

# A study on red potato peel (*Solanum tuberosum* L. cv. Red Holland): characterization, composition and formulation of tablet using different drying techniques

Divya Tripathi<sup>1</sup> · Muskan Kumari<sup>1</sup> ·  
Anil Kumar Chauhan<sup>1</sup>  · Dinesh Kumar<sup>2</sup> ·  
Madhukiran R. Dhondale<sup>2</sup>

Revised: 20 May 2024 / Accepted: 5 June 2024 / Published online: 17 June 2024  
© Association of Food Scientists & Technologists (India) 2024

**Abstract** Potato peels are one of the most under-utilized wastes which can be highly beneficial to mankind. The red potato peel powder was prepared by using tray drying and vacuum-oven drying method. The proximate analysis of red potato peel powder was conducted followed by its characterization which includes FT-IR, XRD, TGA, DSC, and SEM. Bioactive compounds were then extracted from the peel using ultrasound-assisted extraction. The qualitative estimation for tray-dried potato peel powder and vacuum-oven potato peel powder suggested that the drying techniques have a substantial effect on the bioactive compounds. The values obtained for total phenolic content (TPC), total flavonoid content (TFC) and DPPH for both samples showed that red potato peel powder is a rich source of antioxidants. The pre-compression properties results indicated that neither of the potato peel powders exhibited ‘Excellent’ flow characteristics. However, the addition of croscarmellose sodium improved the flow characteristics, making it feasible to create a tablet from the peel itself. This study highlights the potential of potato peels, a waste product, as a source of valuable bioactive compounds. Thus, it can be utilized in formulation of functional foods and nutraceuticals;

promoting sustainability and value addition in the food processing industry.

**Keywords** Potato Peel · Polyphenols · Antioxidant · Pre-compression properties · Physical properties

## Abbreviations

AOAC	Association of official analytical chemists
CQA	Caffeoyl feruloyl quinic acid
DPPH	2,2-Diphenyl-1-picrylhydrazyl (antioxidant assay)
DSC	Differential scanning calorimetry
FTIR	Fourier transform infrared
H-ESI	High-resolution electrospray ionization
HPLC	High-performance liquid chromatography
HRMS	High-resolution mass spectrometry
PPE	Potato peel extract
PPP	Potato peel powder
SEM	Scanning electron microscopy
TAC	Total anthocyanin content
TFC	Total flavonoid content
TGA	Thermogravimetric analysis
TPC	Total phenolic content
TPPP	Tray-dried potato peel powder
VPPP	Vacuum oven-dried potato peel powder
XRD	X-ray diffraction
TPP-CS	Tray-dried potato peel granule along with croscarmellose sodium
VPP-CS	Vacuum oven-dried potato peel granule along with croscarmellose sodium

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s13197-024-06015-y>.

✉ Anil Kumar Chauhan  
anilchauhancfst@gmail.com; achauhan@bhu.ac.in

<sup>1</sup> Department of Dairy Science and Food Technology,  
Institute of Agricultural Sciences, Banaras Hindu University,  
Varanasi, U.P. 221005, India

<sup>2</sup> Department of Pharmaceutical Engineering and Technology,  
Indian Institute of Technology (BHU), Varanasi,  
U.P. 221005, India

## Introduction

The food processing industry is a major global sector; however, it generates a significant amount of organic waste that must be appropriately managed to avoid environmental contamination and to stimulate economic growth using byproducts. This waste can be used as a starting material to produce economically significant substances, value addition, and product extraction, such as dietary fibre, biopolymers, natural antioxidants, and natural food additives.

Annually, the food sector generates a substantial amount of waste from potato peels. It is estimated that the industry produces between 70,000 and 140,000 tons of this waste each year (Sampaio et al. 2020). It is estimated that around 8000 kilotons of potato peel waste might be generated by the year of 2030 (Khanal et al. 2023). Currently, potato peels are primarily used for low-value applications such as animal feed, fertilizer, or biogas production. However, this approach leads to the loss of many beneficial components that possess antioxidant, antimicrobial, apoptotic, or anti-inflammatory properties.

