



Effect of Osmo-Dehydration and Gamma Irradiation on Nutritional Characteristics of Dried Fruit

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THE objective of this study is to assess the impact of osmotic dehydration using solutions of 1% citric acid, 20% sucrose, and a combination of 1% citric acid and 20% sucrose, as well as gamma irradiation doses of 1 and 3 kGy, on the nutritional properties of dried fruit. The chemical composition, mineral content, color measurement, texture profile, phenolic acids and flavonoids, vitamin C levels, DPPH radical scavenging activity and sensory evaluation of dried fruit were measured. Results indicated that treating fruit with a combination of 1% citric acid and 20% sucrose (F4) led to the highest contents of carbohydrates, flavonoids, antioxidant activity, total phenolic compounds and vitamin C content compared to other treatments. Panelists preferred F4 sample for its superior attributes in color, crispness, aroma and overall acceptability. There were no significant differences in proximate chemical composition, mineral content, and texture profile analysis among irradiation doses at 1 and 3 kGy. However, sensory evaluation scores revealed that the sample irradiated dose at 1 kGy scored higher attributes than sample irradiated at 3 kGy and the unirradiated sample. This study recommends treating fruit with a combination of 1% citric acid and 20% sucrose before drying at the irradiation dose 3 kGy for enhancing most of the nutritional characteristics of dried fruit.

Keywords: Gamma irradiation, Osmotic solutions, Phenolic acids profile.

Introduction

Dried fruits are versatile ingredients, suitable for various purposes such as breakfast, snacking, or as additions to prepackaged cereals and baked goods. Moreover, dried fruits offer health benefits akin to fresh fruits, promoting satiety and positively influencing glycemic index and blood pressure. Kowalska et al. (2018) noted consumer interest in food products abundant in dietary fiber, macro- and micronutrients. Traditional dried fruits, devoid of added sugars, are valued for their inherent sweetness, elevated fiber content, and prolonged shelf life, boasting a nutritional profile akin to their fresh counterparts. Moreover,

increasing the consumption of natural sweeteners is believed to positively impact body weight and metabolism (Royen et al., 2020; Sullivan et al., 2021).

Osmotic dehydration is a technique used to partially remove water from plant tissue by employing a hypertonic solution. The process relies on osmotic pressure to facilitate the exchange of mass between the substances involved. Here, water migrates from the material into the osmotic solution, while the osmotic agent moves from the solution into the food. An ideal osmotic substance should be easily soluble, cost-effective, convenient, non-toxic,

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and may even possess additional preservative properties, while being compatible with the material being dehydrated. Although alternatives containing ingredients with high nutritional value (such as fruit concentrates) or those with a low glycemic index (polyols) are gaining popularity, sucrose remains the most commonly used agent for osmotic dehydration (Ghellam *et al.*, 2021). Moreover, it is applied to various fruits like pineapple, mango, banana, apple, strawberries, pears, kiwi, plums, nectarines, melons, and coconut slices. This method effectively maintains their distinctive color, odor, and nutritional value (Zhang *et al.*, 2017). Osmotic dehydration is one of the least energy-consuming food technology processes, preserving the natural organoleptic and nutritional qualities of the processed materials to a large extent. Furthermore, it allows for the enrichment of plant tissues with health-promoting ingredients such as polyphenols, anthocyanins, flavanols, procyanidins, and vitamins, beneficial to human health. This non-thermal method offers flexibility in selecting raw materials and shaping their taste profile, color, and flavor with increased levels of bioactive compounds. It also enables the production of functional and designer foods with special properties (Salehi, 2023). Furthermore, OD is used to reduce water activity, acting as a preliminary step to save time and energy in subsequent processes. Moisture moves from the food to the hypertonic solution, primarily influenced by the cell membrane's permeability. Water transfer in the liquid solution involves mechanisms such as molecular diffusion, liquid diffusion, hydrodynamic flow, capillary transport, surface diffusion, or a combination of these. Higher solution concentrations result in increased rates of water loss and solid gain. Fruits treated with osmotic dehydration, especially in sliced form, retain sensory qualities similar to fresh fruits (Ahmed *et al.*, 2016).

The utilization of gamma ray irradiation in food preservation emerged as a technology in the latter part of the 20th century and has since become a widely adopted strategy for enhancing microbiological safety and extending the shelf life of food products. This method is known for its safety, efficacy, environmentally conscious nature, and energy efficiency, making it particularly significant in the field of industrial food preservation. Using gamma irradiation to protect dried foods, such as spices, herbs, nuts, and fruits, with doses from 3 to 10 kGy, offers a useful alternative to using microbicidal gases for

fumigation. Generally, when subjected to gamma radiation doses ranging from 1 to 10 kGy, food products experience negligible losses in nutritional value because this irradiation treatment does not raise the temperature of the food (Shahbaz *et al.*, 2014).

Pumpkin (*Cucurbita Pepo*) belonging to the extensive cucurbit family (Cucurbitaceae), is recognized for its diverse functional compounds present in both its flesh and skin. These include polyphenols, carotenoids, ascorbic acid, low-energy sugars, and a significant amount of dietary fiber. As a globally cultivated variety, pumpkin is distinguished among the three medicinal plants acknowledged for their anti-diabetic properties. Moreover, the consumption of pumpkin is linked to beneficial effects on human well-being, reducing the risk of neurodegenerative, cancer, and cardiovascular-related ailments. Additionally, pumpkin provides preventive measures against osteoporosis and hypertension, contributing to overall health (Hussain *et al.*, 2021).

kiwi fruit (*Actinidia Chinensis*) belonging to the Actinidiaceae family, has undergone extensive research, revealing its robust nutritional profile and associated health benefits which contribute to digestive, immune, and metabolic well-being, as well as, it is considered as one of the most crucial sources of essential vitamins (B, C, K, A, and E), fiber, folate, K, and various minerals. Moreover, it harbors an array of phytochemicals like carotenoids, flavonoids, anthocyanins, and lutein, demonstrating diverse pharmacological characteristics, including anti-diabetic, anti-cancer, hepatoprotective, antifertility and antiulcer effects (Khutare & Deshmukhs, 2023). The sweet cherry (*Prunus avium* L.) holds a distinctive position as one of the earliest fresh fruits available in northern China, carrying considerable economic importance. Celebrated for its vibrant color and rich nutritional content, this fruit is abundant in various carbohydrates, proteins, vitamins, and essential nutrients like Fe, Ca, and K (Gonçalves *et al.*, 2021). Apple (*Malus domestica*) is considered as a widely cultivated, sweet, and a globally consumed fruit with substantial nutritional value. It holds a crucial position in diverse diets, providing a rich source of polyphenolic compounds, including oligomeric flavanols (e.g., quercetin), flavanols (e.g., phlorizin), p-hydroxybenzoic acids, p-hydroxycinnamic acids, and anthocyanidins. and monomeric. Moreover, Apples exhibit functional

