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Research article

Color, antioxidant and nutritional composition of dehydrated country bean (*Lablab purpureus*) seeds using solar drying techniques and pretreatments in Bangladesh

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ABSTRACT

The country bean (*Lablab purpureus*), is a significant contributor of dietary protein and other essential components in human nutrition. Because of its elevated moisture content, it is susceptible to rapid decay, leading to losses after harvesting. The utilization of solar drying has attracted significant attention as a tactic to minimize nutrient depletion in dried goods and enhance their longevity. This study employed four solar drying techniques, namely long chimney, short chimney, box solar drying and open sun drying, along with pretreatments such as potassium metabisulfite, potassium-sodium tartrate, citric acid and ascorbic acid. The objective was to determine an effective solar drying method, combined with pretreatment, that can maintain the color and nutritional qualities of dried country bean seeds. The treatment combinations were organized in a factorial randomized complete block design (RCBD) with three replications. The data were subjected to a two-way analysis of variance (ANOVA) and a Duncan Multiple Range Test (DMRT) was conducted at a significance level of 5 % ($p < 0.05$). Results revealed that box solar dryer having the highest drying efficiency, retained the highest β-carotene (82.94 %), vitamin C (90.15 %), protein (96.48 %), fat (11.63 %), and ash (90.50 %) with maximum DPPH radical scavenging activity (lowest IC_{50} 209.49 μg/ml) compared to other driers. Besides, country bean seeds have noteworthy proximate compositions, antioxidant activity, and bioactive components treated with 1 % potassium metabisulfite. Furthermore, the country bean seeds dehydrated in box solar dryer after 1 % potassium metabisulfite treatment received the highest acceptance score on the five-point Hedonic scale (4.83–4.89 out of 5.00) and color appearance and the similar trend was further supported by principal component analysis. Thus, it can be inferred that using a box solar dryer with a 1 % potassium metabisulfite pretreatment is a feasible

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method for preserving the color and nutritional value of country bean seeds and reducing post-harvest losses.

1. Introduction

Nutrition security stands out as one of the significant concern among various global concerns such as climate change, food availability, and accessibility. It aims to ensure that everyone has access to a sufficient amount of safe and nutritious fresh and processed meals. Nutrition security is achieved when individuals have reliable access to a diet that is both nutritious and appropriate for their needs, together with a clean environment and sufficient healthcare and support, all of which contribute to maintaining a healthy and active lifestyle [1]. Vegetables in the human diet are rich sources of phytonutriceuticals, including vitamins (C, A, B1, B6, B9, E), minerals, dietary fibers, and phytochemicals. These substances have antioxidant properties and other secondary metabolites that help reduce the risk of chronic diseases by protecting against damage caused by free radicals. They also play a role in modifying the activation and detoxification of carcinogens, as well as influencing processes that can alter the behavior of tumor cells. According to reports, inadequate intake of fruits and vegetables is responsible for 14 % of deaths from gastrointestinal cancer, 11 % of deaths from heart disease, and 9 % of deaths from stroke worldwide [2]. However, variations in seasonal weather result in vegetables being unevenly accessible throughout the year. They are abundant during the brief winter but scarce throughout the extended summer, which is a typical occurrence in tropical and sub-tropical regions, including Bangladesh. In addition, there is a significant issue of substantial postharvest loss of vegetables, which further exacerbates the problem of inadequate nutrition from vegetable-based diets. Tadesse et al. observed that 17 % of the global yield is degraded during post-harvest processing [3]. Hence, it is imperative to urgently minimize postharvest loss and prolong the shelf life of products in order to guarantee a year-round supply of vegetables. Dehydration, which involves removing moisture from fresh cut vegetables, can be used as a method to preserve vegetables for extended periods of time while minimizing nutritional degradation. This procedure extends the duration that products can be stored by decreasing the amount of moisture in them using hot air circulation. This stops enzymatic reactions, the growth of microorganisms, and other degradative processes [4].

Country bean (*Lablab purpureus*) is highly favored leguminous winter vegetable and widely cultivated in tropical and sub-tropical areas. It is regarded as an affordable source of protein due to its seeds containing a high amount of protein along with other beneficial nutrients such as carbohydrates, lipids, vitamins, minerals, antioxidants, and phytochemicals [5]. The young pods containing green seeds are commonly consumed by boiling or used in the preparation of curries. On the other hand, the mature seeds are mostly eaten as pulses, frequently in the form of a soup called "dhal". Occasionally, the mature seeds are dried in the sun and preserved to be used as vegetables. However, in Bangladesh, the yearly gross postharvest loss of the country bean from harvesting to consumption was around 28.62 % of the total production of 170.07 thousand metric tons. This high loss can be attributed due to the glut of the crop throughout the winter season [6]. Therefore, as drying is a crucial technique for preserving fresh vegetables, it is possible to harvest bean pods at the proper stage of maturity, remove the green seeds, and dehydrate them in order to store them beyond the growing season.

Insufficient drying can result in heat damage to dehydrated material and significant modifications to their physical, chemical, and sensory properties. Therefore, the selection of a suitable method for removing water is of utmost importance. Current research and development endeavors have prioritized the advancement of dehydrating technologies to satisfy the increasing need for dehydrated items that possess superior quality, fewer operational expenses, and diminished environmental consequences. The most prevalent and uncomplicated technique in numerous rural regions of developing nations involves drying items under direct sunlight. Although this method is cost-effective, it results in significant post-harvest food losses due to insufficient drying and increased fungal development, as well as infestation by insects, birds, rats, and other pests [7]. Solar drying technology distinguishes itself from typical open-air systems by utilizing instruments to harness solar radiation instead of merely relying on the sun's energy. Due to the controlled atmosphere in which the crops are kept, they maintain a high level of hygiene. Furthermore, it diminishes the probability of infestation by insects or fungi. The rapid drying process minimizes the degradation of nutritious content. Pretreatment is typically performed before to the drying process in order to inactivate enzymes that have the potential to break down the product, including polyphenol oxidase, peroxidase, and phenolase. It also helps prevent unwanted chemical reactions and maintain the color of dried items [8]. Commonly employed pretreatment chemicals in commercial applications are citric and ascorbic acid, methyl and ethyl ester, potassium carbonate, potassium and sodium hydroxide and potassium metabisulphate [9]. However, there is currently no existing research that investigates the most effective method of dehydrating country bean seeds while still preserving their color and nutritional makeup, in combination with pretreatments. Hence, exploring an effective solar drying technique that includes pretreatment shows potential in significantly reducing losses after harvest with well retention of physical appearance and nutritional qualities of the dehydrated products. Given the circumstances, it has hypothesized that country bean seeds that have undergone dehydration subsequent to pretreatment in solar dryers would preserve a substantial quantity of color, nutrients, and bioactive compounds in comparison to their fresh counterparts. The aim of this study was to identify the optimal solar drying technique and pretreatments for maintaining the color, antioxidants, and nutritional properties of dehydrated country bean seeds.

2. Materials and methods

2.1. Study location and layout

The experiment was carried out on the rooftop and at the analytical laboratory of Horticulture Department, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), located in Salna, Gazipur-1706, Bangladesh at coordinates 24.02° N latitude and 90.23° N longitude. The experiment employed a randomized complete block design (RCBD) with a factorial structure, comprising of four drying methods and five pretreatments (including a control/untreated group). The dehydration of mature green country bean seeds (CBS) was conducted using several methods, namely long-chimney solar drying (LSD), short-chimney solar drying (SSD), open sun drying (OSD), and box solar drying (BSD) (Supplementary Fig. 1). In addition, the seeds underwent pre-drying treatment, including control (untreated), potassium metabisulfite (KMS), potassium sodium tartrate (KT), citric acid (CA) and ascorbic acid (AA). Three replicates of each treatment were assigned to each dryer. The study was conducted from March 2022 to March 2023, encompassing both drying and chemical analyses. The drying process took place for a period of seventeen days, specifically from March 14, 2022 to March 30, 2022. The drying conditions were sunny, with an ambient temperature ranging from 30 to 33 °C and a relative humidity of 25–28 %.

2.2. Preparation of the sample and processing for pretreatment

In March 2022, fresh country bean (*Lablab purpureus*) seeds were acquired from the vegetable research field, Horticulture Department of Bangabandhu Sheikh Mujibur Rahman Agricultural University in Gazipur-1706. The seeds were categorized based on their diverse dimensions, morphology, level of ripeness, and lack of physical damage, insect invasion, or bacterial pollution. Upon arriving at the laboratory, the seeds were washed with tap water and then submerged in water for a duration of 4 h in order to easily eliminate the outer layer of the seed. Following that, 300 g of seeds were immersed in solutions containing 1 % ascorbic acid, 5 % citric acid, 0.3 % potassium sodium tartrate, and 1 % potassium metabisulfite for 10 min as part of the pretreatment process. Additionally, an equal amount of seeds was immersed in distilled water for the same duration as a control treatment. The treatment application process was done three times.

2.3. Drying process of country bean seed

The pretreated country bean seeds, weighing 300 g, were evenly dispersed across three trays, with each tray serving as a replication. Subsequently, the trays underwent four separate drying techniques. The drying process was continued until the moisture content of the seeds reached a nearly steady level, and there was no additional decrease in seed weight observed throughout the day. The uncoated country bean seeds were arranged in thin layers on a square mesh tray, which was constructed with a wooden frame and covered with black netting. The tray was positioned in direct sunlight to dry the sample, as part of the open sun drying process. In the chimney-based solar dryer, both the LSD (Long Solar Dryer) and SSD (Short Solar Dryer) configurations involve placing the tray atop a horizontal air flow desk chamber that is sheltered with a thin black polythene sheet. The BSD approach involved placing the tray inside a wooden box with many apertures to allow for the inflow and outflow of air. The box was then coated with clear white polythene (See Supplementary Fig. 1). The temperatures, humidity, and weight change of the seeds due to moisture loss were measured every hour from 9:00 a.m. to 5:00 p.m. on each drying day. This was done using a thermometer, hygrometer, and precision balance, respectively. Before conducting the dehydration study on pre-treated samples, a drying test was carried out in triplicate using fresh untreated country bean seeds to assess the drying effectiveness of the four different types of solar driers.

2.4. Assessing the physical, nutritional, and functional characteristics of dried country bean seeds

Dehydrated country bean seeds were physically and chemically analyzed to observe the retention capacity of seed color, antioxidants, secondary metabolites, nutrition and other related physiochemical attributes after drying the pre-treated seeds. The dehydrated CBS sample (which had not been pretreated or dried using solar dryers) was evaluated against the fresh sample in terms of colour, approximate components, antioxidant potentiality, and sensory quality.