Studies show that potato peel has a high content of dietary fibre, protein, carbohydrates, mineral matters, vitamins, phenolic, and antioxidants (Yuksel and Durmaz 2022). The bioactive compounds found in potato peels (PP) is found to possess antioxidant properties, bactericidal and bacteriostatic properties that can be beneficial to human health. Additionally, potato peel has been utilized to make several by-products such as lactic acid, bioplastic, bio composites, and nanocrystals (Awogbemi et al. 2022). The concentration of phenolic compounds in potato skin is higher as compared to nearby tissues (potato flesh) and decreases as one moves towards the middle of the potato flesh or tuber. The most prevalent phenolic chemicals in potato peel are phenolic acids, along with anthocyanins (Singh et al. 2020). The content of chlorogenic acid was found to be highest among the phenolic acid. Low amounts of gallic acid (GAC), caffeic acid (CFA) and protocatechuic acid have also been found (Samarin et al. 2012). The findings by Singh et al. (2005) suggests that potato peel might be successfully employed as an ingredient in healthy and functional foods to treat specific diseases, like diabetes.

Consequently, it is crucial to explore more efficient methods to utilize potato peels and fully harness their potential (Liang and McDonald 2014). In this study, we carried out a detailed study on red potato peel. We examined the composition, structural characterisation, antioxidant potential and flow properties of red potato peel prepared by two different drying techniques. The impact of granulation on the flow properties of both the potato peel powder were also analysed followed by tablet making process.

## Material and methods

### Preparation of potato peel powder

The powder was prepared from the same methodology followed by (Brahmi et al. 2022; Hossain et al. 2016) with slight modifications. The variety of potato which is used in this experiment is Red Holland (*Solanum tuberosum L. cv. Red Holland*). Washed and cleaned potato peels were placed on a stainless-steel plate followed by peeling. Once the peels were collected, drying was conducted. Two different drying methods were used for the preparation of the peel powder i.e., Tray Drying and Vacuum-oven drying. The temperature used for tray drying and vacuum-oven drying was 45 °C for 16 h and 70 °C for 13 h, respectively. The dried peels were ground using a grinder machine at maximum speed after which it was sieved using a stainless sieve to obtain a fine powder. The remaining coarse peels were ground again. The powder of red potato peels was packed in LDPE pouches and stored at 20 °C for further analysis.

### Proximate analysis of red potato peel powder

Proximate composition of dried potato peels was determined using the following AOAC (2000) methods: moisture, ash, Fat, crude fibre, and protein. The protein was calculated as  $N \times 6.25$ . A total carbohydrate was calculated by difference.

### Characterization of red potato peel powder

#### *Fourier transform infrared spectroscopy (FTIR)*

The method used was described by (Liang and McDonald 2014). A small amount of PPP was taken and was placed on the sensor sterilized by alcohol. The reading was taken from 4000 to 400  $\text{cm}^{-1}$  wavelengths.

#### *Thermogravimetric analysis (TGA)*

The specimen was first put in an aluminum pan on the platinum basket in the chamber, which was then heated from ambient temperature to 700 °C at a continuous rate of 10 °C/min in a nitrogen environment.

#### *Differential scan calorimetry (DSC)*

The Differential Scan Calorimetry (STAR SW 10,000 Instrument) was carried out under nitrogen atmosphere and

was used to understand the physical state and nature of the sample.

#### Scanning electron microscopy (SEM)

The microstructure of red potato peel was studied by using the scanning electron microscope (Zeiss SUPRA-40 model, Carl Zeiss AG, Germany). The images of SEM were obtained at a magnification of 500X and 100X at scale bars of 10  $\mu\text{m}$  and 20  $\mu\text{m}$ , respectively. The accelerated voltage used for the image was 15.00 and 20.00 kV.

#### X-ray diffraction (XRD)

The X-ray diffraction of red potato peel powder was done to study its crystalline form using X-ray diffractometer (Rigaku Smart Lab 9 kW Powder type, Rigaku Corporation, Japan). The analysis was conducted at room temperature with Cu  $\alpha$  with a wavelength of 0.154 nm. The range of angular region was  $20^\circ$ – $100^\circ$ .

#### Determination of water activity (Aw)

The Aw of the red potato peel powder (PPP) was determined using a water activity meter (Aqualab, 4TE, Decagon Devices Inc., Pullman, WA). All measurements were performed in triplicate.

#### Extraction of polyphenols from red potato peel

The extraction of polyphenols from red potato peel was done by adopting the method of (Ansari and Goomer 2020) with a slight change in the procedure. 10 g of grounded peel powder was mixed in 100 mL of 80% ethanol. An ultrasonic probe was immersed at 2 cm into the solution. The experimental conditions used for the extraction were: 100W with pulse cycle of 1 s (0.6 s of power discharge and pause of 0.4 s) for 15 min. The solute–solvent mixture was filtered using muslin cloth and then subjected to centrifugation for 10 min at 3000 rpm. The supernatant was separated from the residue and again filtered using muslin cloth.