and health-promoting properties attributed to their antioxidant potential, anti-inflammatory activity, cholesterol-lowering effect, cardiovascular protective effect, antidiabetic activity, and anticancer activity, primarily stemming from their major phenolic compounds (Patocka et al., 2020; Acquavia et al., 2021). Hence, the aim of this study is to investigate the impact of osmotic dehydration using solutions of 1% citric acid, 20% sucrose, and a combination of 1% citric acid and 20% sucrose, as well as gamma irradiation doses of 1 and 3 kGy, on the nutritional properties of dried fruit (apple, kiwi, pumpkin, and sweet cherry) as a method to extend their shelf life.

Materials and Methods

Materials

Pumpkin, kiwi, sweet cherry, and apple were sourced from local markets in Alexandria, Egypt. The study also acquired citric acid, sucrose, and various packaging materials for experimentation. All chemicals and reagents utilized in this study were of analytical grade and sourced from Sigma Company.

Methods

Technological method

(1) Samples preparation

Flow sheet in Fig. 1 illustrates the samples preparation process. A total weight of three kilograms of fresh fruit, comprising pumpkin, kiwi, sweet cherry, and apple, was thoroughly

rinsed by running tap water to remove any remaining soil, dust, or dirt. Subsequently, the fruits were peeled using a sterile knife and sliced uniformly to a thickness of 2 mm using a circular stainless-steel mold, excluding the sweet cherry. The resulting fruit slices, especially those of apple and pumpkin, underwent blanching by immersing them in boiling water for approximately 5 min. After blanching, the samples were allowed to cool, and any excess moisture on the fruit was carefully absorbed using tissue.

(2) Osmotic dehydration pretreatment of fruits samples

Distilled water and commercial sucrose were used in the preparation of the osmotic solutions, citric acid at 1%, and a combination of sucrose at 20% with citric acid at 1%. In the initial step, one kilogram of each type of fruit was immersed in the three Osmotic solutions, undergoing osmotic treatment for duration of 4-6 hr at 4°C within a stainless-steel bowl. Throughout this osmosis process, water migrated from the fruit into the solution, while a portion of the solute was transferred to the fruit. Following the treatment duration, the fruits were carefully extracted from the solution. After being promptly rinsed with water, the fruit that underwent osmotic treatment were uniformly arranged on stainless steel trays. These trays were then placed in a dehydrator set at 50°C for duration of 12 hr (a hot air oven

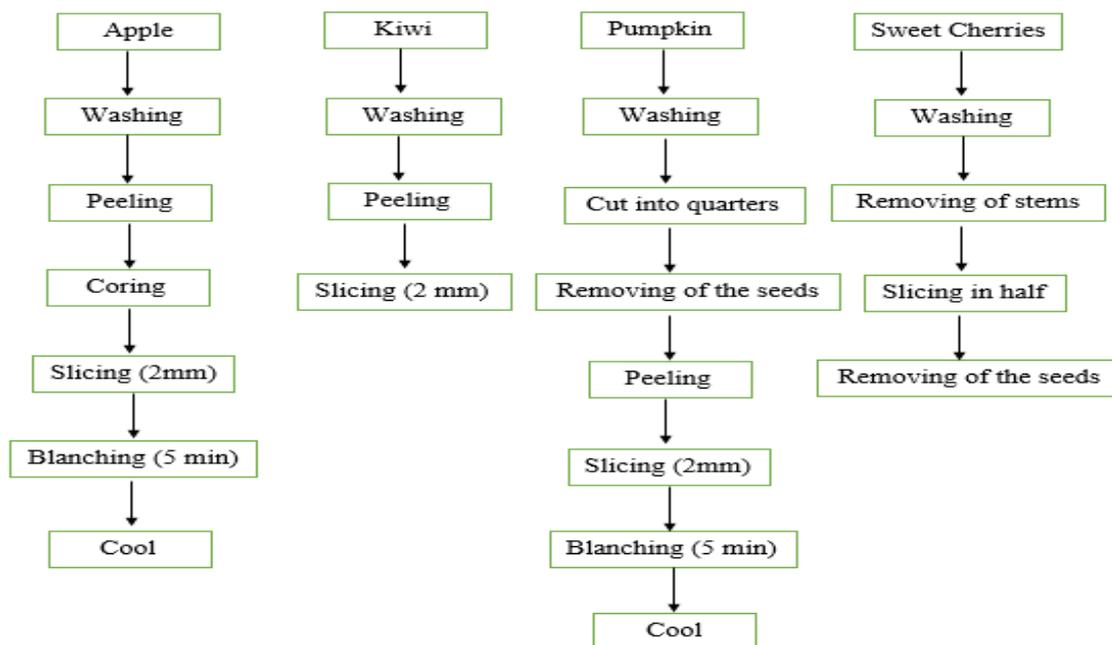


Fig. 1. Flow sheet for samples preparation process .

under thermostatic control, Vacuum Oven Model 3618, USA). Subsequently, the dried fruits were meticulously sealed in airtight polyethylene bags and stored at room temperature.

(3) Gamma irradiation process

The gamma irradiation process was executed using a cobalt-60-based gamma chamber situated in a Russian gamma chamber facility with a dose rate of 422.9 Gy/h, overseen by the Cyclotron Project at the Nuclear Research Center, Atomic Energy Authority, Egypt. The mixed dried fruits were carefully enveloped in polyethylene bags and exposed to irradiation doses at 1 and 3 kGy. Subsequently, both the treated and control samples were kept at room temperature until the analysis was conducted. The treated mix fruit samples were divided into six distinct categories of treatments. The initial treatment (F1) acted as the control and underwent no specific treatment. In the second treatment (F2), the samples were soaked in a 1% Citric acid solution. In the third treatment (F3) the fruits samples were immersed in a solution containing 20% sucrose. In the fourth treatment (F4), samples were soaked in a solution containing 20% sucrose and 1% citric acid. The fifth treatment (F5) involved subjecting the samples to an irradiation dose at 1 kGy. Lastly, the sixth treatment (F6) exposed the samples to an irradiation dose at 3 kGy.