2.4.1. Assessment of color and enzyme inactivation test for color retention confirmation

The Minolta CR-400 colorimeter (Minolta Conica, Japan) was used to evaluate the color variables of the fresh and dehydrated country bean seeds. The evaluation was done following the CIE L*, a*, b* system, where L* represents lightness, a* represents the red-green axis, and b* represents the blue-yellow axis. The standard illuminant used was D65. The ΔE (Total color difference) between the fresh and dried sample was determined based on the estimated L*, a*, and b* coordinates, using formula (1) [10].

$$\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \quad (1)$$

the variables ΔE, ΔL*, Δa*, and Δb* indicate the comprehensive color variation, difference in lightness, variation in greenness, and variation in yellowness, respectively, among freshly harvested and dehydrated country bean seeds.

Furthermore, polyphenol oxidase (PPO) and peroxidase (POD) assays were conducted to validate whether the dehydration process, pretreated or not, successfully maintained the intended coloration of the dehydrated substances. POD was determined with some

modifications proposed by Ref. [11]. Exact 1g of dried sample powder was ground with 5 mL of distilled water in a mortar and pestle. In addition, 10 mL of distilled water was added and the mixture was kept at ambient temperature for 2 h. Before filtration, the mixture was centrifuged at 6000 rpm for 10 min. In a test tube containing a 5 mL filtered sample, 10 mL of distilled water was added. Then 1 mL of 0.5 % guaiacol and 1 mL of 0.8 % hydrogen peroxide were each added to the mixture and the reaction was observed for 3.5 min to make decision on the enzyme inactivation with the colorless solution. In this case, when the enzyme is functioning in the sample solution, the peroxidase undergoes rapid conversion into water and oxygen. The oxygen then interacts with Guaiacol, resulting in the formation of a brown or dark brown color, which is observable in this study. Conversely, in the absence of enzyme activity, the sample solution does not exhibit the characteristic brown color and remains colorless. Again, polyphenol oxidase (PPO) enzyme induced color change was assessed using a spectrophotometer (APEL, UV-VIS Spectrophotometer, PD – 303 UV, PD 33-3-OMS-101 b, Japan) at a wavelength of 408 nm [11]. The preparation of the PPO solution generated from country bean seed (CBS) involved extracting 20 g of CBS powder with 100 mL of 0.1 M Tris-HCl buffer, pH 7.0, at a temperature of 4 °C for a duration of 16 h. The extraction solution also contained 2 % (w/v) PVPP and 1.2 % (w/v) NaCl. The sample was subjected to centrifugation at a force of 8500 times the acceleration due to gravity for a duration of 30 min. Ammonium sulphate (22.6 g/100 mL) was added to the liquid portion until it reached 40 % saturation at a temperature of 4 °C. The protein that had been precipitated was separated by centrifugation at 8500*g* for 30 min, and then disposed of. The supernatant was treated with solid ammonium sulphate (25.8 g/100 mL) in a gradual manner at a temperature of 4 °C, and left undisturbed overnight. The supernatant was utilized as a solution containing the enzyme polyphenol oxidase (PPO). The sample consisted of 3 mL of sample solution in the same buffer as the standard reaction. The reaction consisted of 0.3 mL of PPO solution and 2.7 mL of 14 mg/mL catechol in a 0.1 mol/L phosphate buffer with a pH of 6.0 [8]. The change in absorbance of 0.001 per min was used to define a unit of PPO activity compared to the initial value and expressed in percentage (%). Besides, a panelist of 30 members evaluated the appearance and sensory characters of the dehydrated CBS on the basis of five-point hedonic scale: 1 = Dislike extremely, 2 = Dislike moderately, 3 = Neither like nor dislike, 4 = like moderately and 5 = like extremely [12].

2.4.2. β – carotene quantification

The quantification of β–carotene content in both fresh and desiccated seeds was conducted using a sample of 1 g of rehydrated and fresh seeds. The operational specimen was pulverized using a grinder and mortar, and then immersed in a solvent combination consisting of 10 mL of acetone and hexane in a 4:6 ratios. The resulting mixture was thoroughly mixed. The spectrophotometer (PD-303 UV Spectrophotometer; APEL Co.) was used to measure the optical density of the filtrate sample at four different wavelengths: 663 nm, 645 nm, 505 nm, and 453 nm. The concentration of β–carotene was calculated utilizing formula (2) as described in Refs. [8,13].

$$\beta - carotene\ (mg\ /\ 100\ g\ DW) = 0.216\ (OD663) + 0.452(OD453) - 1.22(OD645) - 0.304(OD505) \quad (2)$$

Where,

DW refers to the Dry Weight (For fresh sample, mg/100 g fresh weight (FW))

OD represents the optical density at a specific wavelength. The values 0.216, 0.452, 1.22, and 0.304 correspond to the absorption coefficient of the corresponding absorbance.

2.4.3. Determination of ascorbic acid (Vitamin-C)

Ascorbic acid content or vitamin-C of fresh and dehydrated seed was analyzed using titration method [14] with some modifications. About 20 g of grinded sample powder was diluted with distilled water and centrifuged at 0 °C for 20 min at 4000 rpm with a centrifuge machine (MPW-260R). The supernatant liquid was collected in a test tube and covered with foil paper. 5 mL of the obtained supernatant was placed in a 50 mL conical flask. Then, 5 mL of 5 % KI, 2 mL of glacial acetic acid, and 2 mL of 2 % starch solution were added to the extract. Then, it was titrated with 0.001 N KIO_3 solution. Finally, the ascorbic acid (mg/100 g DW) was estimated using the following equation (3) [8].

$$\text{Ascorbic acid content}\ \ (\text{mg}\ /\ 100\ \text{g DW}) = \frac{T \times F \times V \times 100}{v \times W} \quad (3)$$

Here,

DW denotes Dry weight (For fresh sample, mg/100g fresh wight (FW));

T represents the volume of 0.001 N KIO_3 (mL) that has been;

F indicates the concentration of ascorbic acid in the solution is 0.088 mg per mL of 0.001 N KIO_3;

V denotes the total volume of sample extracted (mL);

v indicates the volume of the extract (mL) that is titrated with 0.001 N KIO_3;

W represents the weight of the plant sample that is taken (g).

2.4.4. Quantitative assessment of total phenolic content, total flavonoid content and antioxidant activity

The antioxidant activity, phenolic content, and flavonoid content in both the dehydrated and fresh samples were determined by extracting 1 g of powdered sub-sample with 25 mL of methanol [8]. The specimen was immersed in a water bath set at a temperature of 30 °C for a duration of 2.5 h. Subsequently, it was subjected to centrifugation at a speed of 6000 revolutions per minute (rpm) for a period of 15 min. The liquid part was transferred into a foil-covered test tube after passing through filter paper (Whatman no. 42) [8]. The samples were then refrigerated at 4 °C until they could be analyzed.

The DPPH radical scavenging assay (RSA) was used to evaluate the antioxidant activity of both fresh and dehydrated country bean

seeds, following the methodology described in Refs. [8,13] with minor modifications. The spectrophotometric reading was measured at 517 nm against a blank solution of methanol. After that, the radical scavenging activity was calculated by following formula (4)-

$$\%\ \text{Radical scavenging activity} = \frac{A0 - A1}{A0} \times 100 \quad (4)$$

Where,

A0 = Absorbance of control (4 mL methanol + 0.5 mL methanolic DPPH solution).

A1 = Absorbance of sample.

The antioxidant capacity was measured by graphing the percentage of radical scavenging activity against the concentration of the extract for both the standards and the test sample. The inhibitory concentration (IC50) was utilized to specify this antioxidant capacity. A reference solution of ascorbic acid was prepared for the antioxidant assay. In order to accomplish this, a solution of ascorbic acid was created by dissolving 2 mg of ascorbic acid in 2.5 ml of distilled water and thoroughly mixing it. This solution was then divided into numerous concentrations of 10, 20, 40, 80, 100, and 200 μg/ml. Methanol was added to each concentration to bring the total amount to 3 ml. Subsequently, a 1 ml aliquot of methanolic DPPH solution (containing 0.004 mg of DPPH) was added into a mixture of 100 ml of methanol and thoroughly combined. The resultant mixture was incubated in a light-free environment for 30 min and the absorbance was measured at 517 nm using a spectrophotometer, with methanol as the blank. A lower IC50 value corresponds to greater antioxidant activity and IC50 was calculated using the following formula (5) –

$$IC_{50} = \frac{y - b}{a} \quad (5)$$

where,

y was replaced by 50 in the above equation.

Value of a and b was found from regression line plotted for each sample separately.

The total phenol content (TPC) was determined using the Folin-Ciocalteu (FC) procedure [15] with specific modifications. A mere 0.5 mL of the sample extracts were collected in a test tube. The sample was treated with 2.5 mL of FC reagent and incubated for 10 min. Subsequently, the solution was combined with 2 mL of sodium carbonate solution with a concentration of 7.5 %. The resulting combination was then subjected to incubation at a temperature of 30 °C for a duration of 1 h. The spectrophotometer (UV-VIS PD-303 UV Spectrophotometer; APEL Co.) was used to measure the absorbance reading of the country bean seed sample and the gallic acid standard at a wavelength of 760 nm. The absorbance was measured and then compared to a reference solution of methanol. The results were expressed as milligrams of gallic acid equivalents per 100 g of dry weight (mg GAE/100 g DW).

The total flavonoid content was determined using the aluminium chloride colorimetric method [15] with slight changes. Specifically, 100 μl of the sample extract was placed in an Eppendorf tube and 400 μl of methanol was added. Subsequently, each individual sample extract was combined with 100 μl of a 10 % $AlCl_3$ (w/v) solution and 100 μl of a 1 M sodium acetate solution. Afterwards, the sample was placed in an incubator at ambient temperature and protected from light for a duration of 40 min. Subsequently, the spectrophotometer (UV-VIS PD-303 UV Spectrophotometer; APEL Co.) was used to measure the absorbance at a wavelength of 420 nm, with methanol being used as the standard solution. The TFC results were obtained by utilizing the quercetin standard calibration curve and expressed as mg of quercetin equivalent (QE) per 100 g of dry weight (mg QE/100 g DW).