#### Quantitative analysis of red potato peel extract

##### Determination of total phenolic content

The total phenolic content was determined using the methods described by (Zhang et al. 2016) with slight modifications. The 0.1 mL of red potato peel extract (PPE) was taken in triplicate. Then, 0.6 mL of Folin–Ciocalteu reagent was added to PPE and kept for incubation (5 min). After incubation, 1.5 mL of 20% sodium bicarbonate and 5 mL of distilled water were added. The solution was shaken well

and incubated in dark at room temperature for 30 min. The absorbance of the solution was taken at 765 nm. The results of Total phenolic content were expressed as mg GAE/g.

##### Evaluation of total flavonoid content

The  $\text{AlCl}_3$  colorimetric method was used to evaluate the total flavonoid content described by (Zhang et al. 2016) with slight modifications. 0.2 mL of red potato peel extract (PPE) was taken in triplicate then 0.2 mL of 2%  $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$  was added to the extract and mixed properly. The solution was kept for incubation in dark at room temperature for 15 min. The absorbance of the solution was measured at 430 nm. The results of total flavonoid content were expressed as mg QuE/g.

##### Determination of total anthocyanin content

The TAC was analyzed by the pH differential method (Teow et al. 2007) with minor modification. Aliquots of the samples were diluted with potassium chloride (0.025 M, pH 1.0) or sodium acetate (0.4 M, pH 4.5). The pH of the two solutions was set at 1.0 and 4.5 using concentrated hydrochloric acid prior to taking the absorbance readings at 520 nm and 700 nm. Absorbance was calculated as:  $A = (A^{520\text{nm}} - A^{700\text{nm}})_{\text{pH 1.0}} - (A^{520\text{nm}} - A^{700\text{nm}})_{\text{pH 4.5}}$ . The total anthocyanin content was calculated using the Eq. (1) below:

$$C = (A/eL) \times M \times D \times (V/W) \times 100 \quad (1)$$

where C is the total anthocyanin content, A is the absorbance, e is the molar absorbance of cyanidin 3-glucoside (26,900 L/cm/mol), L is the cell path length (1 cm), M is the molecular weight of cyanidin 3-glucoside (449.2 g/mol), D is the dilution factor, V is the final volume (mL), and W is sample weight (mg). The TAC was expressed as milligrams of cyanidin 3- glucoside equivalents per 100 g dry weight (mg CGE/100 g DW).

##### Evaluation of DPPH

##### (2,2-diphenyl-1-picryl-hydrazyl-hydrate) scavenging activity

The scavenging ability assay was done by adopting the methods of (Zhang et al. 2016) with slight modifications. 0.4 mL of different concentrations of the extract were taken in triplicate then it was mixed with 0.8 mL of 0.15 mM of DPPH solution. Then, the solution was incubated in dark for 30 min. The absorbance was taken at 515 nm. The per cent radical scavenging ability was calculated by using Eq. (2) as follows:

$$\text{Radicalscavenging ability(\%)} = \frac{A_c - (A_s - A_b)}{A_c} \times 100 \quad (2)$$

where  $A_c$ : Absorbance of Control;  $A_s$ : Absorbance of Sample;  $A_b$ : Absorbance of Blank Ascorbic acid was used as a positive control.

#### High-performance liquid chromatography-high resolution mass spectrometry (HPLC-HRMS) analysis

HPLC-HRMS analysis of extracts was analysed using an Orbitrap Eclipse Tribrid Mass Spectrometer (COMPOUND DISCOVERER 3.3.2.31, Thermo Fisher Scientific, USA) at SAATHI Lab, Varanasi. HPLC was used to separate small molecules chromatographically. Here, a three-solvent system was used as the mobile phase: Solvent A was water with 0.1% formic acid; Solvent B was 100% acetonitrile with 0.1% formic acid; and Solvent C was 100% methanol with 0.1% formic acid. The metabolites were separated using a GOLD C<sub>18</sub> selectivity HPLC column (inner diameter 2.1 mm, length 100 mm and particle size 1.9 μm). The injection volume was 5 μl, the run time was 30 min., and the flow rate was 0.3 ml/min. The column outlet was connected to a mass spectrometer via H-ESI (electrospray ionization). Both negative and positive modes of H-ESI were used to ionize the compounds that were channelized using Orbitrap. For the identification of compounds present in the extract, the MS spectra for the analysed samples were compared to those from the Predicted Compositions, mz Cloud Search, Chem Spider Search, and Mass List Search databases.

