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Effect of microwave-assisted vacuum and hot air oven drying methods on quality characteristics of apple pomace powder

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Abstract

Apple pomace, which makes up 20–30% of all processed apples, is an accessible source of bioactive ingredients that could be used in the food industry. A research of the impact of drying techniques on the quality characteristics of apple pomace powder was carried out to efficiently utilize this waste. The pomace was dried at 50 °C and 60 °C in a vacuum-assisted microwave dryer and an oven dryer, respectively. The different temperatures chosen for the drying of apple pomace were selected based on preliminary tests. Microwave drying resulted in reducing the drying time and improving the physicochemical, functional and morphological properties of the powder. The TPC (Total phenolic content) and AA (antioxidant activity) of pomace powder were found to be considerably influenced by the drying technique. Maximum TPC, DPPH and FRAP values observed for the apple pomace powder dried in the microwave were 5.21 ± 0.09 mg GAE/g, 93 ± 1% and 3.22 ± 0.04 µg/mg, respectively while as in oven drying, the values were 3.14 ± 0.06 mg GAE/g, 89 ± 1% and 2.22 ± 0.02 µg/mg. Microwave drying led to increasing bulk density (0.55 ± 0.01 g/cc), water hydration capacity (3.35 ± 0.09 mL/g), oil binding capacity (0.95 ± 0.04 g/g), solubility index (14.0 ± 0.9%), and emulsion capacity (60.0 ± 1.0%) of the powder. Lower values for bulk density (0.50 ± 0.01 g/cc), water hydration capacity (3.04 ± 0.08 mL/g), oil binding capacity (0.70 ± 0.03 g/g), solubility index (10.0 ± 0.8%), and emulsion capacity (48.0 ± 0.9%) were observed in oven-dried powder. Microwave drying resulted in a more disordered, crystalline and porous structure of apple pomace powder as compared to oven-dried powder as confirmed by SEM (Scanning electron microscopy) and XRD (X-ray diffraction). Microwave-dried powder also had a higher vitamin C content (20.00 ± 0.12 mg/100 mg) than oven-dried powder (12.53 ± 0.08 mg/100 mg). This study may be helpful in the pre-processing of apple pomace for bioconversion processes and extraction of valuable components from apple pomace.

Highlights

✓ Vacuum-assisted microwave dryer reduced the drying time of apple pomace by 87% as compared toconventional oven drying

✓ Microwave dryingimproved the physicochemical, morphological and functional properties of applepomace powder

✓ The overall quality ofthe apple pomace was improved by microwave drying than conventional oven drying

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Keywords Apple pomace, Bioactive compounds, Functional properties, Physicochemical characteristics, Antioxidant activity, SEM, XRD

Graphical abstract

Introduction

The apple (*Malus domestica* Borkh) is the fruit of the domesticated tree *Malus domestica*, which belongs to the rose family (Rosaceae). The apple is a pome (fleshy) fruit, which is commonly grown all over the world. It is a prominent addition to countless diets as the primary source of polyphenolic compounds (Manzoor et al. 2021). In India, the total area under apple cultivation is 0.313 Mha and mainly grown in northern provinces, such as Himachal Pradesh and Jammu and Kashmir (Kumar 2017). Apples are the world's fourth most consumed fruit crop, after oranges, bananas and grapes (Musacchi & Serra 2018). According to the FAO's most recent report, global apple production amounted to a total of 86.44 million metric tons in 2020 increasing from approximately 83.14 million tons in 2017. Asia, as the world's largest apple producer, accounts for 65.4% of global output, with China producing 41.4 million metric tons (Lyu et al. 2020). In India, the annual production is about 2.3 million metric tons and ranks 7th in total apple production in the world (Bhat et al. 2022).

During the production of apple juice or apple cider, apple pomace is a significant by-product, accounting for 25% of the dry mass of the apple (O'Shea et al. 2012; Vidović et al. 2020). Apple skin/flesh makes up 95% of apple pomace (by weight), seeds make up 2 to 4%, and the stem makes up 1% (Perussello et al. 2017). Apple pomace is said to be abundant in calcium, potassium, and magnesium and to have 9.0% moisture, 2.27% fat, 2.37% protein, 1.6% ash, 84.7% carbohydrate, 5.6% starch, and 54.2% total sugar (O'Shea et al. 2015). Apple pomace is a desirable byproduct with good sensory characteristics, high dietary fiber content, and associated phenolic compounds (Sahni & Shere 2018). It also contains phytochemicals such as phenolic acids like chlorogenic,

protocatechuic and caffeic acid, as well as flavonoids like flavanols and flavonols (Kohajdová et al. 2014). Phenols are well-known for their various health benefits, including antioxidant, antimicrobial, anti-inflammatory and anti-tumor properties (Liu et al. 2021). Apple consumption has been linked to a lower risk of various lifestyle diseases like coronary artery disease, cerebrovascular disease, lung, breast, digestive system, oral cavity, and colon-rectal cancer and chronic obstructive pulmonary disease (Fabiani et al. 2016; Knekt et al. 2002). The major cause of mortality and morbidity in the world is CVD. Due to mostly problems pertaining to atherosclerosis, the prevalence of CVD is also rapidly increasing in other emerging countries (such as India and the continents of Africa and Latin America). It is known that the intricate relationships between dietary fibre, intestinal flora, and gut-produced metabolites may be a major factor in CVD (Gan et al. 2022). So it has been seen that dietary fiber reduces glucose absorption in the intestines, lowers cholesterol and LDL levels and improves intestinal health (Kosmala et al. 2011). Fiber sources are used not only for their nutritional worth but also for their functional and technological features, such as increasing cooking yield, fat binding ability, water hydration capacity and texture improvement (Sudha 2011; Thebaudin et al. 1997). According to several studies, apple pomace not only helps to avoid constipation and hypertension, but it can also scavenge certain toxic compounds in the human body, such as free radicals (Bhushan et al. 2008; Lyu et al. 2020; Yadav & Gupta 2015).

The presence of the value-added chemicals also suggests that apple pomace has the potential to be used as a food additive and can also be used to make pectin, xyloglucan, pigment, fragrance compounds, biofuel and natural colors among other things (Bhushan et al. 2008). The dietary fiber content and health-promoting qualities of bakery items such as bread, sweet bakery products and brittle bakery food can be improved by apple pomace (Lyu et al. 2020). Apple pomace can also be used in slices of bread up to 5% without affecting the quality of the bread significantly (Masoodi & Chauhan 1998). Apple pomace was seen not to alter the physical properties of the cake to an unfavorable degree and thus can be used as a source of dietary fiber (Masoodi et al. 2002). It was also used as a fat replacer in meat formulations (Rather et al. 2015). It can also be utilized as a part of substrate for the production of alcoholic beverages and the cultivation of edible mushrooms. There are other potential applications as a flavoring and stabilizing agent (Lyu et al. 2020). Apple pomace was utilized as a substrate in a variety of microbial processes for the manufacture of organic acids (citric acid, lactic acid), enzymes (cellulases, hemicellulases, glucosidase and pectinase), biopolymers (chitosan, xanthan gum), single-cell protein, ethanol, low-alcohol beverages, pigments and even aroma compounds due to its high carbohydrate, vitamin and fiber content (Bhushan et al. 2008; Perussello et al. 2017; Vendruscolo et al. 2008).