2.4.5. Measurement of pH and total soluble solids (TSS)

A quantity of 20 g (20g) of country bean seeds was pulverized using a grinder, and the resulting liquid was utilized to measure the pH using a pH meter with a digital display (SD 300 pH). In order to ascertain the TSS (total soluble solids) (°Brix) of both freshly harvested and dried country bean seeds, about 50 g of seeds were pulverized into a uniform mixture and subjected to centrifugation at 2000*g* for 15 min. The liquid portion was subsequently gathered to quantify total suspended solids (TSS) using a manual refractometer (Model: Atago N1, Japan). For dehydrated seeds, they were immersed in water for 20 min to restore moisture and any extra water was eliminated prior to blending. Conversely, fresh seeds were measured and blended without any pre-soaking.

2.4.6. Determination of minerals (Na, K, Ca, Mg, Fe)

The determination of the mineral composition (including sodium, potassium, calcium, magnesium, and iron) was conducted utilizing an atomic absorption spectrophotometer (AAS) in accordance with the modified protocols described in Ref. [16]. For this experiment, a 10 g sample of dehydrated material was finely pulverized into a powder. Next, 0.5 g of the powder was carefully added to a 50 mL conical flask. Then, a 5 mL mixture with a 5:1 ratio of nitric acid (HNO3) to perchloric acid (HClO4) was carefully added to the flask. The combination was then heated using a sand bath for a period of 3–4 h. For the last part of the digestion process, filtration was done using Whatman no. 42 filter paper. Water was added until the final volume reached 100 mL in a 100 mL volumetric flask, following precise measurements. For the mineral content analysis, a 10 mL sample extract was carefully transferred into a 50 mL volumetric flask. The extract was then diluted with distilled water until the total volume reached 50 mL. Meanwhile, the fresh seeds were dried in an oven, and these dried seeds were then processed using the same method as the previously discussed procedure for dehydrating samples using solar drying. Subsequently, the sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), and iron (Fe) levels were measured using an atomic absorption spectrophotometer (AAS) (model-PinAAcle 900H from PerkinElmer). The mineral concentration was determined by applying formula (6).

$$\%\ \text{Mineral (DW)} = \frac{\text{sample reading} \times \text{final volume} \times \text{dilution factor}}{\text{sample weight}} \quad (6)$$

Here, DW denotes Dry weight.

2.4.7. Measurement of crude protein

The Kjeldahl method [17] was used for protein analysis. The Kjeldahl method is a three-step process that uses titration, distillation, and digestion to estimate protein. In order to begin the digestion process, 0.1g of sample powder collected from the extracted sample of solar drying dehydrated and oven dried fresh seeds (working procedure stated in section 2.4.6) was weighed into a digestion flask and heated before 5 mL of salicylic sulfuric acid (an oxidizing agent) was added. Following the conclusion of digestion, the solution was transferred into a 100 mL volumetric flask and made volume 100 mL with distilled water as the working sample. A 0.5 g catalyst (K_2SO_4, CuSO4, Selenium) was also added to speed up the reaction. In order to distil the ammonium sulphate into ammonia, 10 mL of the sample were placed in a conical flask, and 5 mL of a 40 % sodium hydroxide (NaOH) solution was added. A distillation chamber was used to complete the distillation process. The distilled off solution was collected in a receiving flask of excess boric acid which converted ammonia to ammonium borate. Then titration was done with 0.005 N H_2SO_4 with the use of a suitable end-point indicator (pink) to estimate the total nitrogen content of the sample. Then the percentage of total nitrogen was calculated using the following formula (7) and protein % was calculated using formula (8) [8] -

$$\text{Nitrogen}\ \% = \frac{\text{sample titre} - \text{blank titre} \times \text{normality of acid} \times 14 \times 100}{\text{sample weight} \times 1000} \quad (7)$$

Finally, the protein % was calculated from the total N% using the following formula-

$$\text{Protein}\ \%\ \text{(DW)} = \text{Nitrogen}\ \% \times 6.25 \quad (8)$$

Here,

DW indicates Dry weight.

6.25 represents constant factor.

2.4.8. Crude fat estimation

The fat content of the samples was assessed using a modified variant of the solvent extraction method [17]. Approximately 2g of the sample collected from the extracted sample of solar drying dehydrated and oven dried fresh seeds (working procedure stated in section 2.4.6) was added in a pre-weighed thimble. The thimble, containing the sample, was measured and thereafter inserted into the fat extraction tube of the Soxhlet device. The tube was affixed to a pre-weighed Soxhlet flask on the heating mantle. Approximately 250 mL of hexane was put into the tube, passing through the sample. The cap of the fat extraction tube was attached to the condenser. The sample underwent an 8-h extraction process in which it was immersed in water at a temperature of 70 °C. The water bath was calibrated to facilitate the volatilization, condensation, and continuous deposition of hexane onto the sample, ensuring little loss. After completing the extraction process, the thimble was taken out of the apparatus and the flask was placed in an incubation chamber to thoroughly eliminate the solvent. The flask was weighed after being dried, chilled, and then weighed. The sample's extracted fat was then calculated using the following formula (9) -

$$\text{Fat}\ \%\ \text{(DW)} = \frac{W4 - W3}{W2 - W1} \times 100 \quad (9)$$

Where,

DW = Dry weight.

W1 = Weight of thimble.

W2 = Weight of thimble with sample.

W3 = Weight of empty Soxhlet flask.

W4 = Weight of Soxhlet flask with fat.

2.4.9. Ash content determination

The ash content was determined use the methodology outlined in Ref. [16]. The process involved measuring 3 g of finely ground sample obtained from the extracted sample of solar drying dehydrated and oven dried fresh seeds (as described in section 2.4.6) and placing it into a clean, dry crucible that had been weighed beforehand. The organic stuff was incinerated by subjecting the sample to a low flame until it was scorched. Subsequently, the crucibles were moved to a muffle furnace with a temperature of 550 °C. The procedure of ashing was carried out until the samples reached a grey colour. Subsequently, the crucible was cooled within a desiccator and its weight was measured. The ash content percentage was calculated using the following formula (10) -

$$\text{Ash}\ \%\ \text{(DW)} = \frac{W2 - W1}{Ws} \times 100 \quad (10)$$

Here,

DW denotes Dry weight;

W1 indicates Weight of crucible;
W2 represents Weight of crucible with ash;
Ws express as Weight of sample.

2.5. Statistical analyses

The results from three replications were subjected to statistical analysis and presented as the mean values and standard deviation for each variable. The statistical analysis involved conducting a two-way analysis of variance (ANOVA) and comparing means using the Duncan Multiple Range Test (DMRT) at a significance level of 5 %. The R programme (Version 4.1.2) was used for this analysis. The R program's agricolae, factominer, factoextra, corrplot, and ggplot2 packages were utilized to do correlation matrix analysis, principal component analysis (PCA), biplot creation, and data visualization.

3. Results

3.1. Color of dehydrated country bean seeds

The results obtained for the color coordinates of dehydrated country bean seeds (CBS) showed significant variation compared to the fresh one in accordance with the main effect of solar dryers and pretreatments (Table 1). The dehydrated CBS exhibited a substantial decrease in color indices compared to the fresh sample. The color indices a* and h* did not vary among the drying methods exhibiting greater values in BSD (8.61 and 1.07, respectively) and inferior values in OSD method (7.91 and 1.04, respectively). Whether, significantly maximum L*, b* and C* values were noted in BSD (35.33, 16.99 and 19.09, respectively) being dissonant from other methods and minimum in OSD. On the other hand, KMS pretreated samples showed statistical superiority over others for color retention in dehydrated country bean seeds (Table 1). The highest L* (49.63), a* (9.25), b* (29.44), h* (1.27) and C* (30.54) was determined in KMS pretreatment followed by KT pretreatment except a* value. Dehydrated CBS without pretreatment had the lowest color index.

Regarding the ΔE (Total color difference, TCD), remarkable color changes observed in OSD (36.69) which was statistically similar with LSD (34.56) and the lowest was in BSD (29.21) that was statistically identical with SSD (29.45). On the other hand, considering the pretreatments effect, the highest color differences were observed in control (38.64) and the lowest was in KMS (10.49). Furthermore, the significant variation in browning index (BI) was noticed in the dehydrated samples where maximum browning was appeared in control (25.67) and minimum was in KMS (17.44) treated sample.

In addition, polyphenol oxidase (PPO) and polyphenol peroxidase (POD) enzyme inactivation test was done for color retention confirmation of the dehydrated samples of solar dryers and pretreatments according to the enzyme activities in color changes of sample extract solution. Results revealed remarkable color variations among the treatments (Fig. 1A–I, 1B-I). The OSD, LSD, and SSD exhibited

Table 1
Color changes in dehydrated country bean seeds as influenced by drying techniques and pretreatments.[w]

Drying methods[x]	L*	a*	b*	h*	C*	Δ E (TCD)	BI
Fresh	55.57 ± 0.00a[z]	11.55 ± 1.05a	37.21 ± 0.90a	1.30 ± 0.00a	38.97 ± 1.21a	–	–
OSD	34.15 ± 8.83c	7.91 ± 1.30c	15.61 ± 0.23d	1.04 ± 0.15b	17.89 ± 7.82c	36.69 ± 0.02a	22.45 ± 4.81a
LSD	34.98 ± 7.55c	8.11 ± 1.43c	16.37 ± 0.65c	1.05 ± 0.16b	18.75 ± 6.60b	34.56 ± 0.35a	21.58 ± 2.00b
SSD	34.18 ± 8.40c	8.23 ± 1.37bc	15.95 ± 0.56d	1.02 ± 0.17b	18.10 ± 6.93c	29.45 ± 0.04b	21.49 ± 4.58b
BSD	35.33 ± 8.23b	8.61 ± 1.33b	16.99 ± 0.22b	1.07 ± 0.16b	19.09 ± 6.00b	29.21 ± 0.23b	21.45 ± 3.47b
Pretreatments[y]							
Control	29.14 ± 1.35e	7.39 ± 0.91e	9.36 ± 0.99f	0.88 ± 0.02f	12.07 ± 1.39f	38.64 ± 1.76a	25.67 ± 2.16a
AA	29.19 ± 1.34e	8.79 ± 1.14c	12.16 ± 0.34e	0.94 ± 0.04e	15.02 ± 2.52e	36.54 ± 2.44b	24.88 ± 2.73b
CA	30.11 ± 2.89d	8.04 ± 1.52d	13.65 ± 0.54d	0.97 ± 0.04d	16.51 ± 2.73d	34.80 ± 3.94c	21.25 ± 2.18c
KT	35.22 ± 1.73c	7.61 ± 1.01e	16.54 ± 0.84c	1.14 ± 0.06c	18.14 ± 1.76c	29.41 ± 1.62d	19.42 ± 2.00d
KMS	49.63 ± 1.09b	9.25 ± 1.26b	29.44 ± 0.07b	1.27 ± 0.04b	30.54 ± 1.40b	10.49 ± 2.24e	17.44 ± 1.64e

Δ E (TDC) = Total color difference (TCD) indicates the colour difference of the dehydrated sample from the fresh one; BI= Browning index depicts the overall changes in browning color of the dehydrated products compared to the fresh one.
Dataset under drying methods and pretreatments indicates the main effect of a factorial study explaining the average ones for each drying method averaging the different pretreatments while average ones for each pretreatment denotes average data from all the drying methods.