#### Colour analysis

Hunter Lab Color Flex EZ model was used for calculating L-a-b values which was calibrated first using a white tile followed by black tile. It measures colour using a Three-dimensional scale, such as CIE L\*a\*b\*, which has been developed to objectively quantify colour values. All visible colours can be quantified within this 3-D rectangular space.

#### Pre-compression properties

##### Bulk density

Bulk density was analyzed according to (Sahin-Nadeem et al. 2013) method. 2 g powder was loosely weighed into 10 mL graduated cylinder (rest on flat surface) and the change in volume was recorded. Bulk density of the powder was calculated by using Eq. (3), mentioned below:

$$\rho_B = \frac{\text{Weight of Powder}}{\text{Volume of Powder}} \quad (3)$$

##### Tapped density

The tapped density of the samples was analyzed according to Özdikicierler et al. (2014) by placing 20 g of powder in a 100 ml graduated cylinder and measuring the volume after the sample was gently tapped 1250 times using bulk density apparatus (IK-521, Ikon Instruments, India). Tap density of the powder was calculated by using Eq. (4).

$$\rho_T = \frac{\text{Weight of Powder}}{\text{Tapped Volume of Powder}} \quad (4)$$

##### Hausner index

Hausner's Ratio is an indirect index of ease of powder flow. It is calculated by using Eq. (5):

$$\text{Hausner Index} = \frac{\rho_T}{\rho_B} \quad (5)$$

where  $\rho_T$ : Tapped Density;  $\rho_B$ : Bulk Density.

##### Carr's index/compressibility index

The compressibility index (Carr's Index) of all formulations and powders were determined by using the below mentioned Eq. (6):

$$\text{Carr's Index} = \frac{\rho_T - \rho_B}{\rho_T} \quad (6)$$

where  $\rho_T$ : Tapped Density;  $\rho_B$ : Bulk Density.

##### Angle of repose

The funnel method was utilized to calculate the angle of repose. Granules that were precisely weighted were placed within the funnel. The funnel's height was modified such that the tip could come into contact with the powder blend's apex. The final few bland grains were let to fall down the funnel tip and onto the graph paper surface. The powder cone's diameter was measured, and the angle of repose was computed using the Eq. (7) below:

$$\theta = \tan^{-1} h/r \quad (7)$$

where h = Height; r = Radius.

#### Preparation of granules for tablet

##### Wet granulation method

Wet granulation was done according to the methods used by (Venkatesh, 2014) with a little modification. Each potato peel powder was mixed with 3% croscarmellose

sodium using the geometric dilution method. Water was then added into the mixture powders until a damp mass occurred, and further sieving was done using 18-mesh sieve to form granules. The drying of granules were carried out using hot air oven at 60 °C for 5–6 h. Pre-compression properties were also analyzed for these granules.

### Compression

The dried granules were mixed with 1% magnesium stearate which acted as a lubricant followed by sieving through a 20-mesh sieve and then mixing was done for 3 min. Then, the tablets were formed by compression with the help of single punch tableting machine.

### Post-compression properties

After tablet preparation the batch was sent for evaluation of physical property of tablet.

#### Diameter and thickness

Both diameter and Thickness were determined by (TBH 310 MD), Erweka Tablet Hardness Tester, Heusenstamm, Germany.

#### Hardness

The hardness of the tablet was analyzed by (TBH 310 MD), Erweka Tablet Hardness Tester, Heusenstamm, Germany. Random selection of three tablets from each batch was done and the average hardness was noted.

#### Friability

The test was done using HMK Tablet 1601 friabilator, Dandong Hmktest Instrument Co.,Ltd, China. The rotation speed was kept at  $5 \pm 1$  revolution/minute, timings at 9:59:59 min. Ten pre-weighted tablets were allowed to fall within six

inches of the rotating drum surface while the drum was rotating. Tablets were dust after the rotation cycle, and the weight was recorded once more.

### Statistical analysis

The statistical analysis was carried out using single-factor analysis of variance (ANOVA) with a level of confidence of 95%. Multiple comparison test was applied to differentiate among the means of different attributes and expressed as statistically significant at  $p < 0.05$ .