Analytical methods

Proximate chemical composition

The proximate chemical composition of the mixed dried fruit samples (fat, ash, protein, and crude fiber) was evaluated following the guidelines of AOAC (2023). Total carbohydrates were calculated by difference.

Determination of minerals

Minerals (Ca, Cu, Fe, Mn, Mg, K, Zn, P and Na) were measured by analyzing the ash solution using ICP-OES Agilent 5100 VDV, following the procedures outlined in AOAC (2023). In short, the sample powders (0.5 g each) were accurately weighed and transferred into Telvon digestion tubes. Subsequently, 5 mL of nitric acid was added, and the mixture was vortexed for 30 seconds. The digestion tubes were then evenly positioned in a preheated microwave digester by Peeked (Shanghai, China) and digested at 120°C for 5 min, 150°C for 10 min, and 190°C for 20 min. Following digestion, the tubes were taken out, allowed to cool to room temperature,

and diluted with 50 mL of water for subsequent analysis using ICP-OES. Mineral analysis of the samples was conducted using an ICP-OES Agilent 5100 VDV.

Color measurement

The color attributes, including L^* (lightness), a^* (red intensity), and b^* (yellow intensity), of the samples were evaluated using a Hunter Lab Ultra Scan, VIS model colorimeter (USA) and measured according to the method described by Santipanichwing and Suphantharika (2007). The samples were placed into a 20 mm cuvette and measured within a white spectrum. To ensure accuracy, three readings were taken. The measurements were displayed in L^* (light–dark spectrum) a^* (green–red spectrum) and b^* (blue–yellow spectrum). The recorded values represent the average of five measurements for each color parameter on the Hunter scale (L^* , a^* , b^*).

Texture Profile Analysis (TPA)

TPA was performed to evaluate the texture characteristics of the mixed dried fruit samples utilizing the TA-XT 2 Texture meter (Texture Pro CT3 V1.2, Brookfield, Middleboro, USA), According to Yuan & Chang (2007). The TPA included hardness cycle 1 (g), springiness (mm), gumminess (g), chewiness, cohesiveness, hardness cycle 2 (g), and resilience.

Bioactive compounds and antioxidant activity

(1) Extraction of ethanol-based extract from mixed fruit samples

Five grams of each fruit sample were combined with 30 mL of ethanol (75%) and agitated for 2 hours at room temperature. Subsequently, the mixtures underwent filtration through Whatman filter paper No.1, and the resultant extracts were preserved at -20 °C until performing analysis.

(2) High-Performance Liquid Chromatography (HPLC) analysis of phenolic acids and flavonoids

The approach outlined by Jakopič *et al.* (2009) was utilized for determining phenolic acids in the samples. In a nutshell, individual samples (100 mg each) were mixed with 10 mL of methanol and subjected to ultrasonication for 45 min. Subsequently, the resulting mixture underwent centrifugation at 2170 RCF for 7 min, leading to the separation of supernatants. These supernatants were then filtered through a 0.45 μm filter and collected in vials for subsequent analysis. High-performance liquid chromatography (HPLC) was conducted using a linear gradient at a flow rate of 1.0 mL/min, employing a mobile phase composed

of solvent A (water/acetic acid 98:2 v/v) and solvent B (methanol/acetonitrile 50:50 v/v). The gradient initiated at 5% solvent B and gradually increased to 30% at 25 min, 40% at 35 min, 52% at 40 mins, 70% at 50 min and reached 100% at 55 min. Phenolic acid and flavonoid content were assessed by generating chromatograms at both 280 nm and 330 nm, respectively. Identification and quantification of components were achieved by comparing peak areas to external standards, following the methodology established by Schiebe et al. (2001).

(3) Determination of total phenolic contents

The determination of total phenolic content (TPC) in the extracts was performed in triplicate following the method established by Abirami et al. (2014). To the water-soluble extract (300µL), a mixture of Folin–Ciocalteu's reagent (1.5mL, diluted 10 times) and Na₂CO₃ (1.2mL, 7.5% w/v) was added. The combination was thoroughly mixed and left in darkness at room temperature for 30 min before measuring the absorbance at 765 nm using a spectrophotometer (Pg T80+, England). The total phenolic content was expressed as milligrams of gallic acid equivalent per gram of plant material extract.

(4) DPPH scavenging activity

The assessment of samples' radical scavenging activity was conducted through the utilization of DPPH (2,2-diphenyl-1-picrylhydrazyl), in accordance with the method outlined by Brand-Williams et al. (1995). The calculation of the DPPH scavenging percentage for the samples was performed using the following formula:

DPPH scavenging activity % =

$$\frac{\text{Abs control} - \text{Abs sample}}{\text{Abs control}} * 100$$

Extraction and vitamin C analysis

The Vitamin C content was assessed following the protocol outlined by Babarinde and Fabunmi (2009). Initially, 10 grams of plant material was combined with an extraction solution consisting of 0.3 M metaphosphoric acid and 1.4 M acetic acid. The resulting mixture was then transferred to a conical flask and subjected to agitation at 10,000 rpm for 15 min. Subsequent to agitation, the mixture underwent filtration using Whatman No. 4 filter paper. Quantification of vitamin C content in the plant material was carried out by comparing it to a standard of vitamin C. This analysis was executed using a high-performance liquid chromatography (HPLC) system, specifically the Agilent Technologies 1200 model.

Sensory evaluation

A sensory evaluation involved 10 staff members from the Special Food and Nutrition Research Department at the Food Technology Research Institute in Egypt. Panelists utilized a 9-point hedonic scale to evaluate sensory parameters, such as crispness, taste, odor, texture, and overall acceptability. The scale ranged from 1 =dislike extremely to 9 =like extremely (Gebreil et al., 2020).

Statistical analysis

The statistical analysis involved conducting one-way analysis of variance (ANOVA) using SAS statistical analysis software (2004). Means were compared using Duncan's test, and significance was considered at $p < 0.05$.

Results and Discussion

Proximate chemical composition of dried fruit samples

The proximate chemical composition of dried fruits samples is shown in Table 1. The findings revealed that the moisture content varied from 6.25 to 7.35%. Notably, the highest moisture content ($P < 0.05$) was found for F1 (control sample), whereas the lowest moisture content ($P < 0.05$) was noted in F4 (containing 20% sucrose and 1% citric acid). This might be attributed to the fact that osmotic dehydration promotes increased water loss. These findings agreed with the findings obtained by Hanafia et al. (2021) who found a reduction for moisture content of dried pineapple with an increased concentration of sugar. Conversely, moisture content of citric acid-treated samples is notably higher ($p > 0.05$), due to the absence of sugar in the solution, resulting in lower water absorption from the fruits. Generally, the osmotic solution pre-treatment exhibits a beneficial impact on moisture content, as it decreases the fruit's moisture content post-drying. This reduction can help decelerate the degradation process and uphold its quality (Oyinloye & Yoon, 2020).