[x] Fresh sample (neither pretreated nor dried); OSD= Open sun drying; LSD = Solar drying long chimney; SSD= Solar drying short chimney; BSD= Box solar drying.

[y] Control (dehydrated without pretreatments); AA = Ascorbic acid (1 %); CA= Citric acid (5 %); KT= Potassium sodium tartrate (0.3 %); KMS= Potassium metabisulfite (1 %).

[z] Data presented as means ± standard deviation in each column followed by different letters are significantly different at $p < 0.05$ as determined by Duncan Multiple Range Test (DMRT) using the R program.

[w] L* = is an approximate measurement of luminosity, which is the property according to which each colour can be considered as equivalent to a member of the greyscale, between black and white; a* = positive values for reddish colours and negative values for the greenish ones; b* = positive values for yellowish colours and negative values for the bluish ones; h* = Hue angle indicates the difference of a certain colour with reference to grey colour with the same lightness; C* = Chroma indicates the degree of difference of a hue in comparison to a grey colour with the same lightness;

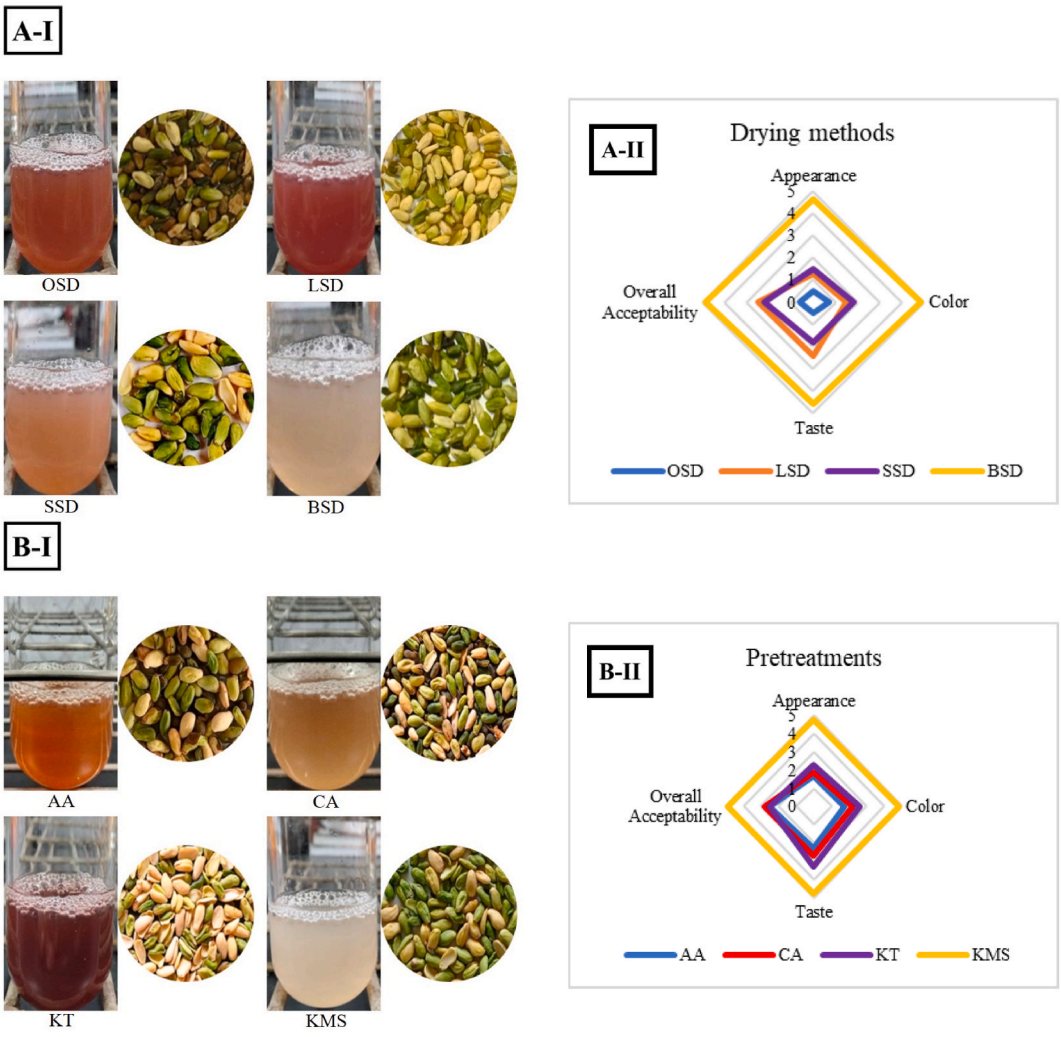

Fig. 1. Enzyme activity test for color retention confirmation of the dehydrated country bean seeds influenced by (A–I) Drying techniques (OSD = open sun drying; LSD = solar drying long chimney; SSD = solar drying short chimney; BSD = box solar drying; (B–I) Pretreatments (AA = ascorbic acid 1 %; CA = citric acid 5 %; KT = potassium sodium tartrate 0.3 %; KMS = potassium metabisulfite 1 %; and their sensory evaluation (A-II); (B-II). Color changes of the solution indicates enzyme active while colorless indicates inactiveness of the enzyme. Dataset under drying techniques and pretreatments indicates the main effect of a factorial study explaining the average ones for each drying averaging the different pretreatments while average ones for each pretreatment denotes average data from all the drying techniques. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

brown, deep brown, and light brown colours, respectively, whereas the BSD displayed a clear solution without any brown colour (Fig. 1A–I). Similarly, a comparable pattern of colour preservation was also noticed in the samples treated with AA, CA, and KT, exhibiting hues ranging from deep brown to light brown. However, the test solution did not exhibit any significant colour change when the sample was treated with KMS during the enzyme inactivation test (Fig. 1B–I).

3.2. Sensory evaluation of dehydrated country bean seed

Sensory evaluation scores in different quality attributes were recorded on five-point Hedonic scale for each dehydrated sample obtained from each of the studied drying methods and pretreatments (Fig. 1A–II, B-II). Among the drying techniques, the highest score for appearance was noticed in the dehydrated products of BSD (4.62) and the lowest was in OSD (0.4). The similar trends of findings were also observed in rest of all the quality attributes (color, taste and overall acceptability) following the order of BSD > SSD > LSD > OSD. On the other hand, considering the pretreatments effect on the quality attributes, it has been revealed that KMS pretreated products received the highest score (4.79) for the appearance followed by KT (3.2) and the lowest score in control (0.7). The similar patterns of findings were also found in terms of the color, taste and overall acceptability following the order of KMS > KT > CA > AA > control.

3.3. Proximate composition of dehydrated country bean seeds

The drying methods and pretreatments showed statistically significant changes ($p < 0.05$) in the total soluble solids (TSS), pH, protein, fat, ash, and mineral contents of the dehydrated country bean seeds (Table 2). Compared to fresh country bean seeds, dehydrated seeds had inferior proximate compositions. Among the driers, BSD method had statistical superiority for retaining TSS (16.20 %), pH (5.66), crude protein (27.33 %), crude fat (1.83 %) and crude ash (4.66 %) in dehydrated CBS followed by SSD method except for Brix (%). While, minimum level pH (5.37), protein (21.86 %), fat (1.36 %) and ash (4.08 %) contents of dried CBS was retained in OSD method and TSS (13.58 %) in LSD method. In terms of pretreatment, KMS performed the best for maximum retention of Brix (16.37 %), pH (6.37), protein (29.36 %), fat (1.73 %) and ash (4.66 %) upon dehydration followed by KT pretreatment except for Brix value. Reversely, non-treated dehydrated product had the lowest content of protein (20.05 %), fat (1.36 %) and ash (4.08 %). KT and CA pretreated samples had minimum TSS (13.05 %) and pH (4.91), respectively. Mineral contents were decreased in the dehydrated CBS compared to fresh bean seeds except for Na and Mg levels (Table 2). Whilst comparing among drying methods, SSD dried CBS reserved the highest amount of Na (0.088 %) and Ca (0.149 %), LSD method retained maximum K (1.944 %) and OSD dried product had top Mg (0.173 %) and Fe (0.761 %) contents. Taking the pretreatments, AA treated samples retained maximum Na (0.096 %), KMS treated CBS contained superior K (1.998 %), KT treatment had the best Ca (0.151 %) and Fe (0.761 %) contents and untreated seeds reserved maximum Mg (0.178 %) level.

3.4. Vitamin A and vitamin C contents in dehydrated country bean seeds

All four drying procedures had a significant impact on the reduction of β-carotene and vitamin C (Ascorbic acid) concentration in the dried country bean seed samples, as compared to the fresh sample (Table 3). The highest concentration of β-carotene (3.44 mg/100 g FW [fresh weight]) was found in the fresh sample, whereas the lowest concentration (0.28 mg/100g DW) was observed in the OSD sample. The BSD drying procedure preserved the highest amount of β-carotene in the dehydrated CBS, with a concentration of 0.40 mg/100 g DW. The untreated dried sample had the highest concentration of β-carotene at 0.36 mg/100 g DW, followed by CA at 0.35 mg/100 g DW. The lowest concentration of β-carotene, at 0.30 mg/100 g DW, was found in both KMS and KT. The vitamin C content in dehydrated country bean seeds was significantly reduced by solar drying methods, except for BSD and SSD. Among the drying methods, BSD kept the maximum amount of vitamin C (12.48 mg/100 g DW), followed by SSD (11.88 mg/100 g DW). The initial vitamin C content in the fresh sample was 13.79 mg/100 g FW. Nevertheless, the OSD had the lowest concentration of 10.82 mg/100 g DW. The pretreated samples showed that the sample treated with KMS had the highest vitamin C content, measuring 12.73 mg/100 g DW. The sample treated with AA had the second highest level, measuring 11.88 mg/100 g DW.