Apple pomace has a high biodegradable organic content (chemical and biochemical oxygen demand) in addition to its moisture content (70–75%) (Bhushan et al. 2008). This causes a high vulnerability to microbial decomposition, resulting in unpredictable fermentation, and thus causing pollution and potentially public health risks (Shalini & Gupta 2010; Skinner et al. 2018). Off-odors, as well as transportation and storage expenses, are reduced when apple pomace is dried and pulverized into powder. It also gives practical products with a longer shelf life at room temperature or materials that are easier for food processors to handle (Fellows 2009). More effort is needed to uncover new possibilities and scale up existing applications to industrial levels (Perussello et al. 2017). Due to its highly perishable nature, the most proposed uses necessitate dehydration as a pretreatment. Dehydration is also a method of extending shelf life, reducing volume and lowering handling and shipping costs for future processing. Drying apple pomace for animal feed or further processing, such as nutrient recovery, appears to be a promising option. The oven-drying of high moisture materials is a process that involves both heat and mass transport (Gullón et al. 2007; Hang & Woodams 1995; Rawal & Masih 2014), resulting in the loss of various phytonutrients with low-quality powder. Microwave drying refers to the application of dielectric heating mechanism, which depends on high-frequency electromagnetic oscillations brought on by molecular motion. Through molecular interactions with an electromagnetic field and the transformation of electrical field energy into thermal energy, the process for energy transfer during microwave heating delivers energy directly to materials. When compared to conventional drying, microwave drying offers a number of benefits since heat is produced by immediately converting electromagnetic energy into kinetic molecular energy. As a result, heat is produced deep into the item that needs to be dried. Specifically in microwave assisted vacuum drying, this technique offers substantial benefits for bulk commodities with poor heat conductivity (Parikh 2015; S. et al. 2012).

Microwave vacuum drying (MWVD) is thus a unique alternative drying process that combines the benefits of microwave heating and vacuum drying in a single operation. The combination of the low temperature provided by vacuum drying and the rapid energy transfer provided by microwave heating produces highly efficient and low-temperature drying, resulting in high-quality dried food products (Han et al. 2010). MWVD, also known

as "volume heating," thus has a lot of benefits, including increased energy efficiency, quick drying times and good final product quality (Staniszewska et al. 2020). The present work aimed to evaluate the effect of two drying methods on the physicochemical, nutritional, nutraceutical and functional properties of apple pomace powder. An efficient drying method with most of the nutrients retained in apple pomace shall have greater industrial demand for the extraction and production of valuable products.

Materials and methods

Apple pomace was obtained from FIL Industries Pvt Ltd (Budgam, J&K, India). Apple pomace is mainly composed of skin and seeds, with a moisture level of more than 75% on a fresh weight basis. Two types of dryers were used to dry the pomace: a vacuum assisted microwave dryer (TW/MWVAC/BATCH/012; Twin Engineers, India) and a hot air oven dryer (NSW-143; Narang Scientific Works Pvt. Ltd., New Delhi, India). A batch of apple pomace weighing 5 kg was dried in each dryer. For the vacuum-assisted microwave and oven dryer, the temperature was set at 50 °C and 60 °C, respectively. The different temperatures chosen for the drying of apple pomace were selected based on preliminary tests. The following two temperatures were optimum for drying AP. For MWD, 50 degrees temperature was the optimum where the pomace dried quickly without any loss of important components from the sample. Below this temperature, the drying in the microwave took more time resulting in a loss of energy. In the case of oven drying, a temperature below 60 degrees took longer time to dry AP which caused fungal growth on the pomace and a temperature above 60 degrees might cause overheating and loss of bioactive components from the pomace. The pomace was dried until it attained a moisture content of 2%. The seeds were manually removed and the grinding was done with the aid of grinder/mixer (Make: JUDGE Electricals UK, Model: JM2). After grinding the fine pomace powder was obtained by sieving using a sieve of mesh size BSS 72 (212 microns). The powder was stored in LDPE pouches in the refrigerator for further analysis. Figure 1 shows the general process for preparation of apple pomace powder.

Chemicals

The chemicals and reagents utilized throughout the experimental work were of analytical grade and were obtained from HiMedia Laboratories (HiMedia Labs, Mumbai, India Pvt. Ltd). Some chemicals were supplied by Sigma Chemicals Co (Sigma Aldrich, India). All the chemicals and reagents were of analytical grade and high purity.

Physicochemical properties

Moisture content

The moisture content of the powder was determined as per the procedure given by (Johnson 1945). 2 g of powder sample was dried in a convection oven at 105 °C for 10 h to determine the average initial moisture content. Moisture content was measured in triplicate ($n = 3$).

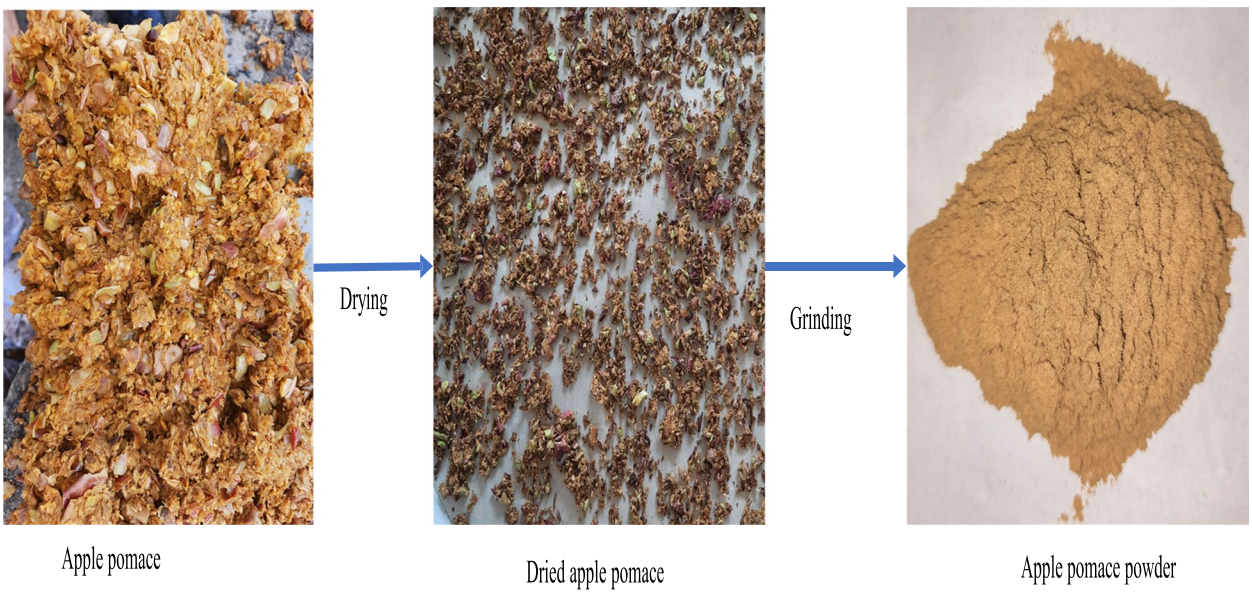

Fig. 1 Apple pomace powder preparation

$$Mc(\%) = (Wi - Wf/Wi \times 100)$$

Mc = moisture content, Wi = initial weight, W_f = final weight.

