-0.694**	0.825***	-0.394	0.919***	0.895***	0.714***	0.721***

+ TSS = Total Soluble solids (ºBrix); *, **, *** means slightly significant, moderately significant and highly significant, respectively.

Discussion

The difference in dried fruit mass in accordance with the different modes of dehydration and types of fig varieties can be explained by the difference in the process of moisture evaporation and resistance to this process. These results are in agreement with previous studies of Manolopoulou et al. (2017) who showed that using hot air dehydration for dehydration of Tsapela figs was accompanied by lower drying time, higher fruit shrinkage and color changes in comparison with sun drying. Recovery rates of dried fruit differ due to different effectiveness of drying modes used. Natural solar drying implies control of temperature and airflow and provides better conditions for dehydration compared with traditional sun drying. In addition, hot air dehydration involves constant temperature and airflow which enables rapid dehydration while preventing excessive mechanical deformation of fruits. On the contrary, sun drying requires taking into account weather conditions and their influence on the rate of dehydration since temperature and humidity affect the process of drying and consequently, determine the amount of mass retained after drying. These observations are consistent with findings by Manolopoulou et al. (2017).

As shown by this study, the Pink Rose cultivar possesses significantly higher recovery rates as compared to the Black Ball cultivar, indicating differences between these fig varieties regarding mass losses. Different skin thickness, density, cellular structures of these cultivars can explain the higher resistance to dehydration in the case of Pink Rose. The significantly higher recovery rate observed in the Pink Rose cultivar may be attributed to inherent varietal differences in fruit structure and composition. Factors such as thicker skin, lower tissue porosity, greater tissue density, and differences in cell wall composition can reduce moisture diffusion and water loss during drying. In addition, variations in soluble solids content and water-binding capacity may influence the retention of solids and overall drying efficiency. This conclusion agrees with previous studies of Nagaraja et al. (2016) who found that the same drying processes involve different response rates and kinetic characteristics depending on the variety of figs. The differences in sizes of the dried fruits can be caused by different modes of dehydration used. Invoking natural solar energy, natural solar drying provides better conditions for the process of dehydration and retains fruit size because of stable temperature and airflow (Ullah et al., 2016).

The present findings are generally consistent with those reported by Noutfia et al. (2021), who observed that traditional sun drying required approximately 10 days, whereas natural convection solar drying reduced the drying period to about 4 days. Similarly, in the current study, solar drying resulted in shorter drying time and improved drying efficiency compared with conventional sun drying. The enhanced performance of solar drying can be attributed to higher and more stable drying temperatures, reduced exposure to ambient humidity and improved air circulation within the drying chamber. However, differences in the magnitude of drying time reduction between the studies may be associated with variations in fig cultivar, initial moisture content, fruit dimensions, environmental conditions, and dryer design. These findings further support previous reports that solar drying is a more efficient dehydration method than traditional sun drying while maintaining product quality. As for the hybrid solar dryer with temperature around 45-55 °C, this dehydration process lasted about 72 hours while traditional drying lasted around 119 hours (5 days). The rapid drying process gives an added advantage to the farmers since it allows for early marketing of the products as compared to conventional sun drying, hence leading to efficiency and possibly more profits (Henriques et al., 2025).

Drying involves removing water from the substance so that the amount of water left makes the microorganisms and enzymes inactive, hence increasing the life span. One of the important factors involved in this process is called water activity, which is defined as the ratio of "free" water to the whole water. Because this free water determines the product’s vulnerability to microbial proliferation, it is vital for ensuring microbiological stability. Since this free water is critical in determining the product’s susceptibility to microbial growth or inhibition, controlling is essential to ensure its microbiological stability. This research is similar to previous work on solar vs traditional drying for figs in Morocco by Noutfia et al. (2018) who noted that using a natural-convection solar dryer reduced drying duration and improved moisture reduction versus traditional sun drying.