## Results and Discussion

### Drying of red potato peel

The results obtained from the drying of potato peels is shown in Table 1. During the initial stage, the moisture removal rate was high as it evaporated freely. However, as the time increased, the rate of moisture removal slows down because of reduction in the moisture content of the peel with the remaining water becoming more tightly bonded as its amount decreases. When comparing the two studied drying processes, it was quite clear that vacuum drying took a shorter time in comparison to tray drying and which might be because of the usage of higher temperatures in the case of vacuum oven drying.

### Proximate analysis

The results are shown in Table 1. This difference may be because of usage of different drying methods. These findings concur that the drying process can change the potato peel's chemical composition.

### Characterization of potato peel powder

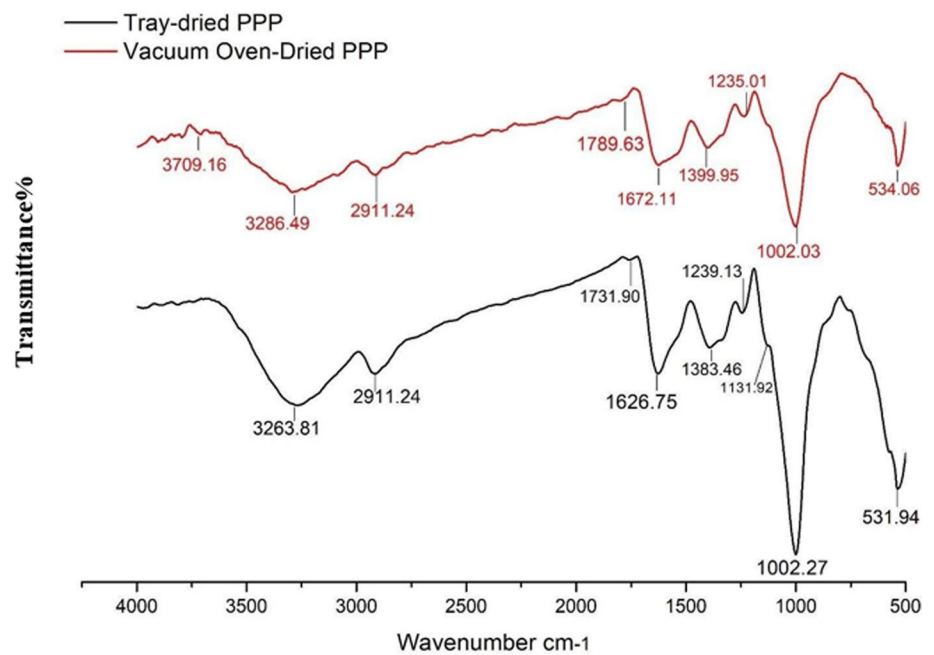
FTIR spectroscopy was employed to analyse different functional group in both the samples, as shown in Fig. 1.

**Table 1** Effect of drying on potato peels

Drying method	Temperature	Time (h)	Initial weight (g)	Final weight (g)	Loss in moisture (%)	Water activity at 25 °C
Tray Drying	45 °C	16	100.04	17.92	88.43%	0.6464 ± 0.13
Vacuum Drying	70 °C	13	52.91	7.10	86.58%	0.4795 ± 0.06
Proximate analysis	Moisture %	Protein %	Fat%	Ash%	Crude fibre%	Total carbohydrate %
Tray drying	4.5 ± 0.39	0.83 ± 0.45	2.42 ± 0.41	14.63 ± 0.23	15.34 ± 0.12	52.93
Vacuum drying	4.3 ± 0.88	0.99 ± 0.27	1.81 ± 0.22	13.82 ± 0.10	15.74 ± 0.32	54.78

\*Values are demonstrated as Mean ± Standard Deviation for triplicate samples

**Fig. 1** Graph of FTIR spectroscopy showing different peaks of tray-dried and vacuum oven-dried potato peel powder



There was a broad absorption of different wavenumbers in the range of  $3500\text{--}3100\text{ cm}^{-1}$  which was found in TPPP and VPPP, which confirms the presence of a hydrogen-bonded O–H stretching band. Liang and McDonald (2014) also reported similar absorption bands at  $3329\text{ cm}^{-1}$ . However, the absorption band was wider in the case of TPPP as compared to VPPP.

The C–H stretching vibration showed a peak at a frequency of  $2911.24\text{ cm}^{-1}$  in TPPP as well as in VPPP. Bouhadjra et al. (2021) also reported similar absorption bands between  $2960$  and  $2850\text{ cm}^{-1}$ .