Ash content

The ash content of apple pomace powder was determined as per the protocol of Owens et al. (1952). Three gram of sample were weighed into a silica ashing crucible and burned, cooled in a desiccator and weighed beforehand. The samples were weighed after being incinerated in a muffle furnace until light grey ash was formed. The following formula was used to compute the amount of ash content:

$$\%Ash = \frac{\{(Weight\ of\ crucible + Weight\ of\ ash) - Weight\ of\ empty\ crucible\}}{Weight\ of\ sample} \times 100$$

Protein content

Protein content was estimated by Lowry's method (Lowry et al. 1951). Five hundred milligram of the sample was weighed and grounded well with a pestle and mortar in 5–10 mL of the phosphate buffer pH 7. The mixture was centrifuged and the supernatant was used for protein estimation. Different concentrations of extract from 0.1 – 0.2 mL were taken in test tubes and the volume was made up to 1 mL by distilled water. One millimeter water was taken as blank and bovine serum albumin as standard. Five millimeter of the alkaline copper solution was added to all the tubes including the blank. After 10 min, 0.5 mL of Folin–Ciocalteau Reagent was added and mixed well. All the tubes were incubated at room temperature in dark for 30 min and absorbance was read at 660 nm by UV–Vis spectrophotometer (U—2900, Hitachi, Tokyo, Japan).

Crude fat percent

The fat content was calculated as per the method given by N. J. Thiex et al. (2003). Fat content was determined by extracting it with solvent petroleum ether. The sample was held in a porous thimble, allowing the solvent to completely cover it. The thimble was placed in an extraction system that allowed the solvent to be recycled multiple times. This increases the amount of time the solvent has in contact with the sample, allowing it to dissolve all of the fat in the sample. Then the sample was inserted into the distillation equipment for extraction after it has been weighed. The solvent was heated in the flask until it boils. The heat source was adjusted so that solvent drips from the condenser into the sample chamber at the rate of about 6 drops per second. Extraction was continued for 6 h. Then the flask was replaced in the extraction unit. The flask was placed in an oven at 102 °C and the contents were dried until a constant weight was attained. Flask was left to cool in a desiccator and the weight of the flask and contents were recorded.

$$Crude\ fat(\%) = \{(Weight\ of\ thimble\ after\ fat\ extraction - Empty\ weight\ of\ thimble\ /Weight\ of\ sample\} \times 100$$

Total sugars

The phenol–sulfuric acid method (Dubois et al. 1951) was used to determine the total sugar content. Five millimeter of 2.5 N HCl was added to 100 mg of the AP powder and the mixture was placed in a heating water bath for 2 h. The solution was neutralized by adding solid sodium carbonate until no effervescence occurred and the final volume of the solution was adjusted to 100 mL by adding distilled water. A series of serially diluted standard and sample solutions were prepared in glass tubes and the final volume was made upto 3 mL. 5% phenol solution (0.5 mL) was added to the test tubes. Then 5 mL of concentrated sulfuric acid was added and the mixture was vortexed for a few minutes. All the tubes were allowed to cool to room temperature for 20 min before being read using a UV–VIS spectrophotometer at a wavelength of 490 nm with a serially diluted 1 mg/mL solution of glucose as standard. The yield of crude polysaccharide extracts was determined as a percentage of dry weight using the following equation.

$$Yeild\ (\%dry\ weight) = (weight\ of\ polysaccharides\ /dried\ \ sample\ weight) \times 100$$

Total dietary fiber The total dietary fiber in terms of both soluble and insoluble fiber was determined according to the method of (McCleary et al. 2012). The dry sample was homogenized with 40 mL MES/TRIS (pH 8.2) solution and the α-amylase solution was added. This mixture was heated in a water bath at 95℃. Then the mixture was cooled at room temperature, washed with distilled water and protease solution was added at

a temperature of 60℃ in a water bath. It was mixed with 5 mL of 0.56 N HCl solution, and the pH was adjusted to 4.0. After then, 300 µL of amyloglucosidase solution was added and stirred at 60 ℃ on a hot plate. To extract the insoluble fiber, the solution was filtered using a glass filter, with 1 g celite, and the filtrate was washed with 78% ethanol, 95% ethanol and acetone in turn. After overnight, the residue in the glass filter was weighed for insoluble fiber. The filtrate collected was added with 95% ethanol and distilled water. For extraction of soluble fiber, the solution was filtered using a glass filter with celite and the filtrate was washed with 15 mL of 78% ethanol, 95% ethanol and acetone, in turn. The filtrate was kept for precipitation at room temperature for 60 min after preheating at 60℃.

Physical characteristics

Color measurement

Using a chromameter (LABSCAN XE Hunterlab, VA, USA), the color value of the powder sample from both dryers was assessed and reported in CIELAB color scales. The degree of lightness to darkness is represented by L* value, the degree of redness to greenness is represented by a* value and the degree of yellowness to blueness is represented by b* value. Before measuring color, black and white standards were used to calibrate the system.

Particle size determination

Particle size was determined by following the method described by Ahmad et al., (Ahmad et al. 2019). A Zetasizer (Nano S, Malvern Instruments, Worcestershire, U.K.) was used to evaluate the particle size of apple pomace powder. The sample (0.01%, w/v) was suspended in milli-Q water (Elix-10, Millipore, Molsheim, France) for particle size measurements. To properly disperse the particles, samples were sonicated for 30 min at 40 kHz in a sonicator bath.

X-Ray Diffraction

X-ray diffraction (XRD) patterns were studied in a poly-crystal X-ray diffractometer (Smartlab, Rigaku Corporation, Japan) using Cu-Kα at operating conditions of 40 kV, 30 mA, the angular range of $2\theta = 2–90°$, and scanning speed of 5°/min with a step size of 0.01° to determine the relative crystalline natures of powders.

Scanning Electron Microscopy (SEM)

Scanning electron microscopy was used to examine the surface morphology of apple pomace powders to identify any changes that may have arisen as a result of the varied drying methods. Before being mounted on a sample table for scanning, dried samples were coated with gold powder under a vacuum. The images were captured with a scanning electron microscope (SEM) (Zeiss EVO, USA) at a 10 kV accelerating potential with magnifications of 100xand 1500x.

Functional properties

Bulk and tapped density

A known amount of apple pomace powder was placed into a 10 mL graduated cylinder, the volume occupied was measured and the bulk density (ρB) was calculated (weight per volume). After tapping the cylinder for 5 min, the tapped density (ρT) was computed (32 taps per minute). The final volume was then scanned and the tapped density was calculated as per the method of Hayes et al. (1998).