The significant impact of drying on TSS is due to the fact that drying removes water, concentrating the soluble constituents in the fruit tissue. The significant increase in TSS following drying can be attributed to moisture removal, which concentrates soluble constituents such as sugars, organic acids, and other dissolved solids within the fruit tissue. As water is progressively removed during dehydration, the relative concentration of soluble solids increases, resulting in higher TSS values. Similar observations have been reported in dried fruit products, where dehydration enhances the concentration of soluble compounds through water loss and associated mass transfer phenomena (Radojčin et al., 2021). In solar drying, the temperature and airflow are more controlled (or elevated) compared with traditional sun drying, which tends to be more variable, slower, and less uniform. The higher and more consistent drying rates in solar dryers can reduce time during which biochemical changes (e.g. respiration, enzymatic activity) degrade or consume soluble solids; thus, a solar dryer tends to produce a product with higher retained TSS. Our studies are in line with previous research of Noutfia et al. (2021) who found that solar drying permitted to conserve TSS content at a higher level compared to direct sun drying. Previously Henriques et al., (2025) studied that figs dried under hybrid solar vs sun drying, the TSS values retained were higher in solar/hybrid solar methods.

The significant differences in acidity among varieties suggest intrinsic biochemical variations such as initial acid content, metabolic pathways, or composition of organic acids between Pink Rose and Black Ball. Varieties differ in the concentration of citric, malic, and other organic acids, as well as their ability to degrade or metabolize these acids during ripening or drying. A variety with lower initial acid or higher buffer capacity, or faster acid breakdown, will tend to have lower titratable acidity in the dried product. Similarly, Lachtar et al. (2022) reported that variety significantly influences traits such as organic acid content in dried figs.

There are differences in initial levels of sugars (glucose, fructose, sucrose) among different fig cultivars because of genetic characteristics, growing conditions and ripeness when harvested. For instance, the pink rose variety may produce more sugars in comparison to black ball before drying. Besides, tissue structure, skin thickness, and permeability determine residual amounts of sugars after drying. Cultivars that retain more water inside their cells and experience less mechanical injury during drying conserve more sugars. It was discovered by Şen et al. (2021) that sugar concentration is increasing when the fruit progresses from fresh to partially dried and then fully dried in previous studies conducted on Sarılop fig variety. It is worth noting that climatic conditions and the year in which research was conducted had significant impact on sugar content in fresh and dried fruits. According to Henriques et al. (2025), different drying techniques applied to the Pingo de Mel fig influenced several quality attributes; however, the soluble solids content, which reflects sugar concentration, remained relatively stable across all drying methods, with only minor variations observed.

Such important differences between fig varieties suggest that the natural characteristics of fruits play an essential role in the preservation of ascorbic acid, including initial content of vitamins in fresh fruit, ability to protect against oxygen and light during drying, as well as tissue structure. Those varieties, which have higher initial content and more protection mechanisms for vitamin C, retain more ascorbic acid. It is possible to assume that Pink Rose is more efficient in ascorbic acid conservation compared to Black Ball because of more stability or fewer injuries during drying. In addition, solar drying may provide moderate temperatures and lower exposure to UV radiation. On the contrary, electric hot-air drying may lead to ascorbic acid loss if air temperature and movement are improperly regulated. These results are supported with previous study of Tikent et al. (2023) on different fig varieties dried using different drying techniques.

Antioxidants neutralize free radicals and inhibit reactive oxygen species, which are implicated in diseases such as cancer and diabetes. The dark-skinned “Black Ball” variety, having a richer pigmentation, showed greater antioxidant levels than the light-colored “Pink Rose.” In a study by Konak et al. (2017), light-colored “Sarilop” figs dried in the sun had higher antioxidant activity, while the oven-dried “Sarizeybek” figs showed superior antioxidant capacity. Slatnar et al. (2011) using the DPPH radical scavenging method, found that the antioxidant activity was roughly similar between figs dried by different methods. Phenolic compounds found in fruit and other foods may be valuable to consumers due to their beneficial health effects, notably their capacity to act as antioxidants, reduce inflammation, support heart and brain health, and combat microbial pathogens. This research is similar to previous results of Arvaniti et al. (2019). According to Madrau et al. (2009), long drying periods under oxygen exposure led to degradation of phenolic compounds in apricots, mediated by polyphenol oxidase (PPO), which promotes their conversion into dark brown polymers (melanins). Solar drying (especially natural convection solar dryers or solar tunnels) tends to provide more consistent, elevated temperatures, reduced fluctuations, and protection from environmental contaminants (dust, insects) compared to open sun drying. Such favorable environmental conditions might help in maintaining flavors, minimizing over-oxidation, preventing spoilage by microbes and avoiding discoloration. Noutfia et al. (2021) reported that the application of a solar greenhouse dryer in Morocco increased the drying temperature by approximately 8 °C, resulting in a faster drying rate. The reduced drying duration contributed to improved sensory attributes of the dried fruits, including better taste, color retention, and texture. Another researcher Lachtar et al. (2022) mentioned that solar tunnel dryers or greenhouses produce better quality of color characteristics (lightness and yellowness) along with increased sensory acceptance.