Results also indicated that protein content in the dried fruit samples varied between 3.81% and 4.64%. The highest protein content was noted with F2 sample, whereas the lowest was recorded in F3 sample. These findings could be attributed to variations in protein content among the types of fruit samples employed in this study. These obtained results are in line with those reported by Bolarinwa and Ajetunmobi (2020) who found that the protein content was lower in the sample treated with a sugar solution of 60° compared to the control which showed the highest protein content.

TABLE 1 . Proximate Chemical Composition of dried Fruits samples:

Treatments	Moisture (%)	Protein (%)	Ash (%)	Crude Fiber (%)	Fat (%)	*NFE (%)
F1	7.200 ^c ±0.04	4.490 ^{ab} ±0.14	2.213 ^a ±0.22	2.980 ^a ±0.03	4.83 ^b ±0.03	78.29 ^c ±0.24
F2	7.352 ^a ±0.11	4.640 ^a ±0.04	1.900 ^b ±0.10	2.913 ^a ±0.02	3.93 ^d ±0.01	79.27 ^c ±0.22
F3	6.443 ^d ±0.09	3.813 ^c ±0.07	1.360 ^c ±0.04	2.740 ^b ±0.04	5.41 ^a ±0.01	80.23 ^b ±0.08
F4	6.250 ^e ±0.04	4.420 ^b ±0.06	1.080 ^d ±0.08	2.637 ^c ±0.03	4.71 ^c ±0.02	80.9 ^a ±0.07
F5	7.221 ^{bc} ±0.04	4.457 ^{ab} ±0.16	2.210 ^a ±0.22	2.993 ^a ±0.10	4.82 ^b ±0.02	78.3 ^{dc} ±0.15
F6	7.240 ^b ±0.08	4.473 ^{ab} ±0.10	2.223 ^a ±0.31	2.923 ^a ±0.05	4.82 ^b ±0.03	78.32 ^d ±0.21

Values are means ±SD of three independent replicates. Means in the same column with different letters are significantly different ($p < 0.05$). F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy)

*(NFE) N- free extract, Calculated by difference

This result is attributed to the formation of complex compounds between free amino acids and sugar molecules through the Maillard reaction, rendering the protein unavailable for precise measurement.

Findings also indicated that the ash and crude fiber contents in the F4 sample (1.08% and 2.64%, respectively) were significantly lower than in other treatments. Meanwhile, the significantly highest ash and crude fiber contents were found in F1 (2.21 and 2.98% respectively). The findings presented here agree with those reported by Bolarinwa and Ajetunmobi (2020) who reported a higher crude fiber content in the untreated sample compared to osmotically treated samples. This discrepancy is attributed to the osmotically dried samples' ability to bind with water molecules in the flakes, leading to a reduction in fibrous texture. On the contrary, the osmotically dehydrated samples exhibited higher ash content values in comparison to the untreated sample. This result is attributed to adding sugar in the osmotically dried apple.

Regarding the fat in dried fruit, as shown in Table 1, the osmotic pretreatments before drying had a significant effect on fat content, with fat content in the samples ranging between 3.39% and 5.41%. The significantly highest value was found in F3 (soaking in sucrose solution) compared to other samples. This contrasts with the results of our study, Ela *et al.* (2015) found decrease in fat content of pawpaw slices treated with a

sugar solution at 60° Brix osmotic concentration compared to those exposed to lower osmotic solution concentrations.

As for the content of carbohydrates (NFE), it ranged between 78.29% in the F1 sample to 80.90 in F4 (soaked in 1% citric acid and 20% sucrose solution). There were significant differences in NFE content among osmotic pretreatments, as presented in Table 1. Data presented here agree with the results obtained in the study of Bolarinwa and Ajetunmobi (2020). The carbohydrate contents of the Apple flakes increased with higher sugar concentration. This attributed to the use of sugar as an osmotic solution; meanwhile, the sugar is a substantial source of carbohydrates.

Additionally, based on the findings presented in Table 1, It is clear that there are no significant differences ($p > 0.05$) in the ash, protein, fat, crude fiber, and NFE contents in the dried fruit samples for gamma irradiation doses at 1 and 3 kGy (F5 and F6), except for the sample irradiated at 3 kGy. These findings are in line with those found by Al-Bachir (2021) who reported that gamma irradiation doses did not significantly influence factors such as fat, protein, and reducing sugar. On the other hand, the findings indicate an elevated moisture percentage in the irradiated apricot kernel samples. This increase could be attributed to differences in the extent of water hydrolysis induced by gamma irradiation.

Minerals and vitamin C contents of dried fruits samples

The data in Table 2 show the minerals content of dried fruits samples. The findings demonstrate that the Ca and Cu contents in the dried fruit ranged from 102.40 to 209.29 mg/100 g and 0.40 to 0.75 mg/100g respectively. The highest contents of Ca and Cu were found with the F1 sample. In contrast, F4 (soaked in a solution containing 20% sucrose and 1% citric acid) exhibited a significant decrease in Mg, K, P, and Na contents (38.31, 203.63, 47.15, and 19.59 mg/100g, respectively,) as compared to the F1 sample (112.44, 958.29, 169.52, and 192.82 mg/100g, respectively). However, the Mn content increased from 0.24 in F2 to 1.56 mg/100 g in the F3 sample. Meanwhile, the Zn content varied between 1.30 mg/100g in the F4 sample to 3.39 mg/100g in F2. Notably, the F3 sample exhibited significantly higher Fe content (6.54 mg/100g) compared to other samples. These results are in agreement with those found by Cvetković et al. (2019), who observed that the process of osmotic dehydration of cabbage in molasses (S3) significantly increased Fe and K levels in the dehydrated cabbage. Meanwhile, the Mg, Fe, and Ca levels were the lowest. Furthermore, as depicted in Table 2, it is noted that the minerals contents in the dried fruit samples treated with radiation doses of 1 and 3 such as Ca, Cu, Fe, Mg, K, Zn, P, and Na, were similar in their content to the control sample, except for Mn mineral which decreased in F6. The data obtained in this study are in agreement with those reported by Hidar et al. (2021) who reported that gamma irradiation had no significant effect on the content of minerals like P, Ca and Zn for doses at 0.5 and 2 kGy. 0.05 mg/kg.