Water hydration Capacity (WHC)

A weighed quantity (5 g) of the sample was transferred to a 50 mL centrifuge tube, and the tube was weighed along with the sample. Then after every 5 min, distilled water was added and the mixture was vortexed for 15 s. The same procedure was followed for 40 min until the pasty consistency was attained. It was then centrifuged for 10 min at 4000 g. If there was any supernatant, it was discarded, and the tube was weighed again (Grover et al. 2003).

$$WHC\ (g/g) = (Final\ weight - Initial\ weight) / Initial\ weight$$

Oil binding capacity (OBC)

The oil binding capacity (OBC) of powder was determined by the method of (Ma et al. 2017). Before placing one gram (W_0) of powder into a centrifuge tube, it was weighed separately (W_1). After that, 10 mL of soybean oil was added, and the mixture was vortexed for 5 min. The sample was allowed to sit at room temperature for 30 min before being centrifuged for 20 min at 3000 g. The supernatant was decanted, and the precipitate-filled centrifuge tube was weighed (W_2). Oil absorption was expressed as the amount of oil bound by per g of sample and was calculated as follows:

$$OBC\ (g/g) = (W2 - W1) / W0$$

Swelling power and solubility index

The swelling power and solubility index was calculated by following the method given by (Younis & Ahmad 2015). A total of 1 g of material was extracted and weighed in a test tube (W_1). It was then combined with 50 mL of distilled water. The slurry was heated to 85 °C for 30 min in a water bath. After cooling, the sample was centrifuged for

15 min at 2,200 g. The supernatant was collected in a dish, and 5 mL was placed onto a tarred evaporating plate (A_1) and dried at 100 °C for 4 h before being weighed again (A_2). The weight of the sediment was then calculated (W_2).

$$Swelling\ power\ (\%) = \{(W2 - W1) / Weight\ of\ sample \times 100$$

$$Solubility\ index\ (\%) = \{(A2 - A1) / Weight\ of\ sample\} \times 100$$

Foam Capacity (FC) and Foam Stability (FS)

A homogenizer was used to mix one gram of sample with 100 mL of distilled water and homogenized the solution vigorously for 5 min. The foam volume was measured after the homogenized suspension was transferred to a 250 mL graduated cylinder (Gannasin et al. 2012). After letting the foam stand for 1 h, the foam volume was measured to determine foam stability (FS) (Ahmad et al. 2016).

$$FC\ (\%) = \{[Vol.after\ homogenization\ (ml) - Vol.before\ homogenization(ml)] / Vol.\ before\ homogenization\ (ml)\} \times 100$$

$$FS\ (\%) = (Foam\ vol.after\ 1\ hr / Initial\ foam\ vol.) \times 100$$

Emulsion capacity (EC) and Emulsion stability (ES)

Grover et al. (2003)'s method were used to determine the emulsion capacity (EC) and emulsion stability (ES) of powder. A high-speed mixer was used to homogenize one gram of powder with 50 ml of distilled water and 50 mL of soybean oil for 1.5 min. The mixture was divided into two 50-mL centrifuge tubes (40 mL total). For the emulsion capacity measurement, one tube was centrifuged at 4,000 rpm for 10 min at room temperature. The other centrifuge tube was heated for 30 min in a water bath at 80 °C before being cooled to room temperature. The emulsion stability was next tested by centrifugation under the same conditions. The following formulas were used to compute emulsion capacity (EC) and emulsion stability (ES):

$$EC\ (\%) = (Height\ of\ emulsion\ layer / Total\ height\ \ layer) \times 100$$

$$ES\ (\%) = (Height\ of\ remaining\ emulsion / Total\ height\ of\ emulsion) \times 100$$

Determination of antioxidant activities

Preparation of extract

In an electrical shaker at 30 °C, 10 g of each powdered sample was extracted for 8 h with 50 mL of acidified methanol (5% HCl v/v). The extract was centrifuged for 15 min at 10,000 g, and the supernatant was kept at – 40 °C, in a sealed container until further analysis.

Determination of DPPH radical scavenging activity

The antioxidant activity of apple pomace was determined using a modified version of the method described by (Chaouch et al. 2015). Four millimeter of methanolic DPPH solution (0.1 mM) was added to 1 mL of sample in various concentrations (1–50 mg/ml). The mixtures were vortexed and incubated at room temperature for 30 min in the dark. A UV–Vis spectrophotometer was used to test the absorbance at 517 nm. As a standard, identical amounts of ascorbic acid (AA) were utilized. Higher antioxidant activity is indicated by the lower absorbance of the samples. The activity of the DPPH radical was calculated as follows:

$$DPPH\ radical\ activity\ (\%) = [1 - (Asample \div Acontrol)] \times 100$$

Determination of total phenolic content

The Folin–Ciocalteu technique (Liu & Yao 2007) with certain modifications was used to determine the total phenolic content of the samples. Two hundred millimeter of the extract was combined with 1 mL Folin–Ciocalteu reagent diluted to 1:10 with water. 1 mL of 10% Na_2CO_3 was added to the mixture, which was violently shaken, and the final volume was built up to 5 mL with distilled water. The absorbance was measured through a UV–Vis Spectrophotometer at 765 nm after the mixture had been allowed to stand for 2 h at room temperature. Total phenolic content was measured in mL of gallic acid equivalents per gram of dry weight sample powder.

Ferric reducing antioxidant power (FRAP)

The assay was performed using the Benzie and Strain method (Benzie & Strain 1996). The FRAP reagent was made by adding 0.3 mol/L acetate buffer (pH 3.6), 10 mmol TPTZ solution in 40 mmol HCl, and 20 mmol iron (III) chloride solution in 10:1:1(v/v) proportions. Before use, the reagent was warmed at 37 °C. In 1.5 mL of FRAP reagent, 50 µL of sample extracts were added. After 4 min, the absorbance of the reaction mixture was measured at 593 nm using a UV–vis spectrometer against a blank. The calibration curve was used to calculate the antioxidant activity of the extracts, which was expressed as mg TEAC (Trolox equivalent antioxidant activity)/g dry weight sample powder.

Estimation of Vitamin C (Ascorbic acid)

Ranganna 1986, used a titration approach to determine the ascorbic acid concentration of processed products, using a 2, 6 dichlorophenol indophenol dye solution. The basic concept includes ascorbic acid in an alkaline solution reducing 2, 6 – dichlorophenol indophenols dye to a colorless state. For ascorbic acid in a solution with a pH range of 1 to 4, the reaction is quantitative and specific. The dye solution was first calibrated against standard ascorbic acid to determine the dye factor in the method that followed. The filtered apple pomace fractions were diluted with 3 percent metaphosphoric acid and then titrated against the solution until a pink color appeared, which lasted 15 s. The dye factor was calculated as follows:

Dye factor = 0.5/titre vol.

$$mg\ of\ ascorbic\ acid\ /100ml\ =\ [titre\ \ vol\ (mL\ of\ \ dye\ used)\ \times\ dye\ factor\ \times\ vol\ made\ up\ \times\ 100\ \times\ 100]/\ sample\ taken\ \times\ vol\ of\ sample\ extract.$$

Statistical analysis

Results from each experiment were carried out in triplicate and expressed as mean ± SD. Analysis of variance (ANOVA) and Duncan's multiple range test was used to analyze the data at the 5% level of significance.