Conclusion

The findings of this study indicate that solar drying is an effective and sustainable method for preserving fig quality and extending shelf life. Among the treatments evaluated, the Pink Rose cultivar subjected to solar drying exhibited superior quality attributes and dried fruit recovery. Solar drying reduced drying time while maintaining desirable physicochemical characteristics, demonstrating its potential as an alternative to traditional sun drying. However, the study was limited to two cultivars and specific drying conditions. Future research should focus on evaluating additional fig varieties, storage stability, sensory quality, drying kinetics, and the economic feasibility of solar drying systems to support their wider commercial adoption.

Conflict of Interest: The authors declare that there is no conflict of interest.

Authors' Contribution Statement: SR conducted experiment and wrote the manuscript. MN assisted in writing manuscript, HF assisted in data collection, RH assisted in reviewing and revising the final draft. MA and MMA supervised the research. AJK and NM performed data analysis. All authors approved the final draft of the manuscript.

References

Aksoy, U. (2021). Dried fig industry: progress and challenges. *Acta Horticulturae*, *1310*, 191-198. https://doi.org/10.17660/ActaHortic.2021.1310.24

AOAC. (2012). Official Methods of Analysis (19th ed.). Washington DC.

Arvaniti, O. S., Samaras, Y., Gatidou, G., Thomaidis, N. S., & Stasinakis, A. S. (2019). Review on fresh and dried figs: Chemical analysis and occurrence of phytochemical compounds, antioxidant capacity and health effects. *Food Research International, 119*, 244–267

Du, G., Li, M., Ma, F., & Liang, D. (2009). Antioxidant capacity and the relationship with polyphenol and vitamin C in *Actinidia* fruits. *Food Chemistry, 113*, 557–562

FAO. (2025). Food and agriculture organization. Available online with updates at http://www.fao.org/faostat/en/#data/QC

FV&CS. (2022-23). Fruit, Vegetable and Condiments Statistics, Ministry of National Food Security and Research, Islamabad, Pakistan. www.mnsr.gov.pk

Galván, A. I., Córdoba, M. G., Rodríguez, A., Martín, A., López-Corrales, M., Ruiz-Moyano, S., & Serradilla, M. J. (2022). Evaluation of fungal hazards associated with dried fig processing. *International Journal of Food Microbiology, 365*, 109541.

Henriques, B. R., Neves, C. M. B., Moumni, M., Romanazzi, G., Le Bourvellec, C., Cardoso, S. M., & Wessel, D. F. (2025). A comparative study of traditional sun drying and hybrid solar drying on quality, safety, and bioactive compounds in "Pingo de Mel" fig. *Antioxidants, 14*, 362

Konak, R., Kösoğlu, İ., & Yemenicioğlu, A. (2017). Effects of different drying methods on phenolic content, antioxidant capacity and general characteristics of selected dark colored Turkish fig cultivars. *Acta Horticulturae, 1173*, 335–340.

Lachtar, D., Zaouay, F., Pereira, C., Martin, A., Ben Abda, J., & Mars, M. (2022). Physicochemical and sensory quality of dried figs (*Ficus carica* L.) as affected by drying method and variety. *Journal of Food Processing and Preservation, 46*(3), 16379. https://doi.org/10.1111/jfpp.16379

Lane, J. H., & Eynon, L. (1923). Determination of reducing sugars by means of Fehling's solution with methylene blue as internal indicator. *Journal of the Society of Chemical Industry, 42*, 32–37.

Madrau, M. A., Piscopo, A., Sanguinetti, A. M., Del Caro, A., Poiana, M., Romeo, F. V., & Piga, A. (2009). Effect of drying temperature on polyphenolic content and antioxidant activity of apricots. *European Food Research and Technology, 228*, 441–448.

Manolopoulou, E., Tsiavtari, E., & Demopoulos, V. (2017). Sun drying and hot air drying of figs: Performance evaluation. *Acta Horticulturae, 1173*, 341–346.