The absorption band at  $1731.90\text{ cm}^{-1}$  was found in TPPP whereas in VPPP it was observed at a frequency of  $1789.63\text{ cm}^{-1}$  which may be because of presence of ester bands for fatty acid, hydroxy fatty acid, and diacids in lipids.

At a frequency of  $1002.27\text{ cm}^{-1}$ , a sharp absorption band was observed in TPPP. In case of VPPP, a less sharp absorption band was observed at a frequency of  $1002.03\text{ cm}^{-1}$ . These bands may be because of the presence of C–O–C vibrations of pyranose sugar rings (carbohydrates) which corresponds from  $1200$  to  $900\text{ cm}^{-1}$ .

### Thermogravimetric analysis of red potato peel powder

The temperature range for TGA was kept between  $20\text{ }^{\circ}\text{C}$ – $700\text{ }^{\circ}\text{C}$  at  $10\text{ }^{\circ}\text{C}/\text{min}$ . The thermogravimetric analysis can be classified into three stages. In the first stage, a reduction in the mass of potato peel was found and the reason for this was dewatering. In tray drying, first stage was found from  $32\text{ }^{\circ}\text{C}$ – $190\text{ }^{\circ}\text{C}$  whereas in vacuum-oven dried PPP it was between  $40\text{ }^{\circ}\text{C}$ – $180\text{ }^{\circ}\text{C}$ . (Liang and McDonald 2014) also observed a similar loss in weight up to  $230\text{ }^{\circ}\text{C}$ .

In the second stage, there is a sharp decline in the weight, and the reason for this can be the evaporation of volatile compounds and decomposition of hemicellulose, starch, and cellulose content of the peels. In case of tray drying, it was found between  $190\text{ }^{\circ}\text{C}$  and  $430\text{ }^{\circ}\text{C}$  whereas in vacuum-oven dried PPP it was between  $180\text{ }^{\circ}\text{C}$  and  $370\text{ }^{\circ}\text{C}$ , similar degradation was observed at  $220\text{--}370\text{ }^{\circ}\text{C}$  due to thermolysis/pyrolysis of polymers (depolymerization) by Liang and McDonald (2014).

In the final stage charr formation has occurred, and the reason for this can be the combustion of carbon content. The final stage was observed between  $350\text{ }^{\circ}\text{C}$  and  $700\text{ }^{\circ}\text{C}$  in tray-dried PPP whereas in vacuum-oven dried PPP it was between  $370\text{ }^{\circ}\text{C}$  and  $700\text{ }^{\circ}\text{C}$ .