Results and discussion

Proximate composition

The study on quality analysis of powder dried in a hot air oven and microwave-assisted vacuum dryer was based on physicochemical and morphological characteristics. The drying time for MWVD and OD was noted as 3 h and 24 h respectively. The values recorded for the moisture, ash, protein and fat content are mentioned in Table 1. Moisture content is among the most important factors assessed in food as the moisture content is inversely related to a food's dry matter. Food's moisture level has an impact on its storage stability and quality

Table 1 Proximate analysis of apple pomace powder dried from two different dryers

Components	Microwave dried powder	Oven dried powder
Moisture (g/100 g)	2.03 ± 0.02^{a}	2.05 ± 0.04^{a}
Protein (g/100 g)	4.56 ± 0.06^{b}	4.03 ± 0.06^{a}
Crude fat (g/100 g)	1.84 ± 0.05^{a}	2.07 ± 0.03^{b}
Total sugars (g/100 g)	47.05 ± 0.10^{b}	41.01 ± 0.09^{a}
Total dietary fiber (g/100 g)	42.9 ± 0.1^{a}	49.5 ± 0.1^{b}
Soluble fiber (g/100 g)	25.54 ± 0.09^{b}	23.91 ± 0.06^{a}
Insoluble fiber (g/100 g)	17.4 ± 0.07^{a}	25.6 ± 0.10^{b}
Ash (g/100 g)	1.87 ± 0.06^{b}	1.56 ± 0.04^{a}

Table shows mean values with standard deviations of the mean (the results were averaged over three measurements)

a and b superscript letters in the same row indicate significant differences ($p < 0.05$) between samples

(Ishrat et al. 2020). The value for the moisture content was recorded at around 2% for both OD powder and MWVD powder. The moisture content differences were not statistically significant. The value for the protein content, crude fat, and ash content were 4.56 ± 0.06 g/100 g, 1.84 ± 0.05 g/100 g and 1.87 ± 0.06 g/100 g respectively in case of MWVD and 4.03 ± 0.06 g/100 g, 2.07 ± 0.03 g/100 g and 1.56 ± 0.04 g/100 g for OD powder. The slightly higher value of ash content, protein content and sugar content in microwave dried apple pomace powder was observed as compared to hot air oven-dried powder. As per the drying conditions, less drying time and the temperature were applied in the preparation of MWVD powder which might have led to the retention of more nutrients and inorganic matter in the MWVD powder than OD powder which underwent more severe drying conditions for a longer period of time. Crude fat percent was seen slightly higher in oven-dried apple pomace powder as compared to MWVD apple pomace powder. Sugar content was recorded as 47% in microwave dried powder and 41% in oven-dried powder, similar results were obtained by Wang et al. (2019) for apple pomace. Total dietary fiber was estimated as 42.9 ± 0.1 g/100 g in the case of MWVD apple pomace powder whereas in the case of OD apple pomace powder its value was recorded as 49.5 ± 0.1 g/100 g. The same has been reported by Sudha et al. (2007) in the case of dried apple pomace powder. Apple pomace is generally poor in protein and rich in fiber and sugars (Shalini & Gupta 2010). Overall protein content was seen lower in both (4.56 ± 0.06 g/100 g for MW and 4.03 ± 0.06 g/100 g for OD) apple pomace powders with.

Table 2 Techno-functional properties of the powders

Functional properties	Microwave dried powder	Oven dried powder
Bulk density (g/cc)	0.55 ± 0.01^{b}	0.50 ± 0.01^{a}
Tapped density (g/cc)	0.56 ± 0.03^{b}	0.52 ± 0.02^{a}
Water hydration capacity (WHC) (mL/g)	3.35 ± 0.09^{b}	3.04 ± 0.08^{a}
Oil binding capacity (OBC) (g/g)	0.95 ± 0.04^{b}	0.70 ± 0.03^{a}
Swelling power (SP)(%)	770 ± 1^{b}	764 ± 2^{a}
Solubility index (SI) (%)	14.0 ± 0.9^{b}	10.0 ± 0.8^{a}
Foam capacity (FC) (%)	2.07 ± 0.07^{b}	1.05 ± 0.06^{a}
Foam stability (FS) (%)	NS	NS
Emulsion capacity (EC) (%)	60.0 ± 1.0^{b}	48.0 ± 0.9^{a}
Emulsion stability (ES) (%)	52.0 ± 1.0^{b}	31.0 ± 0.8^{a}

Table shows mean values with standard deviations of the mean (the results were averaged over three measurements)

NS Not stable

a and b superscript letters in the same row indicate significant differences between samples ($p < 0.05$).

Table 3 Color measurements of powders

Physical parameters	Microwave dried powder	Oven dried powder
L*	54.15 ± 1.02^{a}	55.09 ± 1.05^{b}
a*	7.02 ± 0.09^{b}	5.76 ± 0.07^{a}
b*	38.65 ± 1.01^{b}	37.24 ± 1.02^{a}
Hue	79.69 ± 1.13^{a}	81.27 ± 1.17^{a}
Chroma	39.28 ± 1.08^{b}	37.68 ± 1.05^{a}

Table shows mean values with standard deviations of the mean (the results were averaged over three measurements)

a and b superscript letters in the same row indicate significant differences between samples ($p < 0.05$)

Physicochemical parameters

Table 2 shows the bulk and tapped density, water-hydration capacity, oil binding capacity, solubility index, swelling capacity, foam stability, foam capacity, emulsion activity, and emulsion stability of two apple pomace powders dried in different drying conditions. As MWVD powder was given less drying time and temperature, it showed a higher bulk density value. The findings were consistent with (Tonon et al. 2008), who discovered that higher temperatures induced a decrease in bulk density. Also, the results suggested that the microwave dried apple pomace powder has a high value of water hydration capacity and oil binding capacity, so can bind more water and oil. Because of its importance in foods, water-binding capacity has been extensively explored in food functioning. The presence of soluble components such as sugar and soluble fibers may account for the high solubility and WHC values (Andrade-Mahecha et al. 2012). As a result, greater WHC values in microwave dried powder suggest more polysaccharides and fibers are retained as removing moisture at a higher temperature could result in the cell wall break down of polysaccharide network (Holloway & Greig 1984; Rana et al. 2015). Soluble fibers also have a high hydration ability and can generate viscous solutions, which improves product stability and reduces water separation (Kaushal et al. 2012). The high OBC values could be related to the high number of hydrophobic groups in the sample's molecules (Tharise et al. 2014). Because of the rise in hydrophobicity, oil absorption capacity is related to the degree of acetylation and esterification of the molecules (Rubio-Senent et al. 2015; Shekhar Mohapatra et al. 2017). Ingredients with high OBC values can be used as emulsifiers and can also help improve the viscosity and texture of manufactured foods (Aydin & Gocmen 2015). It has been seen that ingredients with a high WHC can be used as a thickening agent or to reduce syneresis in food products containing a lot of water, and ingredients with a high OBC can be used as an emulsifying agent. The apple pomace powder can be used in products where syneresis needs to be reduced or texture needs to be improved. The swelling capacity of microwave dried apple pomace powder was also high which indicates its water absorption capacity during heating. This could be because increasing the drying temperature can influence the porosity and particle size of the final powder, which is a key parameter impacting the pomace's hydration properties (Carvalho et al. 2009; Elleuch et al. 2011). During the process of removing water at low temperatures, porous structures emerge within the cell wall matrix, allowing for easy and full rehydration (Cui et al. 2010) thus enhanced value of swelling capacity was seen in MWVD powder. The emulsion stability (ES) and emulsion capacity (EC) values for the two powders were significantly different, which may be due to variation in the protein and dietary fiber content of apple pomace powder. The EC and ES values were recorded in the MWVD powder sample which might be likely attributed to the high dietary fiber content in these samples. This might have enhanced the aqueous phase viscosity and reduced the tendency of scattered oil globules to migrate and coalesce, thus enhancing emulsion stability. Foam capacity was observed very low for both the powders leading to a formation of non stable foam.