Results of vitamin C content of the dried fruits samples is present in Fig. 2 It could be observed that the highest vitamin C content was found in the F4 sample (45.2 mg/100g). However, the F1 sample (41.6 mg/100g) exhibited lower vitamin C content. These findings are contrasts with the findings of Bolarinwa and Ajetunmobi (2020). The untreated apple flakes exhibited notably higher vitamin C in comparison to treated samples. This attributed to the release of these vitamins during the extended osmotic dehydration process, which lasted for 24 hr. Likewise, Phisut and Aekkasak (2013), who observed that during osmotic dehydration, leaching of natural

solutes, such as vitamins, acids, and phenolic compounds, into the osmotic solution can take place. Moreover, the removal of surface sugar from osmotically treated samples can also lead to the leaching of vitamins into the washing water. Furthermore, the drying temperature was set at 55°C, a moderate level that doesn't induce significant vitamin losses.

Findings also revealed that the irradiated sample at 1 and 3 kGy exhibited a lower vitamin C content (40.1 and 36.6 mg/100g) compared to the non-irradiated sample (41 mg/100g, respectively). These findings agree with de Figueiredo et al. (2014), who observed a significantly lower vitamin C content in irradiated samples compared to non-irradiated ones. Furthermore, Hussain et al. (2021a) noted that vitamin C content in the irradiated samples was slightly ($P < 0.05$) lower immediately after the treatment compared to the control samples.

Color measurement of dried fruits samples

Color is a critical sensory attribute that holds significant importance in consumer preference and acceptance of food products. The color characteristics, including lightness, yellowness, and redness, of the dried fruits samples are presented in Table 3. The pattern observed in the lightness value was consistent with that of the yellowness value, with the significantly highest lightness and yellowness values ($P < 0.05$) found in F2 (subjected to soaking in a solution containing 1% citric acid). While, the lowest ($P < 0.05$) lightness and yellowness values were found in F1. Otherwise, the redness in F3 sample was significantly higher than other treatments. These findings agree with those of Bolarinwa and Ajetunmobi (2020) who noted that the lightness values of apple samples treated with a 60% sugar solution were significantly higher compared to the control sample. This attributed to the protective effect of the high sugar content within the fruit cells, which may shield the treated apples from direct thermal damage. Additionally, no significant differences were found in lightness value between all treatments. However, as the sugar concentration increased, the treated samples exhibited higher redness and yellowness compared to untreated sample. This might be attributed to pigment's stability during osmotic dehydration.

Results also indicated that the highest lightness value was found in F6 compared to F1 (control sample). Likewise, both redness and

yellowness values followed a similar pattern, significantly increasing ($p < 0.05$) in the F6 sample. The positive impact of radiation treatment on preventing the decline in lightness value, coupled with the concurrent increase in redness value, and yellowness is likely due to its ability to decrease polyphenol oxidase activity and chlorophyll degradation (Hussain *et al.* 2021a) In contrast to our findings, Aljahani *et al.* (2022) reported that the control pumpkin jam exhibited significantly higher levels of lightness and

redness values compared to the irradiated treated samples. However, the control sample showed the lowest yellowness value. Alterations in the color of pumpkin jam can be attributed to the fading of its natural hues during the processing stages. Moreover, Harde *et al.* (2021) observed a decrease in redness and yellowness values as irradiation doses increased. This could be attributed to the Maillard reaction, which occurs between sugars and proteins or the transformation of residual phenols.

TABLE 2 Minerals content of dried fruits samples.

Minerals (mg/100g)	F1	F2	F3	F4	F5	F6
Ca	209.29 ^a ±2.47	102.40 ^d ±1.88	167.77 ^b ±2.01	116.82 ^c ±0.37	209.03 ^a ±3.06	209.70 ^a ±2.47
Cu	0.75 ^a ±0.02	0.39 ^b ±0.02	0.41 ^b ±0.02	0.41 ^b ±0.01	0.75 ^a ±0.01	0.75 ^a ±0.02
Fe	5.89 ^b ±0.01	4.31 ^c ±0.02	6.54 ^a ±0.02	2.92 ^d ±0.01	5.88 ^b ±0.03	5.89 ^b ±0.10
Mn	0.74 ^b ±0.01	0.24 ^c ±0.01	1.56 ^c ±2.03	0.28 ^d ±0.01	0.75 ^a ±0.01	0.42 ^b ±0.01
Mg	112.43 ^c ±1.29	57.980 ^c ±1.02	78.163 ^b ±1.60	38.313 ^d ±1.17	112.80 ^a ±0.95	112.73 ^a ±1.29
K	958.29 ^a ±1.58	93.18 ^a ±2.89	480.59 ^f ±1.46	203.62 ^b ±1.19	957.83 ^b ±0.41	958.64 ^b ±1.58
Zn	2.01 ^b ±0.01	3.93 ^a ±0.02	1.58 ^c ±0.02	1.30 ^d ±0.02	2.02 ^b ±0.02	2.01 ^b ±0.01
P	169.52 ^a ±0.85	89.61 ^c ±1.42	92.840 ^b ±0.96	47.15 ^d ±1.42	169.86 ^a ±1.16	169.52 ^a ±0.85
Na	196.81 ^a ±1.30	24.28 ^c ±0.78	45.41 ^b ±0.63	19.59 ^d ±0.86	197.32 ^a ±1.04	197.08 ^a ±0.49

Values are means ±SD of three independent replicates. Means in the same column with different letters are significantly different ($p < 0.05$). F1 (control without treatments), F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