### Differential scanning calorimetry (DSC)

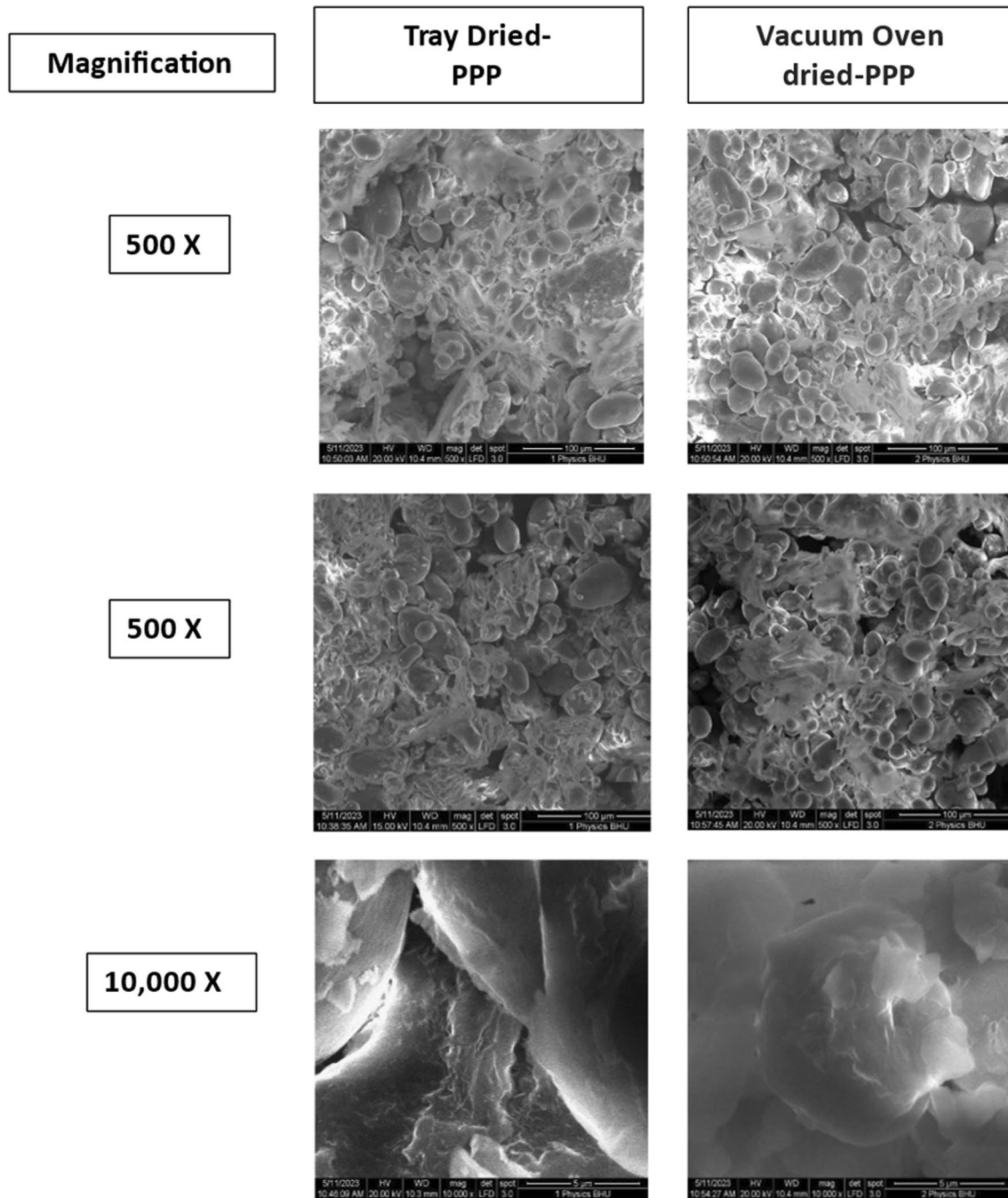
For DSC analysis, measurements were taken in the range between  $0\text{ }^{\circ}\text{C}$  and  $170$  with heating rate  $10\text{ }^{\circ}\text{C}/\text{min}$ . For TPPP, the endothermic reaction was observed between  $86\text{ }^{\circ}\text{C}$  and  $100\text{ }^{\circ}\text{C}$  whereas in VPPP, it was observed between  $92\text{ }^{\circ}\text{C}$  and  $110\text{ }^{\circ}\text{C}$ . The endothermic peak for TPPP was lower than the endothermic peak for VPPP ( $98.38\text{ }^{\circ}\text{C}$ ). These transitions are linked to the decomposition of hemicellulose and cellulose (Pardo et al. 2021). No glass transition temperature was observed.

### Scanning electron microscopy analysis (SEM)

The SEM images of potato peel powder at different magnifications is depicted in Fig. 2. The SEM analysis of potato peel powder (PPP) revealed that the particles are spherical

to oval in nature. Both the samples showed the rough and uneven surface along with voids and cracks. At 500X magnification, it was observed that presence of voids in VPPP were more prominent in contrast to TPPP. In both the samples, the particle size varied greatly. It was also revealed that tray-drying caused more damage to the particles as compared to vacuum oven drying. (Wang et al. 2020) used

ultrasound-assisted methods whose SEM images revealed some ruptured cells with large perforations which resulted due to cavitation. (Wang et al. 2020) suggested that the disruptions in the cells caused the solvent to enter the cells which further hastened the release of phenolic chemicals from the peels.



**Fig. 2** SEM images of potato peel powder (PPP) at different magnifications

### X-ray diffraction of potato peel powder

The XRD- diffractograms for both tray-dried and vacuum oven- dried potato peel powder is shown in Fig. 3. The XRD- diffractograms for both tray-dried and vacuum oven-dried potato peel powder revealed two distinct cellulose phases: amorphous and crystalline. (Daimary et al. 2022) also observed a diffraction peak in potato peel, between 18–22°, and the reason for this could be the presence of cellulose. Crystalline cellulose results in a strong XRD peak, whereas the amorphous area is attributed due to non-crystalline cellulose, hemicellulose. The peaks observed in the range of 2 $\theta$ : 27–47 is maybe due to the drying procedures.