Color analysis

The L*, a*, b* values of apple pomace powder determined for color estimation are shown in Table 3. In practice, a number of elements, such as the type of fruit and its maturity may affect the color, but especially the drying techniques play an important role as far color is concerned (Borchani et al. 2011). The color of apple

pomace can be used to determine chemical changes during drying. The L* (lightness) values of the apple pomace powder were found at 54.15 ± 1.02 and 55.09 ± 1.05 for MWVD and OD powders. The L* value for oven-dried powder was seen more as compared to MWVD powder. L* value may be suggestive of browning events that occur during drying, according to Krokida et al. (2001), browning reactions, which occur at higher temperatures, cause a drop in lightness value (L*) and shift to increased redness. Thus, the color of MWVD powder was seen darker than OD powder. Enzymatic browning is more responsible for the development of redness and yellowness in the samples than non-enzymatic browning, as is evident from the lower values of a* and b* for pomaces dried in OD compared to pomace dried in MWVD. The perceived color is represented by the hue angle, which is 0° for red, 90° for yellow, 180° for green, and 270° for blue. The Chroma value goes from 0 (neutral grey, black, or white) to 100 for very high chroma (or color purity). As apparent from the table a difference was seen in hue angle between the two powders, however, the OD powder had a modest increase in hue angle. The hue angle for MWVD powder was 79.69 ± 1.13°, whereas the hue value for OD powder was 81.27 ± 1.17°, indicating a red-to-yellow tint. Chroma values ranged from 39.28 ± 1.08 for MWVD powder to 37.68 ± 1.05 for OD powder, indicating low color saturation.

Particle size analysis of powder

The structural–functional relationship of polymers in solution requires an understanding of their molecular size distribution. The surface characteristics of apple pomace are influenced by particle size. Particle size exhibits a stronger impact on fat binding capacity and emulsifying qualities of pomace powder (Grover et al. 2003).The particle sizes of MWVD and OD powder are displayed in Table 4. MWVD and OD powder particles have hydrodynamic particle sizes of 4451 nm and 2692 nm, respectively. The polydispersity index (PDI) for MWVD powder particles was reported to be 29%, while it was 25% for OD powder particles. The particle size of OD powder has decreased significantly, which might be due to powder particle breakdown or breakage produced by high drying temperature and longer drying time as Guillon and Champ (2000) claim that the nature of cell walls and the technological interventions (degree of grinding, thermal treatment, etc.) affect the particle size distribution. The polydispersity index (PDI) is a measurement of particle size distribution; a higher PDI indicates a wider size distribution, which could include aggregates or big particles (Ahmad & Gani 2021). The polydispersity index value of OD powder particles was seen low, indicating a significantly smaller size distribution. As a result of the higher temperatures, the particles dried were smaller and more rounded. It is possible because the pomace that had been dried at a higher temperature was more delicate and hence more easily cracked during the grinding process. Larger particle size may be an important feature in improving the quality characteristics of some food commodities. In one of the studies, it was revealed that the apple pomace with the largest particle size produced cookies that were less firm and had a larger spread ratio, both of which are desirable characteristics (Rocha Parra et al. 2019).

Table 4 Particle size and polydispersity index of MWVD and OD powder samples

Sample	Hydrodynamic diameter (nm)	Polydispersity index (%)
MWVD	4451 ± 76^{b}	29 ± 1^{b}
OD	2692 ± 49^{a}	25 ± 2^{a}

Table shows mean values with standard deviations of the mean (the results were averaged over three measurements), a and b superscript letters in the same column indicate significant differences between samples ($p < 0.05$)

X-Ray analysis of powder

X-ray diffraction is a technique used to obtain information about the molecular structure of a substance (crystalline or non-crystalline). X-ray diffraction is a well-established method for studying crystal lattice configurations and provides valuable information on sample crystallinity (Bourbon et al. 2011). Similarly, XRD analysis was used to determine how different drying processes affected crystallinity. The x-ray diffraction pattern of both microwave-assisted vacuum and oven-dried powder is shown in Fig. 2.

X-ray diffractograms of both powders showed a semi-crystalline pattern with an amorphous broad hump and crystalline peaks. The x-ray diffraction patterns of the MWVD and OD powder showed the diffractive peak in the region from $2\theta = 5°$ to 80° with MWVD showing the maximum intensity of about 1210.1 counts at $2\theta = 21.6°$. The OD powder showed the peaks with the highest intensity of about 1304 counts at $2\theta = 21.4°$. Microwave treatment without heating led to an increase in the crystallization of glass ceramics as compared to conventional heating. In the influence of the microwave field, many metals precipitate which leads to many crystal nuclei (Li et al. 2020). According to Roncero et al. 2005, the intensity peak for crystalline materials is maximum at a 2θ angle between 22 and 23, while for amorphous materials it is between 18 and 19. From the data, it is evident that during the processing, a slight loss of crystallinity

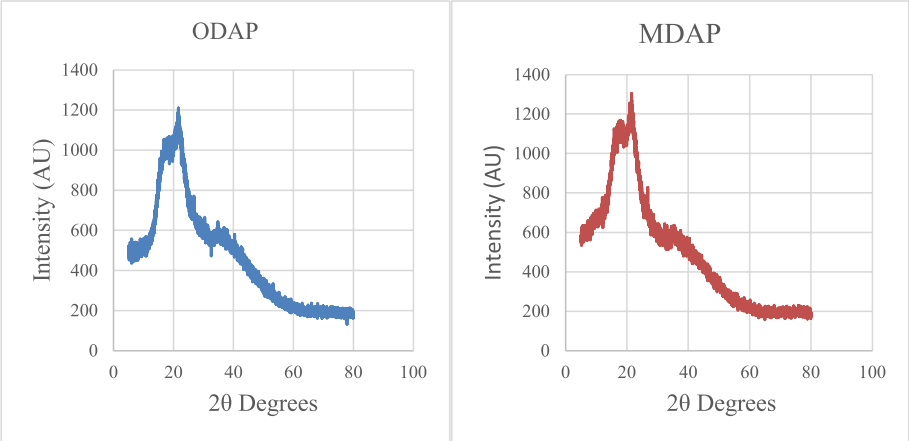

Fig. 2 X-ray diffraction pattern of oven-dried (ODAP) and microwave dried powder (MDAP)

occurred in OD powder. It is possible that subjecting the molecule to the harsh circumstances experienced during drying causes a change in the molecule lattice, irregularly exposing part of the components, resulting in the loss of an ordered structure, which would otherwise have a little higher crystallinity (Palacio-Lopez et al. 2020). The semi-crystalline nature of pomace powders indicates the presence of less crystalline cellulose, which may be due to the presence of high content of hemicelluloses and lignin (Chen et al. 2011; Zain et al. 2014).