Table 2
Proximate composition of dehydrated country bean seeds as influenced by drying techniques and pretreatments.

Drying methods[x]	Brix (%)	pH	Protein (%)	Fat (%)	Ash (%)	Na (%)[z]	K (%)	Ca (%)	Mg (%)	Fe (%)
Fresh	16.40 ± 0.00a[w]	6.55 ± 0.00a	32.95 ± 0.00a	2.03 ± 0.00a	4.83 ± 0.00a	0.073 ± 0.00b	2.522 ± 0.00a	0.157 ± 0.00a	0.163 ± 0.00d	0.761 ± 0.00a
OSD	14.56 ± 0.73c	5.37 ± 0.52d	21.86 ± 0.31e	1.36 ± 0.25e	4.08 ± 0.41e	0.071 ± 0.04c	1.801 ± 0.11e	0.146 ± 0.01c	0.173 ± 0.01a	0.761 ± 0.01a
LSD	13.58 ± 0.54e	5.60 ± 0.51c	22.93 ± 0.33d	1.60 ± 0.54d	4.10 ± 0.53d	0.064 ± 0.05e	1.944 ± 0.04b	0.144 ± 0.01d	0.166 ± 0.02c	0.757 ± 0.00c
LSD	14.24 ± 0.66d	5.58 ± 0.70c	24.52 ± 0.47c	1.75 ± 0.30c	4.12 ± 0.37c	0.088 ± 0.04a	1.908 ± 0.15d	0.149 ± 0.01b	0.166 ± 0.02c	0.757 ± 0.00c
BSD	16.20 ± 0.18b	5.66 ± 0.75b	27.33 ± 0.67b	1.83 ± 0.21b	4.66 ± 0.52b	0.070 ± 0.03d	1.923 ± 0.13c	0.146 ± 0.00c	0.167 ± 0.02b	0.758 ± 0.01b
Pretreatments[y]										
Control	16.15 ± 0.34b	5.67 ± 0.45d	20.05 ± 0.40f	1.36 ± 0.22f	4.08 ± 0.45f	0.077 ± 0.04b	1.875 ± 0.13e	0.144 ± 0.01e	0.178 ± 0.02a	0.759 ± 0.00b
AA	13.15 ± 0.76d	4.97 ± 0.09e	23.49 ± 0.54d	1.64 ± 0.30e	4.15 ± 0.09e	0.096 ± 0.03a	1.788 ± 0.15f	0.143 ± 0.00f	0.149 ± 0.02f	0.754 ± 0.00e
CA	15.25 ± 0.33c	4.91 ± 0.30f	22.93 ± 0.37e	1.66 ± 0.48d	4.32 ± 0.30d	0.065 ± 0.03d	1.925 ± 0.09c	0.147 ± 0.01c	0.174 ± 0.01c	0.758 ± 0.00c
KT	13.05 ± 0.86e	5.86 ± 0.36c	24.96 ± 0.55c	1.69 ± 0.31c	4.51 ± 0.36c	0.074 ± 0.04c	1.891 ± 0.09d	0.151 ± 0.01b	0.177 ± 0.02b	0.760 ± 0.02 ab
KMS	16.37 ± 0.48a	6.37 ± 0.07b	29.36 ± 0.32b	1.73 ± 0.30b	4.66 ± 0.07b	0.055 ± 0.04e	1.998 ± 0.02b	0.145 ± 0.01d	0.161 ± 0.01e	0.757 ± 0.00d

Dataset under drying methods and pretreatments indicates the main effect of a factorial study explaining the average ones for each drying method averaging the different pretreatments while average ones for each pretreatment denotes average data from all the drying methods.

[x] Fresh sample; OSD= Open sun drying; LSD = Solar drying long chimney; SSD= Solar drying short chimney; BSD= Box solar drying.

[y] Control (without pretreatments); AA = Ascorbic acid (1 %); CA= Citric acid (5 %); KT= Potassium sodium tartrate (0.3 %); KMS= Potassium metabisulfite (1 %).

[z] Na= Sodium; K= Potassium; Ca= Calcium; Mg = Magnesium; Fe= Iron.

[w] Data presented as means ± standard deviation in each column followed by different letters are significantly different at $p < 0.05$ as determined by Duncan Multiple Range Test (DMRT) using the R program.

Table 3
Vitamins, bioactive compounds and antioxidant activity of dehydrated country bean seeds affected by drying methods and pretreatments.

Drying methods[x]	β-carotene[z] (mg/100 g DW)	Ascorbic acid (mg/100 g DW)	IC_{50} (μg/ml)	TPC (mg GAE/100 g DW)	TFC (mg QE/100 g DW)
Fresh	3.44 ± 0.00a[w]	13.79 ± 0.00a	8.73 ± 0.00d	49.73 ± 0.00a	31.95 ± 0.00a
OSD	0.27 ± 0.05e	10.82 ± 0.61e	303.82 ± 22.06a	9.32 ± 6.88b	8.96 ± 0.61b
LSD	0.29 ± 0.08d	11.68 ± 0.72d	296.70 ± 18.51a	10.73 ± 6.98b	9.08 ± 0.52b
SSD	0.35 ± 0.03c	11.88 ± 0.02c	243.23 ± 21.74b	15.99 ± 5.83b	9.26 ± 0.35b
BSD	0.40 ± 0.03b	12.48 ± 0.02b	209.49 ± 24.68c	15.44 ± 6.93b	12.21 ± 0.35b
Pretreatments[y]					
Control	0.36 ± 0.04b	7.46 ± 0.04f	291.82 ± 19.91a	8.54 ± 4.31b	8.88 ± 0.40b
AA	0.32 ± 0.05d	11.88 ± 0.02c	285.70 ± 32.36a	8.63 ± 2.65b	11.13 ± 0.69b
CA	0.35 ± 0.05c	9.85 ± 0.05e	256.25 ± 21.34b	14.52 ± 3.34b	9.09 ± 0.61b
KT	0.31 ± 0.09e	10.61 ± 0.08d	247.32 ± 16.78b	15.35 ± 1.19b	9.01 ± 0.31b
KMS	0.30 ± 0.01f	12.73 ± 0.01b	235.46 ± 23.46c	17.32 ± 2.40b	11.28 ± 0.91b

Data presented as means ± standard deviation in each column followed by different letters are significantly different at $p < 0.05$ as determined by Duncan Multiple Range Test (DMRT) using the R program. Dataset under drying methods and pretreatments indicates the main effect of a factorial study explaining the average ones for each drying method averaging the different pretreatments while average ones for each pretreatment denotes average data from all the drying methods.

[x] Fresh sample; OSD= Open sun drying; LSD = Solar drying long chimney; SSD= Solar drying short chimney; BSD= Box solar drying.

[y] Control (without pretreatments); AA = Ascorbic acid (1 %); CA= Citric acid (5 %); KT= Potassium sodium tartrate (0.3 %); KMS= Potassium metabisulfite (1 %).

[z] β-carotene = β-carotene; Ascorbic acid = Vit C; IC_{50} = Antioxidant activity; TPC = Total phenol content; TFC = Total flavonoid content.

[w] Values determined in fresh sample depicted as mg/100 g of fresh weight (FW) and in dehydrated sample as mg/100 g dry weight (DW) basis.

3.5. Antioxidant activity and phytochemicals of dehydrated country bean seeds

In this experiment, the free radical scavenging activity with respect to the IC_{50} values significantly ($p < 0.05$) increased in the dehydrated products compared to the fresh sample (8.73 μg/mL) and this IC_{50} value is inversely proportional to antioxidant activity that denotes the decrease of antioxidant capacity due to all drying techniques (Table 3). Among the dryers, OSD denoted the highest IC_{50} values (303.82 μg/mL) having statistical uniformity with LSD (296.70 μg/mL) followed by SSD (243.23 μg/mL). BSD dried CBS with minimum IC_{50} value (209.49 μg/mL) had the maximum antioxidant activity. The pretreatment effect on antioxidant activity was evaluated, and it was found that the lowest IC50 value (indicating the maximum antioxidant activity) was seen in KMS (235.46 μg/mL), followed by KT (247.32 μg/mL) and CA (256.25 μg/mL). Dehydrated sample without pretreatment retained minimum antioxidant activity (IC_{50} value 291.82 μg/mL).

The study observed that the drying procedures and pretreatments had a statistically significant ($p < 0.05$) impact on the total

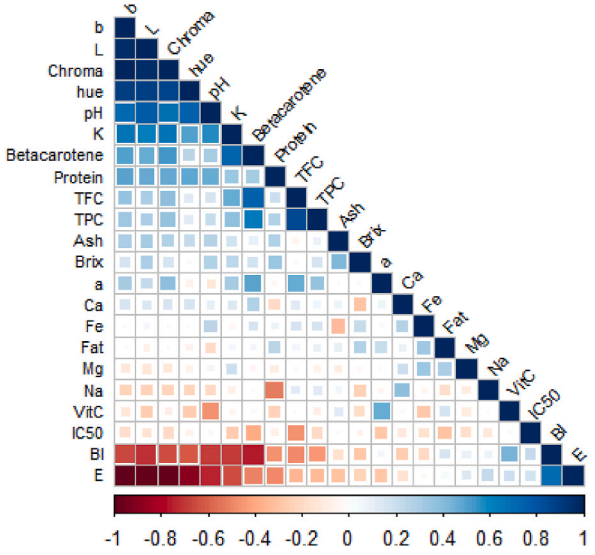

Fig. 2. Pearson correlation matrix among the proximate nutritional composition of the pretreated dehydrated country bean seeds.
[Red color scale bar at the bottom indicates negative correlation and blue color positive correlation between the variables with a significance level alpha = 0.05.L*; a*; b* = The CIELAB color scale coordinates, Chroma, hue = Color changes; E = Total color difference, BI= Browning index; pH, Brix, Vit-A; Vit-C, Protein, Fat, Ash = Physiochemical and proximate composition; IC50 = Antioxidant activity, TPC = Total phenol content; TFC = Total flavonoid content; Na, K, Ca, Mg, Fe = Minerals]. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

phenolic content (TPC) and total flavonoid content (TFC) of dehydrated country bean seeds, as shown in Table 3. The highest amount of TPC (49.73 mg GAE/100 g FW) and TFC (31.95 mg QE/100 g FW) was observed in fresh sample followed by the others. Among the pretreated samples, KMS enabled to retain maximum amount of TPC (17.32 mg GAE/100 g DW) and TFC (11.28 mg QE/100 g DW) being statistically identical to other pretreatments and control but different from the TPC of fresh sample.