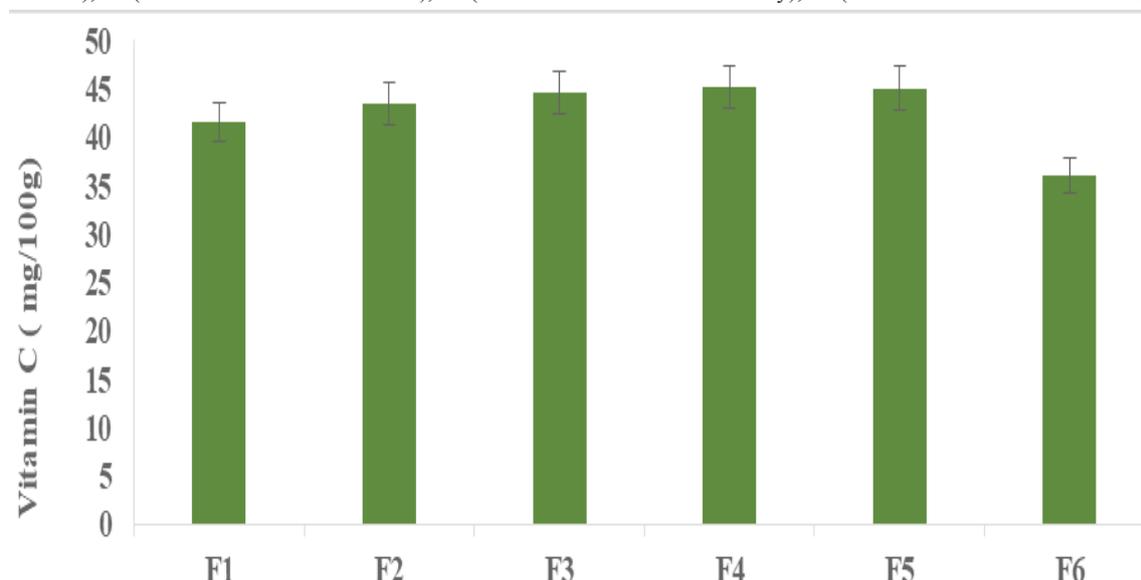


Fig. 2. Vitamin C contents of dried fruits samples.

F1 (control without treatments), F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

TABLE 3. Color Measurement of dried fruits samples

Treatments	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)
F1	51.94 ^e ±0.02	8.060 ^e ±0.02	17.22 ^e ±0.02
F2	63.17 ^a ±0.03	9.62 ^c ±0.03	28.40 ^a ±0.02
F3	58.93 ^c ±0.03	9.86 ^a ±0.02	24.64 ^c ±0.02
F4	61.63 ^b ±0.03	9.70 ^b ±0.02	26.66 ^b ±0.02
F5	51.94 ^{de} ±0.02	8.09 ^{de} ±0.02	17.28 ^d ±0.05
F6	52.03 ^d ±0.08	8.12 ^d ±0.03	17.32 ^d ±0.03

Values are means ±SD of three independent replicates. Means in the same column with different letters are significantly different ($p < 0.05$). F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

Texture profile of dried fruits samples

Texture is a critical factor that significantly influences the overall acceptance of food products; especially in the context of dried items. The texture characteristics, including parameters like hardness cycle 1, springiness, chewiness, cohesiveness, hardness cycle 2, gumminess, and resilience of the dried fruits samples, are presented in Table 4. The findings indicated that the hardness cycle 1, 2 exhibited a similar trend to the cohesiveness value with F2 (containing 1% citric acid) demonstrating the highest values. Conversely, F3 demonstrated the highest gumminess and chewiness values, while the lowest ($P < 0.05$) gumminess value was observed in F1. Additionally, the highest resilience was found in F2 and F4 samples, while the lowest resilience was observed with F1. This could be attributed to the interaction between pectin molecules in the fruit structure and the presence of citric acid which likely contributes to strengthening the firmness of the texture.

These findings are in a line with the findings presented by Wang et al. (2023a) who revealed that samples subjected to sucrose pretreatment before drying exhibited reduced hardness compared to untreated dried peach sample. This reduction in hardness could be attributed to a robust interaction occurring among the hydroxyl groups in the tissue of yellow peach slices and sucrose molecules through hydrogen bonds, thereby strengthening the cell wall. This observation is in a line with the results reported by Wang et al. (2023b) who noted a substantial increase in hardness, chewiness, cohesiveness, and resilience in peach samples dehydrated. This may be due to water loss, with the sugar treatment acting as an osmotic. Results also revealed that there were

no significant differences ($p > 0.05$) in hardness cycle 1 and 2, springiness, gumminess, and chewiness among gamma irradiation treatments at 1 and 3 kGy. In contrast, the cohesiveness value showed a pattern similar to resilience, showing a significant ($p < 0.05$) decrease in samples subjected to gamma irradiation at 3 kGy. This could be due to the irradiation induces changes in the synthesis of enzymes responsible for breaking down polymers crucial for structural integrity, like polygalacturonates and pectin methyl esterase (Cancino-Vázquez, 2020)

Phenolic compounds, flavonoids profile and antioxidant activity of dried fruits samples

According to the HPLC findings shows that the phenolic compounds in dried fruits samples are gallic acid, pyrogallol, catechin, catechol, benzoic, caffeic, chlorogenic, vanillic, ferulic, ellagic, and coumarin (Table 5). Notably, the F4 sample (soaked in a solution containing 20% sucrose and 1% citric acid) exhibited elevated levels of certain phenolic compounds like gallic acid, catechin, chlorogenic, benzoic acid, caffeine, and ferulic acid. In contrast, F2 (soaked in a solution containing 1% citric acid) displayed the highest amounts of pyrogallol, vanillic acid, ellagic acid, and coumarin compared to other treatments. Additionally, F1 showed the lowest concentrations of catechin, gallic acid, benzoic acid, chlorogenic acid, vanillic acid, caffeic acid, caffeine, ellagic acid, and ferulic acid. These findings agree with Pinakin et al. (2020) who observations, where citric acid treatment led to an increase in phenolic compound concentrations, attributed to citric acid's stabilizing effect on phenolic compounds, reducing their susceptibility to oxidation due to the lower pH. Similarly, Mohammed et al. (2022).

TABLE 4. Texture profile of dried fruits samples.

Treatments	Hardness cycle 1	Springiness	Gumminess	Chewiness	Cohesiveness	Hardness cycle 2	Resilience
F1	284.0 ^d ±4.33	12.22 ^a ±1.41	208.0 ^d ±4.24	20.99 ^b ±2.83	0.73 ^b ±0.04	229.5 ^d ±3.39	0.21 ^{ab} ±0.01
F2	389.0 ^a ±3.05	9.75 ^b ±0.04	234.67 ^c ±3.05	15.33 ^c ±2.06	1.03 ^a ±0.02	431.67 ^a ±3.05	0.24 ^a ±0.03
F3	339.0 ^c ±2.0	6.08 ^c ±0.05	377.67 ^a ±3.1	31.67 ^a ±3.05	0.61 ^c ±0.03	342.67 ^b ±3.06	0.22 ^{ab} ±0.03
F4	346.7 ^b ±3.06	4.51 ^c ±0.03	356.66 ^b ±3.05	22.70 ^b ±0.35	0.38 ^d ±0.02	326.67 ^c ±3.05	0.24 ^a ±0.02
F5	282.7 ^d ±2.15	11.64 ^a ±1.5	209.3 ^d ±2.52	22.25 ^b ±1.47	0.62 ^c ±0.08	228.0 ^d ±2.5	0.20 ^b ±0.01
F6	281.7 ^d ±0.61	12.01 ^a ±1.11	210.0 ^d ±3.61	22.17 ^b ±0.64	0.60 ^c ±0.05	224.66 ^d ±4.07	0.18 ^b ±0.01