Scanning Electron Microscopy (SEM)

SEM is a type of surface imaging method that provides information about surface topography and structure. Scanning electron microscopy analyzes differences in size and shape of intercellular and cellular spaces, as well as structural changes, that occur when the food is processed, using microscopic techniques (Alzamora et al. 1997). Food's physical qualities are closely related to its microscopic structure (Tortoe & Orchard 2006). Scanning electron micrographs at varying magnifications of both apple pomace powders are depicted in Fig. 3. Apple pomace is seen as having a porous and fibrous nature. This might be due to the presence of hemicelluloses and fibers in the peel and flesh (Liu et al. 2021; Naqash et al. 2021; Skinner et al. 2018). Both types of powders have an uneven finish, with distorted and deformed surfaces. As depicted from SEM pictures, it can be observed that drying resulted in structural alterations in the powders. The MWVD dried sample granules were more irregular than the OD sample granules and showed more cracks and micropores, resulting in changes in surface area. This might be due to the leaching out of more phenolics from the bonded structure. Similar results were shown by Lohani & Muthukumarappan 2014, also this was following the findings of research by Giri & Prasad 2007 for mushrooms. As for OD powder particles, there was seen greater retention of the basic matrix in apple pomace. The variation in microstructures of dried samples could be attributed to the fact that the lower temperature under vacuum and the shorter microwave drying time caused accelerated removal of moisture, resulting in a hasty fluid flow that helps prevent compression and case-hardening. This results in a substantial puffing effect during microwave vacuum drying when compared to hot air drying. Similar results were recorded by Han et al. 2010 for apple slices. The severity of drying conditions might have led to particle deformation and cellular structural changes in powder samples. The same was depicted by Sargent 1988; Tortoe & Orchard 2006 for apples and bananas, respectively, concluding that dehydration caused the movement of water and deformation of the pectin, hemicellulose, and cellulose of the cell structure plasma membrane and middle lamella, resulting in the collapse of the cell and plasmolyzed cells. A study also showed that the level of cell wall collapse during drying is proportional to the amount of water lost during the drying process (Zogzas et al. 1994). This is comparable to what Mavis et al. 2014 found in a study on the structure of oven dried tomatoes. The SEM images make it abundantly evident that drying temperature has a significant impact on particle structure. The rate of drying as well as the rate of a number of other reactions, which are regulated by the amount of water and drying temperature, may be the cause of the changes in the size and form of the particles (Afrin et al. 2021).

Antioxidant activity

Apple polyphenols have a variety of pharmacological actions, including antibacterial and antiviral activity (Bai

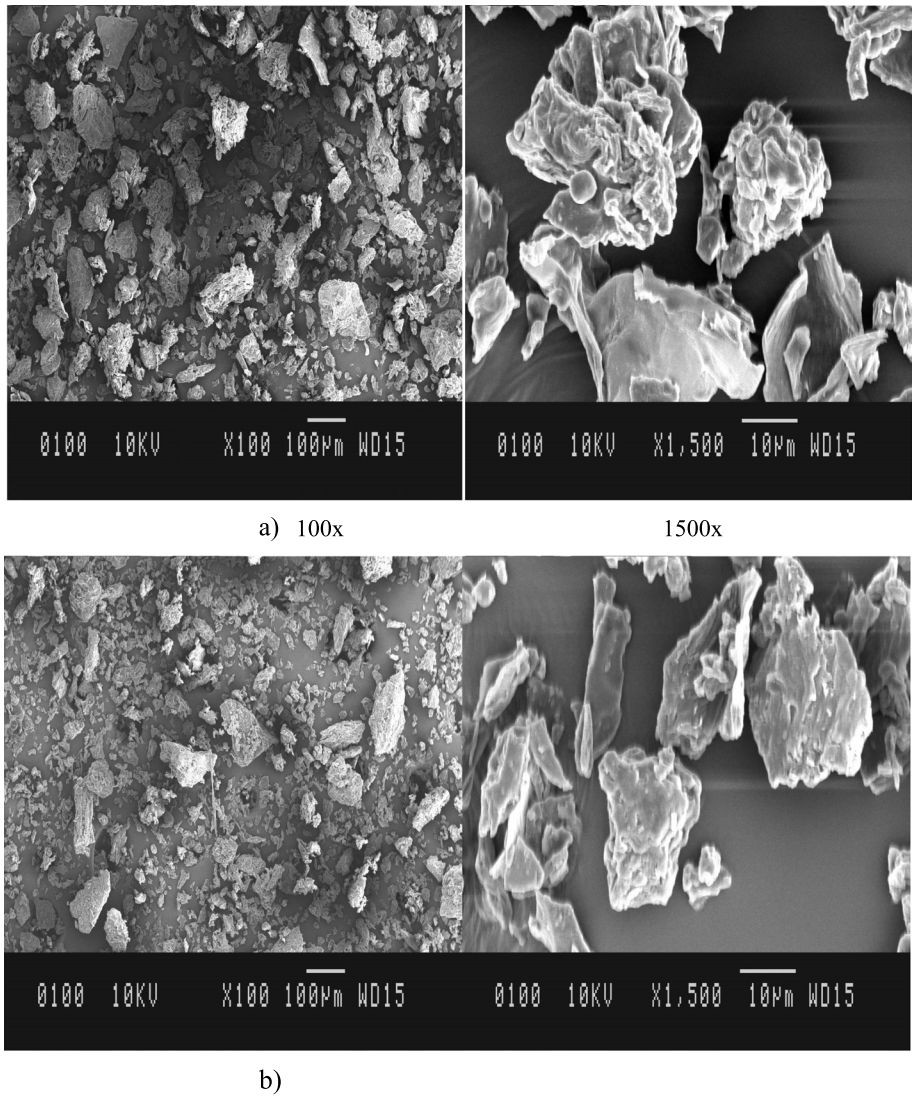

Fig. 3 SEM images of MWD (**a**) and OD (**b**) powder at 100 × and 1500 × magnification power

et al. 2013). Their main medicinal value, however, comes from the antioxidant and antiradical action, which is because of the specific chemical structure of polyphenols. Each phenolic acid is made up of a single aromatic ring connected by hydroxyl and carboxyl residues. They can neutralize reactive oxygen species (ROS), reduce transition metals responsible for Fenton's reaction and reduce oxidative stress by acting as a hydrogen atom or single electron donor. Antiradical activity refers to a compound's ability to scavenge free radicals, whereas antioxidant activity refers to the ability to suppress the oxidation process (Spiegel et al. 2020).These polyphenols are thought to alter food products' organoleptic features, such as color, flavor, and odor, as well as their antioxidant potential (Perussello et al. 2017; Rana et al. 2015). According to numerous studies, adding AP to food formulations increases AO activity, avoiding or delaying oxidative change, such as lipid oxidation in the food product (Gorjanović et al. 2020).

Total phenolic content

Phenolic acids are naturally occurring chemicals with antioxidative and antiradical properties. The Folin-Ciocalteu method was used to evaluate the total phenolic content of pomace powders, which is based on electron transfer from the phenolic component to the Folin-Ciocalteu reagent in an alkaline medium. Phenolic content determination is one of the most essential aspects of determining antioxidant capabilities.