Michailides, T. J., Morgan, D. P., Felts, D., & Doster, M. A. (2008). Control of decay in caprifigs and Calimyrna figs with fungicides. *Acta Horticulturae, 798*, 269–275.

Mujić, I., Bavcon Kralj, M. B., Jokić, S., Jug, T., Šubarić, D., Vidović, S., Živković, J., & Jarni, K. (2014). Characterization of volatiles in dried white varieties figs (*Ficus carica* L.). *Journal of Food Science and Technology, 51*(9), 1837–1846

Nagaraja, K., Sunil, C. K., Chidanand, D. V., & Ramachandra, M. (2016). Drying kinetics of fig (*Ficus carica* L.) under various drying methods. *Journal of Agricultural Engineering (India), 53*(4), 42–50.

Noutfia, Y., Benali, A., Alem, C., & Filali Zegzouti, Y. (2018). Design of a solar dryer for small farm level use and studying fig quality. *Acta Scientiarum Polonorum Technologia Alimentaria, 17*(4), 359-365.

Noutfia, Y., Benali, A., Guirrou, I., El Fazazi, K., & Tantaoui, H. (2021). Effect of two drying methods on key physicochemical properties and sensory profile of dried figs (*Ficus carica* L.). *Moroccan Journal of Agricultural Sciences, 10*(1), 894.

Onwude, D. I., Hashim, N., Janius, R. B., Nawi, N. M., & Abdan, K. (2022). The effectiveness of combined infrared and hot-air drying strategies for agricultural products: A review. *Food and Bioprocess Technology*, 15, 1–29.

Peryam, D. R., & Pilgrim, F. J. (1957). Hedonic scale method of measuring food preferences. *Food Technology, 11*, 9–14.

Radojčin, M., Pavkov, I., Bursać Kovačević, D., Putnik, P., Wiktor, A., Stamenković, Z., Kešelj, K., & Gere, A. (2021). Effect of selected drying methods and emerging drying intensification technologies on the quality of dried fruit: A review. *Processes, 9*(1), 132

Şen, F., Aksoy, U., Özer, K. B., & Can, H. Z. (2021). Effect of yearly conditions on sugar composition of fresh, partially dried and sun dried fig fruit. *Acta Horticulturae, 13*(10), 185–192.

Shelar, S. D., Kad, V. P., & Yenge, G. B. (2022). Studies on dehydration of fig (*Ficus carica* L.). *Journal of Agriculture Research and Technology, 47*(3), 297–305

Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology, 299*, 152-178.

Slatnar, A., Klancar, U., Stampar, F., & Veberic, R. (2011). Effect of drying of figs (*Ficus carica* L.) on the contents of sugars, organic acids, and phenolic compounds. *Journal of Agricultural and Food Chemistry, 59*, 11696–11702.

Soni, N., Mehta, S., Satpathy, G., & Gupta, R. K. (2014). Estimation of nutritional, phytochemical, antioxidant and antibacterial activity of dried fig (*Ficus carica*). *Journal of Pharmacognosy and Phytochemistry, 3*(2), 158–165.

Steel, R. G. D., Torrie, J. H., & Dickey, D. A. (1997). *Principles and procedures of statistics: A biometrical approach* (3rd ed.). McGraw-Hill.

Tikent, A., Laaraj, S., Marhri, A., Taibi, M., Elbouzidi, A., Khalid, I., Bouhrim, M., Elfazazi, K., Elamrani, A., & Addi, M. (2023). The antioxidant and antimicrobial activities of two sun dried fig varieties (*Ficus carica* L.) produced in Eastern Morocco and the investigation of pomological, colorimetric, and phytochemical characteristics for improved valorization. *International Journal of Plant Biology, 14*, 845–863.

Ullah, F., Kang, M., Hassan, L., Li, N., Yang, J., Wang, X., & Khattak, M. K. (2016). Impact of drying method of figs with small scale flat plate solar collector. *World Journal of Engineering, 13*(5), 407–412.

Wang, Z., Cui, Y., Vainstein, A., Chen, S., & Ma, H. (2017). Regulation of fig (*Ficus carica* L.) fruit colour: Metabolomic and transcriptomic analyses of the flavonoid biosynthetic pathway. *Frontiers in Plant Science, 8*, 1990. https://doi.org/10.3389/fpls.2017.01990