Values are means ±SD of three independent replicates. Means in the same column with different letters are significantly different ($p < 0.05$). F1 (control without treatments), F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

Moreover, according to the data presented in Table 5, it is evident that F5 sample exhibited elevated levels of specific phenolic compounds, such as Catechin, Caffeic, Vanillic, Ferulic, Ellagic, and Coumarin, in comparison to the control sample. However, F6 sample (irradiated with a dose of 3 kGy) demonstrated higher concentrations of Gallic acid, Catechol, and Benzoic. The increased presence of phenolic compounds in the irradiated samples could be attributed to the enhanced extraction of antioxidant compounds from glycosides. This might lead to the breakdown of larger phenolic compounds into smaller constituents due to the impact of radiation treatment. These findings agree with the observations of Abdelaleem & Elbassiony (2020), who reported higher quantities of gallic acid, catechin, ellagic acid, and caffeine acid in samples irradiated at a dose of 6 kGy compared to unirradiated samples. Additionally, Hamza *et al.* (2022) noted that syrup irradiated at 1 and 2 kGy exhibited an increase in TPC compared to non-irradiated syrup. It's worth noting that the overall phenolic content depends on the phenolic composition in the extract as well as the magnitude of the radiation dose.

The findings in Fig. 3 and 4 revealed that F4 exhibited the highest TP (796 mg GAE/g) and DPPH scavenging activity (90.85%) significantly compared to the other treatment groups. In contrast, F1 displayed lower values of TP and DPPH scavenging activity (590.73 mg GAE/g and 73.57%, respectively). These findings are nearly in agreement with those found by Nyangena *et al.* (2019) reported that a

1% citric acid pretreatment before drying at 50 °C can enhance the retention of antioxidants in dried mango products. Moreover, Sonkar *et al.* (2020) observed that DPPH radical scavenging activity depends on different factors, like the drying method, type of extraction solvent, antioxidant assays employed, and the interplay of multiple antioxidant reactions. Results also indicated that the highest values for total phenolic content and DPPH scavenging activity values were notably observed in the irradiated sample at 3 kGy (691.37 mg/100g and 125.55%). These findings agree with the reported by Hussain *et al.* (2021b), who observed that kiwi samples irradiated at 2.0 kGy displayed higher value of total phenol content than unirradiated samples. The impact of radiation treatments on antioxidant content in fresh plant produces are contingent on factors such as the administered dose, duration of exposure, and the specific raw material utilized. Several reports highlight that radiation-induced effects on chemical bonds can lead to the liberation of low molecular weight fragments. This outcome is linked to the activation of phenylalanine ammonia-lyase (PAL) biosynthesis, which consequently promotes phenolic compound synthesis, aiding radiation-induced depolymerization of polysaccharides and thereby facilitating the release of phenols (Hidar *et al.* 2021).

Concerning flavonoid content, the results in Table 6, F4 sample showed the highest concentrations of various flavonoids, including Rutin, Naringin, and Quercetin compared with the control sample.

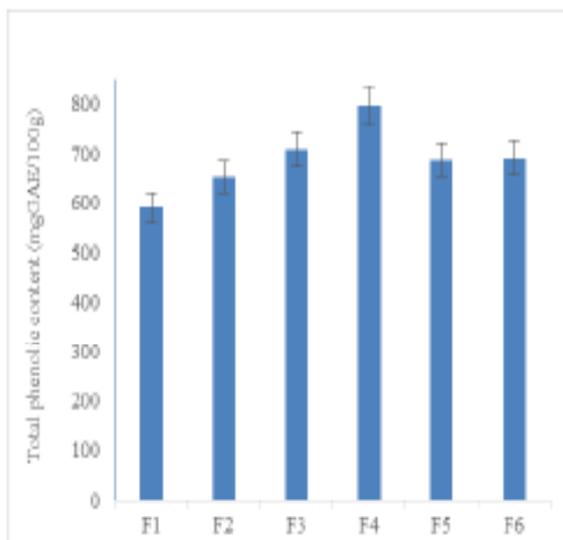


Fig. 3. Total phenolic content of dried fruits samples.

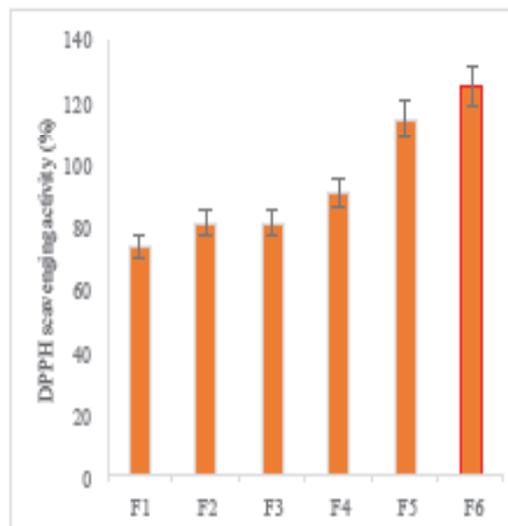


Fig. 4. DPPH scavenging activity of samples dried fruits.

F1 (control without treatments), F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

TABLE 5. Fractionation of Phenols of dried Fruits samples.

Phenols (mg /100 g dry weight)	F1	F2	F3	F4	F5	F6
Pyrogallol	40.36	64.33	60.25	50.56	40.88	39.69
Gallic	2.28	7.37	6.86	8.28	4.82	5.08
Catechol	16.35	75.07	76.53	60.78	15.48	17.16
Catechin	17.77	25.65	24.36	26.91	25.50	22.19
Chlorogenic	19.34	27.19	27.36	30.76	18.54	14.64
Benzoic	16.83	20.61	22.26	26.02	22.49	24.94
Caffeic	19.82	27.62	22.99	23.70	20.19	18.20
Vanillic	15.12	27.20	24.73	25.76	20.69	15.09
Caffeine	17.65	22.83	21.20	23.24	12.31	11.73
Ferulic	4.46	5.40	7.52	13.15	5.67	4.57
Ellagic	25.39	28.27	25.89	23.44	25.70	25.46
Coumarin	1.62	1.88	1.43	1.46	1.80	1.16

F1 (control without treatments), F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

TABLE 6. Flavonoids profile of dried Fruits samples .