3.6. Correlation coefficient analysis

The Pearson correlation matrix displayed the magnitude of both positive and negative correlations among the variables of drying processes and nutritional contents (Fig. 2). The correlation matrix displayed a range of values from negative to positive, represented by squares coloured in shades of red to blue. It indicated that if one variable's response grew, the other variable would also increase for positive correlation, and vice versa for negative correlation. Empty cells were deemed to have no meaningful correlation at a significance level of 5 %. Larger squares indicated a more robust link between the two variables in question. When analysing the 22 variables for country bean seed colour and quality characteristics, a significant positive correlation ($R^2 = 0.99$) was observed between vitamin-A and flavonoid concentration. This indicates that an increase in vitamin-A content leads to an increase in flavonoid content. β-carotene had a significant positive association ($R^2 = 0.74, 0.71$) with both K and phenol, suggesting that a rise in vitamin-A led to an increase in K and phenol content. The pH of the solution showed a substantial correlation with both the K and phenol content, as indicated by the high R^2 values of 0.57 and 0.65, respectively. Based on the protein characteristics, there was a significant negative association ($R^2 = -0.53$) between Na and protein content. This association demonstrated an inverse correlation between the rise in protein content and the decrease in Na. Furthermore, a somewhat significant association ($R^2 = 0.58$) was detected between protein and phenol concentration, indicating that an increase in protein led to an increase in phenol content. The phenol and flavonoid compounds exhibited a significant positive association ($R^2 = 0.72, 0.76$) with K, indicating that a rise in K levels leads to an increase in the content of phenol and flavonoid. The study found a significant positive connection ($R^2 = 0.75$) between phenol and flavonoid, indicating that

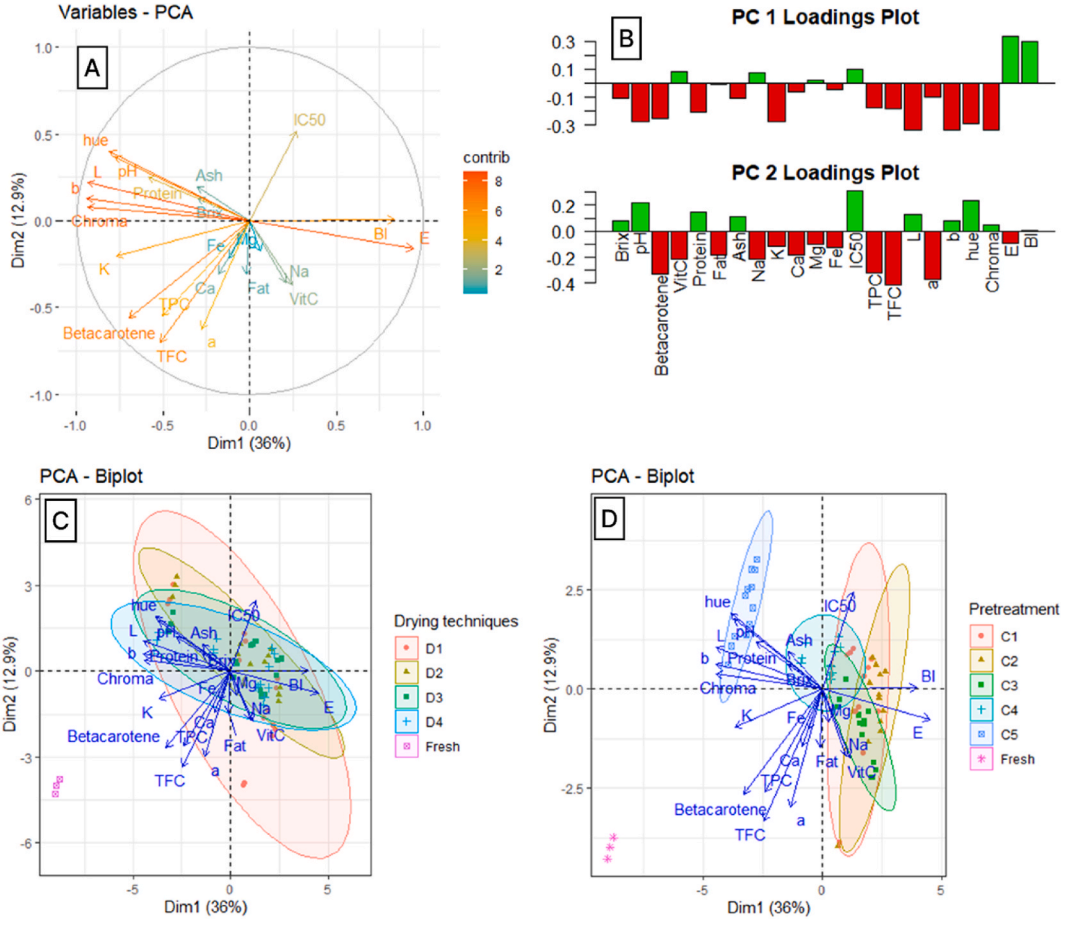

Fig. 3. Biplots of multivariate analysis using the principal components 1 (Dim1) and 2 (Dim2) for the proximate nutritional compositions of dehydrated country bean seeds with pretreatment.
(A) Variables contribution to each of the dimensions of PCA; (B) Loading factors of the studied variables to PC1 (Dim 1) and PC2 (Dim 2); (C) PCA-Biplot for drying techniques; (D) PCA-Biplot for pretreatment.

an increase in phenol content led to an increase in flavonoid concentration in the dried country bean seed. Additionally, flavonoid showed a negative link with antioxidant level. Chroma and hue have a strong positive link with b, L, and a, whereas they have a negative correlation with the BI and total colour difference ΔE.

3.7. Principal component analysis (PCA)

Principal component analysis (PCA) simplified the complex data by reducing the quantity of interrelated variables to a more concise set of variables in order to ascertain the most significant attributes. The correlations between different indices were visually depicted in a biplot, taking into account the first dimension (PC1) and the second dimension (PC2) (Fig. 3 A, B, C, D). The first two principal components (PC) accounted for a significant portion (about 48.9 %) of the overall variations. Specifically, PC1 and PC2 independently explained 36.0 % and 12.9 % of the total variations, as shown in Fig. 3C and D. Regarding the loading factors and contribution to the variances, the positive scores along with Dim1 corresponded to antioxidant, vitamin-C, Na whereas the negative scores along with Dim1 were characterized for TSS, pH, β-carotene, protein, fat, ash, K, Ca, Mg, Fe, phenol and flavonoid (Fig. 3A and B). Meanwhile, the positive score along with the Dim2 corresponded to antioxidant, protein, pH, TSS, ash and phenol. The negative scores along with Dim2 characterized for β-carotene, vitamin-C, fat, Na, Ca, K, Mg, Fe and flavonoid (Fig. 3 Am B). Fig. 3C and D shows that BSD and KMS generate separate clusters compared to other drying procedures and pretreatments. These clusters are formed by incorporating variables with positive loading values. Thus, BSD and KMS may be differentiated from others based on the positive correlation between the variables, taking into account both dimensions of the biplot. Nevertheless, the remaining examined factors pertaining to drying techniques (Fig. 3C) and pretreatments (Fig. 3D) exhibited significant overlap.

4. Discussion

The physical appearance (mostly color) of desiccated meals is a vital factor in determining customers' acceptance of the products. This is because color has a significant influence in the appearance of the food and is also indicative of the content of phytochemicals, antioxidants, and minerals. During the drying process, fresh items experience enzymatic and non-enzymatic browning, which leads to a loss of color. Enzymatic browning is susceptible to fruits and vegetables that contain substantial quantities of polyphenols, peroxidase (POD), and polyphenol oxidase (PPO) [8]. Conversely, non-enzymatic browning is induced by maderization, caramelization, phenol oxidation, temperature, and the Maillard reaction [18]. Therefore, the color and associated vitamins and phytochemicals were effectively preserved through the pre-drying pretreatments, which also effectively decreased the incidence of discoloration. Enhancement of color preservation was observed when dehydrated country bean seeds were treated with a 1 % solution of potassium metabisulfite (KMS) in the present findings. In addition, tests conducted on peroxidase (POD) and polyphenol oxidase (PPO) enzymes demonstrated that samples treated with KMS, which showed excellent color preservation, exhibited the lowest enzyme activity. One common sulfuration technique used as a pretreatment to stop browning is potassium metabisulfite. It successfully prevents enzymatic and nonenzymatic reactions, preserving the product's color [18]. PPO acts as an activator of enzymatic browning by promoting the conversion of phenolics into quinones, which in turn forms melanins and various brown pigments [19]. According to Moon et al. [19], the PPO is extremely sensitive to oxygen exposure, which can lead to the oxidation-induced development of an almost insoluble pigment known as enzymatic browning. Therefore, it is crucial to deactivate PPO activity in order to control the browning response by a mix of physical and chemical techniques. In the experiment, the presence of SO_2 in KMS probably served as a disinfectant to keep country bean seeds from oxidizing and discoloring in the sun, preserving their color [8,20]. According to Ref. [18], SO_2 in KMS functions by depleting oxygen and inhibiting PPO activity by means of an interaction between sulfite ions and quinones. Although ascorbic acid, citric acid, and potassium tartrate were utilized for preserving the color of dried country bean seeds, it has been noted that specific pigments, such as chlorophylls and carotenoids, are vulnerable to the impact of ascorbic acid and citric acid, leading to a transformation in color from green to brown [8,21].

The drying procedures had a similar effect on the color, nutritional, and phytochemical contents of the dehydrated CBS. The box drying processes effectively utilized solar radiation to provide a desirable hue for the final dried products. The black inner surface of the insulated box dryer raised the internal temperature, leading to the efficient expulsion of hot air through the small side holes, resulting in a substantial reduction in drying time [8]. This ultimately prevented the browning of dehydrated CBS (Supplementary Fig. 1, Supplementary Table 1). The higher temperature and lower humidity inside the box drier created stronger driving forces for heat transfer, resulting in a faster drying rate and shorter drying time compared to other dryers and open sun (Supplementary Table 1). As stated in Ref. [19], enzymatic oxidation is about 100 % in fresh samples due to the existence of peroxidase and polyphenol oxidase in the tissues of higher plants. The enzymatic browning in the dehydrated items was reduced by the BSD approach, which rapidly removed moisture.