Table 5 Total phenolic content and antioxidant activity

Parameters	Microwave Dried	Oven Dried
Total phenolic content (mgGAE/g)	5.21 ± 0.09^{b}	3.14 ± 0.06^{a}
DPPH scavenging activity (%)	93 ± 1^{b}	89 ± 1^{a}
FRAP assay (mgTEAC/g)	3.22 ± 0.04^{b}	2.22 ± 0.02^{a}
Vitamin C (mg/100 g)	20.00 ± 0.12^{b}	12.53 ± 0.08^{a}

Table shows mean values with standard deviations of the mean (the results were averaged over three measurements)

a and b superscript letters in the same row indicate significant differences between samples ($p < 0.05$)

The total phenolic content (TPC) of microwave dried powder was recorded as 5.21 ± 0.09 mg GAE/g, while oven-dried powder showed a significantly lower value of 3.14 ± 0.06 mg GAE/g, as shown in Table 5. Because of the less rigorous drying conditions, more phenolic components were released and retained in the microwave dried powder and there was seen a loss of TPC in oven drying due to the thermal degradation of phenolic compounds. Polyphenolic compounds are known to breakdown at high temperatures, especially when they are unbound and in high moisture environments (Sadilova et al. 2007). The rate of degradation varies depending on the product, and some phenolic compounds are seen as more heat resistant than others. Thus, a higher drying temperature leads to a low TPC value in OD.As per several studies, there is seen a link between phenolic content and antioxidant capacity (Candrawinata et al. 2015; Kim et al. 2003). With the increasing value of phenolic content, the antioxidant activity also increases. So a higher value of TPC in MWVD might lead to the enhanced antioxidant activity of the same. The polyphenols that give apples their antioxidant action are still present in the pomace and can be easily extracted for food fortification or the development of nutraceutical products (Bhushan et al. 2008).

DPPH assay

The antiradical activity of both powders was estimated using the DPPH radical scavenging method, which is one of the most practical methods for determining antioxidant activity. DPPH is widely used to assess a compound's potential to operate as a free radical scavenger or hydrogen donor, as well as to assess antioxidant activity in liquids and food samples. DPPH is a violet-colored stable free radical, changing color from violet to pale yellow or colorless if free radicals have been scavenged and provide visual monitoring at 517 nm. Microwave-dried powder showed a scavenging activity of $93 \pm 1\%$, whereas oven-dried powder showed an activity of $89 \pm 1\%$ which may be due to more polyphenols. The temperature and drying time significantly affected antioxidant activity and a higher level of TPC leads to higher antioxidant activity. Abd El-Baky et al. 2011, also found that the DPPH radical scavenging activity of algal extracts varied based on the particular phenolic content, with the highest DPPH radical scavenging activity in samples rich in phenolic compounds.

FRAP value

The reduction of the ferric tripyridyl-s-triazine complex to ferrous colored form in the presence of antioxidants is the basis for this assay. The antioxidants in the samples decrease the ferric tripyridyl-s-triazine complex to generate a blue-colored complex, increasing the absorbance at 593 nm. The ability of a material to transport electrons is related to its reducing power, which can be used to predict its potential antioxidant activity. Microwave dried powder showed a higher FRAP value of 3.22 ± 0.04 mgTEAC/g, whereas oven-dried powder had a FRAP value of 2.22 ± 0.02 mgTEAC/g.

Based on the TPC, DPPH and FRAP values as given in Table 5, it is evident that the microwave dried powder has higher antioxidant activity than oven-dried powder, and showed more retention of phenolic groups. There was a degradation of phenolic compounds, heat-sensitive bioactive chemicals and hence decreased antioxidant activity due to the severe drying conditions and higher temperature in oven drying. Studies have shown that high temperatures can cause phenolic compounds to degrade, and decrease in antioxidant capacity (Candrawinata et al. 2014). As a result, the drying temperature had a significant impact on antioxidant activity. Vardin and Yılmaz (2017) found a similar tendency in dried pomegranate arils. Apart from improving the functional and physicochemical qualities and enhancing the antioxidant activity of AP powder, MWVD reduced drying time by around 87% compared to oven drying.

Vitamin C content

Vitamin C is an antioxidant that is non-enzymatic and is effective in scavenging reactive oxygen species (ROS). Apples are thought to have less vitamin C content than other fruits. When total antioxidant activity contributed by vitamin C is taken into account, apples (97.23 mol of vitamin C equivalents/g) come in second to cranberries (176.98 mol of vitamin C equivalents/g) (Skinner et al. 2018; Sun et al. 2002). The strong bioactivity of apples has been proven to have an antiproliferative effect on cancer cells (Sun et al. 2002). Apple pomace has been found to have 22.4 mg of vitamin C per 100 g, indicating that it could be a good source of antioxidant chemicals (Pieszka et al. 2015). In the

current studies, for microwave dried powder the vitamin C content was reported as 20 mg per 100 g. For oven-dried powder, the value was 12.5 mg of vitamin C per 100 g. As there is a higher temperature and drying period in OD, the amount of ascorbic acid in the OD powder decreased significantly. Because vitamin C is susceptible to both heat and oxidation, its degradation could be ascribed to thermal damage and oxidation during drying (Akdaş & Başlar 2015). Similarly, at greater drying temperatures, Ong and Law (2011) discovered a significant decline in the vitamin C content of salak fruit.

Conclusion

Apple pomace is high in micro and macronutrients, dietary fiber, and polyphenols, all of which are beneficial to human health. The application of two drying methods for the preparation of apple pomace powder played a significant effect in enhancing physicochemical attributes, functional properties and antioxidant activities in AP powder. MWVD AP showed enhanced functional properties like water holding capacity, oil holding capacity, swelling power, foam and emulsion capacity, and stability compared to oven dried pomace. MWVD AP has a high level of carbohydrates, protein, antioxidant activity due to the polyphenols and maintained more polyphenolic compounds than OD, resulting in higher TPC, DPPH, and FRAP values. Microstructural investigation revealed MWV drying generated more cell collapse and disruption, which resulted in phenolic being released from the bonded structure. Microwave-vacuum drying of apple pomace was significantly faster than traditional hot-air oven drying, resulting in quality powder, saving both time and energy. With these high levels of AA and radical-scavenging activity, it may be possible to avoid oxidative stress and as a result, chronic illness when incorporated into food products. The retention of nutrients in the microwave dried apple pomace powder may be helpful in the bioconversion of this waste to produce valuable products through microbial technology and to extract valuable compounds from it.

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Authors' contributions
Iqra Mohiuddin Bhat: Manuscript writing, Methodology, Original research. Shoib Mohmad Wani: Conceptualization,Original research, Review and Editing, Supervision. Sajad Ahmad Mir: Review and Editing, Supervision, Conceptualization. Zahida Naseem: Original Research, Editing. The author(s) read and approved the final manuscript.

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Availability of data and materials
The data regarding this study is available and can be produced on proper request to the corresponding author.

Declarations

Ethical approval and Consent to publish
Not applicable.

Competing interest
The authors declare that they do not have financial or competing interests which may affect the publication of this study.

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