Flavonoids (mg/100 g dry weight)	F1	F2	F3	F4	F5	F6
Rutin	11.70	16.47	20.96	22.43	13.23	12.22
Naringin	14.30	21.65	25.87	30.00	14.19	16.72
Rosmarinic	0.49	0.66	1.574	1.45	0.83	0.89
Quercetrin	4.63	4.59	4.26	4.42	4.46	4.40
Quercetin	3.93	4.28	4.46	4.86	3.91	3.16
Naringenin	0.97	1.58	1.40	1.16	1.03	1.84
Kampferol	1.54	2.10	2.61	2.43	1.56	1.03

F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

However, the F3 sample exhibited the highest levels of Rosmarinus and Kaempferol. In contrast to our findings, Osaie *et al.* (2020) noted that osmotic dehydration pretreatment of dried ginger resulted in a reduction in total flavonoid content. This reduction could be attributed to the loss of certain soluble nutrients within the osmotic solution during the pre-treatment process. Similarly, Hanafia *et al.* (2021) reported a significant difference among samples treated with and without an osmotic solution. Additionally, the untreated sample retained the highest Total Flavonoid Content (TFC) significantly after drying. This phenomenon could be attributed to the inherent characteristics of the plant matrix and the chemical composition of bioactive compounds, which play a role in influencing the retention of flavonoids and other bioactive substances. Both Total Phenolic Content (TPC) and TFC exhibited an increasing trend with the osmotic solution.

The results presented in Table 6 found that the irradiate sample at 3 kGy exhibited increased levels of naringin, rosmarinus, and naringenin in comparison to unirradiated sample. These results given here are in agreement with Abdelaleem and Elbassiony (2020), who reported that the sample irradiated at 6 kGy showed higher quantities of naringin, quercetin, and kaempferol compared to the unirradiated counterpart. Additionally, the results revealed the disappearance of certain phenols, including coumaric acid, vanillin, sinapic, rutin, 4',7-DihydroxyisoFlavone, apigenin, and rosmarinic acid, upon exposure to radiation. This

could be attributed to the transformative effects of radiation treatment on chemical compounds, leading to their conversion from one form to another.

Sensory evaluation provides insights into consumers' potential purchasing and consumption decisions. Hence, such assessments must accurately gauge product quality, encompassing aspects like color, crispness, flavor, aroma, and overall acceptability of the dried fruits samples, as displayed in Fig. 4. Notably, the control sample (F1) yielded notably lower scores in color, crispness, aroma, flavor, and overall acceptability when compared to the other treatment. Conversely, F4 (immersed in a solution containing 20% sucrose and 1% citric acid) attained significantly higher scores in all sensory attributes except flavor. Although all samples garnered considerable acceptance, sample 4 emerged as the panelists' favorite across all sensory characteristics. This may be due to the Maillard reaction, driving color change during drying. The utilization of citric acid further accentuated the treated samples color before drying due to its antioxidant properties. Moreover, it expedited the drying process in comparison to control sample (Dyab *et al.*, 2023). Findings also revealed that F5 (treated with a radiation dose at 1 kGy) exhibited a significant enhancement in color, crispness, aroma, flavor, and overall acceptability. The data obtained in the current study are similar mostly with those reported by Rico *et al.* (2010) found that low doses of gamma radiation did not cause changes in the sensory properties of dried pepper red samples.

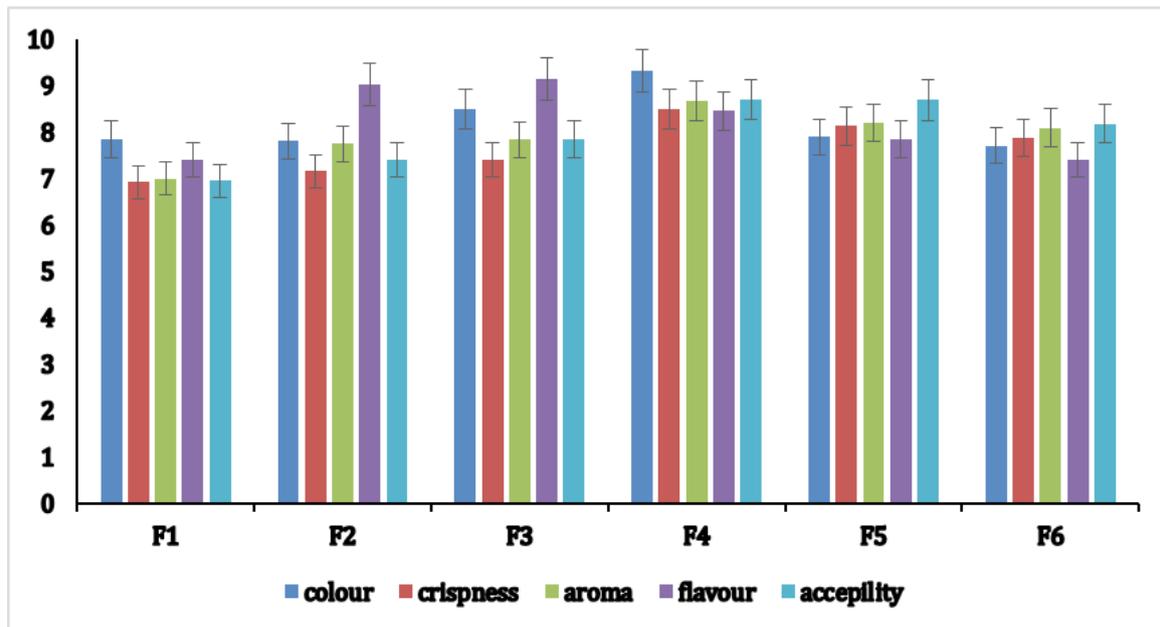


Fig. 5. Sensory Evaluation of dried fruits samples.

F1 (control without treatments), F2 (1% Citric acid), F3 (20% sucrose), F4 (1% Citric acid +20% sucrose), F5 (irradiation treatment does 1 kGy), F6 (irradiation treatment does 3 kGy).

Conclusion

Findings of the present study indicate that osmotic dehydration in a 20% sugar solution with 1% citric acid before drying yielded the highest contents of NFE, flavonoids, antioxidant activity, total phenolic compounds and vitamin C content compared to other treatments. Additionally, it achieved significantly higher scores in all sensory properties except flavor. Furthermore, irradiation at 3 kGy appears to be optimal for enhancing phenolic, flavonoid compounds, as well as antioxidant activity. Moreover, dried fruit samples to a dose of 1 kGy in irradiation received high ratings in color, crispness, aroma, flavor, and overall acceptability in comparison to control sample.

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