The final product showed a significant decrease in its proximate compositional and functional qualities, as well as a few beneficial reductions for improved preservation. However, the preservation of vitamins, minerals, and bioactive components in the dehydrated country bean seeds was significantly affected by the drying processes and the chemicals used in pretreatment, as shown in Tables 2 and 3. The pH was crucial in preventing microbial spoilage [22]. The presence of microbial infection has minimal impact on product deterioration at low pH levels. Therefore, a reduced pH level in the dehydrated CBS can significantly increase its storage life [23]. The final product's low pH may be linked to the higher concentration of organic acids resulting from water loss during drying [24]. The rise in pH value seen in KMS treated seeds across the other pretreatments could be attributed to the alkaline properties of sodium metabisulfite. The inclusion of citric and ascorbic acid in the seeds decreased the pH as a result of their acidic properties. In addition, box solar drying and KMS pretreatments were found to be superior to other drying methods and pretreatments in terms of preserving larger

levels of TSS, vitamin A and C, protein, ash, and fat content in dried country bean seeds, with just a few exceptions. Decreasing the amount of moisture in the seeds increased the total soluble solids (TSS) value of the desiccated seeds. Once again, the decrease in protein content can be explained by the process of denaturation, which leads to the liberation of amino acids from the proteins. These amino acids can then undergo chemical reactions with other substances through the Maillard reaction [25]. Qixing et al. [26] suggested that the decrease in crude protein content at higher drying temperatures could be attributed to thermal denaturation of the protein. The shorter drying time in box drying resulted in less loss of crude protein following denaturation, compared to other drying methods. The reduction in fat content in the dehydrated products was caused by the disintegration of cells, leading to the evaporation of volatile oils from the seeds during the drying process. Furthermore, the carbohydrates present in dried seeds also play a role in the production of fats through an intricate mechanism [27]. Furthermore, the increased degradation of β-carotene and C during open sun drying can be attributed to the extended drying duration and exposure to light, which triggers oxidation of β-carotene and ascorbic acid. It is worth noting that ascorbic acid is particularly susceptible to degradation caused by light. Conversely, the samples treated with KMS had a greater total suspended solids (TSS) content compared to the other pretreatment samples. This phenomenon may be attributed to the fact that the pre-treatment conducted prior to the drying process effectively mitigated the degradation of the dried product by decreasing the drying duration and deactivating the enzymes accountable for the deterioration of its constituents [28]. The variation in ash content can be attributed to the time-temperature connection. Higher drying temperatures resulted in faster drying, which reduced the moisture content of the seed and increased the ash content. The pretreatment also played a significant influence in this process. As stated in Ref. [29], the heat sensitivity of ascorbic acid leads to a decrease in fat content in the sample treated with ascorbic acid, compared to other pretreatments. On the other hand, sulfite and starch treatment resulted in a drop in β-carotene levels during the drying periods. The pretreatment samples that were treated with citric acid had the highest concentration of β-carotene among all the dried samples. This was induced by the presence of acidulants such as ascorbic acid and citric acid, which effectively inhibited the degradation of β-carotene throughout the drying process. Additionally, KMS has the ability to preserve the β-carotene content by preventing enzymatic degradation [30]. The KMS treated samples had significantly higher levels of vitamin C compared to the other samples, whereas the citric acid treated samples had the lowest vitamin C content. The increase could be attributed to the penetration of ascorbic acid into the green mango slices during the pretreatment process with ascorbic acid [31].

Once more, all four drying methods shown a significant decrease in mineral components (potassium, calcium, and iron) when compared to the original sample, with the exception of sodium and magnesium. The exception may be ascribed to severe desiccation, resulting in an augmentation of the dry matter content as well as mineral constituents. The substantial increase in dry matter and mineral content seen during the drying process can be attributed to the concentrated impact of enrichment, which is likely a result of the extreme dehydration of the seeds. The results were in line with the findings of [8,32], which observed a significant positive association between the dry matter and mineral components, as well as the moisture content, in several fruit species and vegetable during and after the drying process.

The antioxidant activity of the dehydrated sample was measured by measuring its IC50 value, which reflects the sample concentration that inhibited DPPH free radicals by 50 % [8,33]. The box sun-drying method had the lowest IC50 value, indicating the highest antioxidant activity. This can be ascribed to the higher temperature and shorter drying time associated with this approach, which resulted in the lowest IC50 value and maximum antioxidant activity [8]. Kapoor and Aggarwal [34] discovered a similar finding, noting that increasing the processing temperature resulted in shorter drying times and higher antioxidant activity. Furthermore, the formation and accumulation of maillard-derived melanoidins with variable amounts of antioxidant activity can improve antioxidant performance at high temperatures [35]. Furthermore, prolonged drying causes the oxidation or degradation of polyphenols and anthocyanin, resulting in a significant loss in antioxidant activity [36]. As a result, it is critical to reduce the drying time to avoid the destruction of antioxidant activity in dried commodities [37]. An et al. reported a stronger relationship between antioxidant activity and total phenolic content (TPC), but a weaker correlation between antioxidant activity and total flavonoid content (TFC) [38]. The box dryer retained the most TFC compared to any dryer, next to the short chimney solar dryer. This occurred due to the formation of oxidized compounds, resulting in an overestimation of TFC. The depletion of TFCs could be attributable to the combined action of temperature and time. The shorter length and less strong heating in the box drier make it better suited for preserving flavonoids.

Pretreatment with multiple agents resulted in significant retention of antioxidant activity, phenol, and flavonoid levels. The drop in polyphenol content could be attributable to heat treatment, which provided energy to dissolve the bond between phenols and insoluble polyesters, potentially increasing polyphenol accessibility [39]. Furthermore, open sun drying may promote thermal destruction of phenolic compounds as well as the activation of oxidative enzymes, resulting in the loss of the phenolic complex [8]. Eim et al. found that increasing the drying temperature greatly reduces the content of phenolic compounds [40]. Several investigations discovered that phenolic compounds and flavonoids in different plant species vary inconsistently across drying procedures [41]. An et al. [38] discovered that the drying process might result in varied levels of total phenolic content (TPC) and total flavonoid content (TFC) depending on the kind of plant material and the specific phenolic compounds present in the cell. KMS was able to preserve the highest level of TPC and TFC among the pre-treated samples. The presence of SO4 in KMS inactivated enzymes and hindered the oxidation of phenols and flavonoids in bean seeds treated with KMS [34,42].

Meanwhile, the correlation matrix and PCA analysis have substantiated the notable disparities in the nutritional composition of dehydrated country bean seeds, contingent upon the types of dryers and variations in pretreatments. Simultaneously, it also highlighted certain distinctive characteristics of the dryers and pretreatments that include superior nutritional qualities and antioxidants. As a result, it is feasible to categorize them separately from the other treatments examined.

5. Conclusion

The study revealed that the physicochemical properties, color, acceptability, and antioxidant activity of country bean seeds varied significantly when dehydrated using various methods of dehydration and pretreatments. The dried country bean seeds had fewer minerals, proteins, bioactive compounds, and antioxidants than the fresh sample. Nevertheless, samples that underwent box sun drying (BSD) retained the highest levels of protein (96.48 %), vitamin C (90.15 %), and β-carotene (82.9 %). Furthermore, seeds that were treated with BSD and 1 % KMS demonstrated the highest level of antioxidant activity, as indicated by the lowest IC50 value for radical scavenging. Furthermore, the enzyme inactivation test demonstrated that the dehydrated country bean seeds treated with BSD and 1 % KMS exhibited reduced color differences and browning indices. This could have positively influenced the overall acceptance of the product by customers, as indicated by the highest scores obtained in the sensory assessment test. Therefore, the box solar dryer, when used in conjunction with a 1 % potassium metabisulfite (KMS) pretreatment, is suggested as a highly promising technology that surpasses traditional sun drying methods for dehydrating country bean seeds. This approach can also be employed to address the excess of seasonal perishable agricultural commodities and the resulting losses after harvesting by using effective drying techniques and enhancing the value of the products.

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Ethical statement

The current study used country bean seeds collected from the Department of Horticulture's research area at Bangabandhu Sheikh Mujibur Rahman Agricultural University in Gazipur, Bangladesh.

Data availability statement

The experiment data will be available upon request.

CRediT authorship contribution statement

Maksuratun Nahar Suborna: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation. **Jahidul Hassan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **M. Mizanur Rahman:** Writing – review & editing, Validation, Methodology, Investigation. **Mohammad Sharif Raihan:** Writing – review & editing, Supervision. **Joydeb Gomasta:** Writing – review & editing, Visualization, Investigation. **Minhaz Ahmed:** Writing – review & editing, Software, Resources, Formal analysis, Data curation. **Md. Mamunur Rahman:** Writing – review & editing, Validation. **Yukio Ozaki:** Writing – review & editing, Validation, Data curation. **Md. Zubayer:** Writing – review & editing, Visualization. **Saud Alamri:** Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

[1] S. McGuire, FAO, IFAD, and WFP. The state of food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress. Rome: FAO, 2015, Adv. Nutr. 6 (5) (2015) 623–624, 10.3945%2Fan.115.009936.

[2] A. Afshin, P.J. Sur, K.A. Fay, L. Cornaby, G. Ferrara, J.S. Salama, E.C. Mullany, K.H. Abate, C. Abbafati, Z. Abebe, M. Afarideh, Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017, Lancet 393 (10184) (2019) 1958–1972, https://doi.org/10.1016/S0140-6736(19)30041-8.

[3] T.F. Tadesse, S. Abera, S. Worku, Nutritional and sensory properties of solar-dried carrot slices as affected by blanching and osmotic pre-treatments, Int. J. Food Sci. Nutr. Eng. 5 (1) (2015) 24–32.

[4] Ó. Rodríguez, P.J. Llabrés, S. Simal, A. Femenia, C. Rosselló, Intensification of predrying treatments by means of ultrasonic assistance: effects on water mobility, PPO activity, microstructure and drying kinetics of apple, Food Bioprocess Technol. 8 (3) (2015) 503–515.

[5] S. Hossain, R. Ahmed, S. Bhowmick, A.A. Mamun, M. Hashimoto, Proximate composition and fatty acid analysis of *Lablab purpureus* (L.) legume seed: implicates to both protein and essential fatty acid supplementation, SpringerPlus 5 (1) (2016) 1–10.

[6] Ahasan Ullah Khan, Md Abdur Razzak Choudhury, Mohammad Samiul Ahsan Talucder, Md Shahadat Hossain, Shajahan Ali, Taslima Akter, Md Ehsanullah, Constraints and solutions of country bean (Lablab purpureus L.) Production: a review, Acta Entomol. Zool 1 (2) (2020) 37–45, https://doi.org/10.33545/27080013.2020.v1.i2a.17.

[7] L.M. Bal, S. Satya, S.N. Naik, Solar dryer with thermal energy storage systems for drying agricultural food products: a review, Renew. Sustain. Energy Rev. 14 (8) (2010) 2298–2314.

[8] J. Akter, J. Hassan, M.M. Rahman, M.S. Biswas, H.I. Khan, M.M.R. Rajib, M.R. Ahmed, M.N.E.A. Khan, M.F.A. Hasan, Colour, nutritional composition and antioxidant properties of dehydrated carrot (Daucus carota var. sativus) using solar drying techniques and pretreatments, Heliyon 10 (2) (2024) e24165, https://doi.org/10.1016/j.heliyon.2024.e24165. PMID: 38293496; PMCID: PMC10825429.

[9] Z. Baomeng, W. Xuesen, W. Guodong, Effect of pre-treatments on drying characteristics of Chinese jujube (*Zizyphusjujuba* Miller), Int. J. Agric. Biol. Eng. 7 (1) (2014) 94–102.

[10] M. Pasławska, K. Sala, A. Nawirska-Olszanska, B. Stępien, E. Pląskowska, Effect of different drying techniques on dehydration kinetics, physical properties, and chemical composition of lemon thyme, Nat. Prod. Commun. 15 (2) (2020) 1934578X20904521.

[11] X. Zhou, Y. Xiao, X. Meng, B. Liu, Full inhibition of Whangkeumbae pear polyphenol oxidase enzymatic browning reaction by L-cysteine, Food Chem. 266 (2018) 1–8.

[12] S.M. Kilonzi, A.O. Makokha, G.M. Kenji, Physical characteristics, proximate composition and anti-nutritional factors in grains of lablab bean (Lablab purpureus) genotypes from Kenya, Journal of Applied Biosciences 114 (2017) 11289–11298, https://doi.org/10.4314/jab.v114i1.2.

[13] I.O. Nyangena, W.O. Owino, S. Imathiu, J. Ambuko, Effect of pretreatments prior to drying on antioxidant properties of dried mango slices, Scientific African 6 (2019) e00148.

[14] I.E.H. Elgailani, M.A.M.G. Elkareem, E. Noh, O. Adam, A. Alghamdi, Comparison of two methods for the determination of vitamin C (ascorbic acid) in some fruits, Am. J. Chem. 2 (1) (2017) 1–7.

[15] S. Mohammed, M. Edna, K. Siraj, The effect of traditional and improved solar drying methods on the sensory quality and nutritional composition of fruits: a case of mangoes and pineapples, Heliyon 6 (6) (2020) e04163.

[16] AOAC, Official Methods of Analysis, eighteenth ed., AOAC International, Maryland U.S.A, 2005.

[17] D.A. Goulding, P.F. Fox, J.A. O'Mahony, Milk Proteins: an Overview. *Milk Proteins*, 2020, pp. 21–98.

[18] Li-Zhen Deng, Arun S. Mujumdar, Qian Zhang, Xu-Hai Yang, Jun Wang, Zhi-An Zheng, Zhen-Jiang Gao, Hong-Wei Xiao, Chemical and physical pretreatments of fruits and vegetables: effects on drying characteristics and quality attributes–a comprehensive review, Crit. Rev. Food Sci. Nutr. 59 (9) (2019) 1408–1432, https://doi.org/10.1080/10408398.2017.1409192.

[19] K.M. Moon, E.B. Kwon, B. Lee, C.Y. Kim, Recent trends in controlling the enzymatic browning of fruit and vegetable products, Molecules 25 (12) (2020) 2754, https://doi.org/10.3390/molecules25122754.

[20] A. Orphanides, V. Goulas, V. Gekas, Drying technologies: Vehicle to high-quality herbs, Food Eng. 8 (2016) 164–180.

[21] L. NgamwonglumLert, S. Devahastin, N. Chiewchan, Natural colorants: pigment stability and extraction yield enhancement via utilization of appropriate pretreatment and extraction methods, Crit. Rev. Food Sci. Nutr. 57 (15) (2017) 3243–3259.

[22] S.O. Owolade, A.O. Akinrinola, F.O. Popoola, O.R. Aderibigbe, O.T. Ademoyegun, I.A. Olabode, Study on physico-chemical properties, antioxidant activity and shelf stability of carrot (*Daucus carota*) and pineapple (*Ananas comosus*) juice blend, Int. Food Res. J. 24 (2) (2017) 534–540.

[23] V. Abe-Inge, J.K. Agbenorhevi, F.M. Kpodo, O.A. Adzinyo, Effect of different drying techniques on quality characteristics of African palmyra palm (*Borassusaethiopum*) fruit flour, Food Res. 2 (4) (2018) 331–339. https://doi:10.26656/FR.2017.2(4).050.

[24] B. Dereje, S. Abera, Effect of pretreatments and drying methods on the quality of dried mango (*Mangifera Indica* L.) slices, Cogent Food Agric. 6 (1) (2020) 1747961.

[25] K. Di Scala, A. Vega--Gálvez, E. Uribe, R. Oyanadel, M. Miranda, J. Vergara, R. Lemus-- Mondaca, Changes of quality characteristics of pepino fruit (*Solanum muricatum*Ait) during convective drying, Int. J. Food Sci. Technol. 46 (4) (2011) 746–753.

[26] J. Qixing, M. Zhengran, W. Shuoshuo, X. Yanshun, T. Fengyu, X. Xueqin, X. Wenshui, Effect of temperature on protein compositional changes of big head carp (*Aristichthysnobilis*) muscle and exudates, Food Sci. Technol. Res. 20 (3) (2014) 655–661.

[27] S. Mujaffar, S. Ramsumair, Fluidized bed drying of pumpkin (*Cucurbita* sp.) seeds, Foods 8 (5) (2019) 147.

[28] G. Putsakum, N. Rahman, H. Kamilah, K. Mahmood, F. Ariffin, The effects of blanching pretreatment and immersion of sodium metabisulfite/citric acid solution on the myristicin content and the quality parameter of nutmeg (*Myristica fragrans*) pericarp, J. Food Meas. Char. 14 (6) (2020) 3455–3461.

[29] H.S. Brar, P. Kaur, J. Subramanian, G.R. Nair, A. Singh, Effect of chemical pretreatment on drying kinetics and physio-chemical characteristics of yellow European plums, Int. J. Fruit Sci. 20 (sup2) (2020) S252–S279, https://doi.org/10.1080/15538362.2020.1717403.

[30] S. Veda, K. Platel, K. Srinivasan, Influence of food acidulants and antioxidant spices on the bioaccessibility of β-carotene from selected vegetables, J. Agric. Food Chem. 56 (18) (2008) 8714–8719.

[31] M. Mishra, P. Kandasamy, R.N. Shukla, A. Kumar, Convective hot-air drying of green mango: influence of hot water blanching and chemical pretreatments on drying kinetics and physicochemical properties of dried product, Int. J. Fruit Sci. 21 (1) (2021) 732–757.

[32] S. Suna, C.E. Tamer, B. Inceday, G.Ö. Sinir, Ö.U. Çopur, Impact of drying methods on physicochemical and sensory properties of apricot pistil, Indian Journal of Traditional Knowledge 13 (1) (2014) 47–55.

[33] M. Karaman, M. Stahl, J. Vulić, M. Vesić, J. Čanadanović-Brunet, Wild-growing lignicolous mushroom species as sources of novel agents with antioxidative and antibacterial potentials, Int. J. Food Sci. Nutr. 65 (3) (2014) 311–319.

[34] S. Kapoor, P. Aggarwal, Drying method affects bioactive compounds and antioxidant activity of carrot, Int. J. Veg. Sci. 21 (5) (2015) 467–481.

[35] A. Vega-Gálvez, K. Di Scala, K. Rodríguez, R. Lemus-Mondaca, M. Miranda, J. López, M. Perez-Won, Effect of air-drying temperature on physico-chemical properties, antioxidant capacity, colour and total phenolic content of red pepper (*Capsicum annuum*, L. var. Hungarian), Food Chem. 117 (4) (2009) 647–653, https://doi.org/10.1016/j.foodchem.2009.04.066.

[36] R. Esteban, L. Balaguer, E. Manrique, R.R. De Casas, R. Ochoa, I. Fleck, J.I. García- Plazaola, Alternative methods for sampling and preservation of photosynthetic pigments and tocopherols in plant material from remote locations, Photosynth. Res. 101 (1) (2009) 77–88.

[37] E. Cruces, Y. Rojas-Lillo, E. Ramirez-Kushel, E. Atala, C. López-Alarcón, E. Lissi, I. Gómez, Comparison of different techniques for the preservation and extraction of phlorotannins in the kelp *Lessonia spicata* (Phaeophyceae): assays of DPPH, ORAC-PGR, and ORAC-FL as testing methods, J. Appl. Phycol. 28 (1) (2016) 573–580.

[38] K. An, D. Zhao, Z. Wang, J. Wu, Y. Xu, G. Xiao, Comparison of different drying methods on Chinese ginger (*Zingiber officinale Roscoe*): changes in volatiles, chemical profile, antioxidant properties, and microstructure, Food Chem. 197 (2016) 1292–1300, https://doi.org/10.1016/j.foodchem.2015.11.033.

[39] I.G.G. Kasunmala, S.B. Navarathne, I. Wickramasinghe, Effect of drying methods on antioxidant activity of *Syzygiumcaryophyllatum* (L.) fruit pulp, Int. J. Fruit Sci. 21 (1) (2021) 634–644.
[40] V.S. Eim, D. Urrea, C. Rosselló, J.V. García-Pérez, A. Femenia, S. Simal, Optimization of the drying process of carrot (*Daucus carota* v. Nantes) on the basis of quality criteria, Dry. Technol. 31 (8) (2013) 951–962.
[41] E.W.C. Chan, Y.Y. Lim, L.F. Wong, F.S. Lianto, S.K. Wong, K.K. Lim, T.Y. Lim, Antioxidant and tyrosinase inhibition properties of leaves and rhizomes of ginger species, Food Chem. 109 (3) (2008) 477–483, https://doi.org/10.1016/j.foodchem.2008.02.016.
[42] R.L. Scalzo, T. Iannoccari, C. Summa, R. Morelli, P. Rapisarda, Effect of thermal treatments on antioxidant and antiradical activity of blood orange juice, Food Chem. 85 (1) (2004) 41–47.