### Quantitative analysis of potato peel powder extract

The TPC of tray-dried potato peel extract ( $18.45 \pm 0.019$  mg GAE/100 g) was higher than of vacuum oven-dried potato peel extract ( $15.30 \pm 0.013$  mg GAE/100 g). Akter et al., (2023) studied the effect of cabinet drying and sun-drying method on the total phenolic content which revealed that cabinet-potato peel flour had more TPC as compared to the sun-drying potato peel flour.

The TFC of tray-dried potato peel extract was  $0.233 \pm 0.002$  mg QE/g, whereas the TFC of vacuum oven-dried extract was found to be  $0.323 \pm 0.008$  mg QE/g. The values for TFC obtained in our study for potato peel extract were in good agreement with 0.06–2.29 mg CE/g DW obtained by Valcarcel et al. (2015) but lower than the  $1.555 \pm 0.568$  mg QE/g reported by Naqvi et al. (2020).

Makori et al. (2022) reported that the TAC in potato peel ranged from 3.61 to 94.48 mg CGE/100 g dry weight by using four varieties of potatoes.

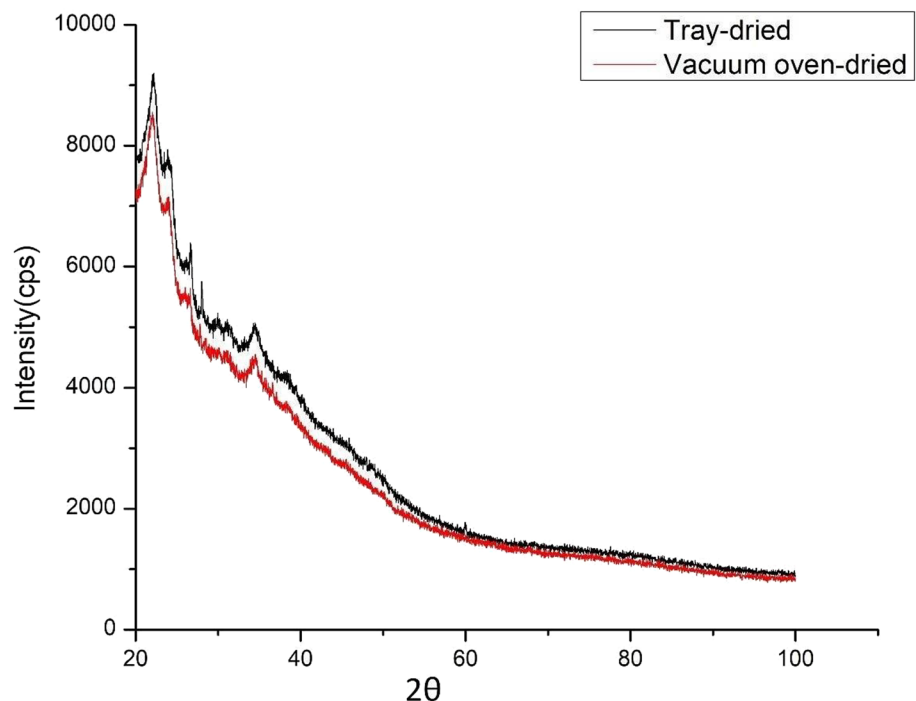
The results showed that the tray-dried and vacuum oven-dried PPP have moderate antioxidant activity. The radical scavenging activity of vacuum oven dried potato peel powder extract was 43.10%, whereas tray-dried potato peel powder extract showed a radical scavenging activity of 35.29% at 50 g/ml. The results showed that vacuum oven-dried potato peel powder extract have high antioxidant activity. Zhu et al. (2016) reported that antioxidant activity percentage of potato peel extract ranged between 36.38 to 58.62%.

The quantitative analysis demonstrates that red potato peel is a rich source of antioxidants. These properties are because of the presence of phenolic acids, flavonoids, anthocyanin, etc.

### High-performance liquid chromatography-high resolution mass spectrometer (HPLC-HRMS) analysis

In the present study HPLC-HRMS was used for qualitative purposes. In this, 2,134 metabolites were identified in tray-dried potato peel extract. The objective of the HPLC-HRMS investigation was to identify different metabolites and confirm the presence of chlorogenic acid, caffeic acid along with glycoalkaloids. The presence of caffeic acid was confirmed using high-resolution mass spectrometry in positive ionization mode. The retention time for caffeic acid was 8.481 min. Another compound was identified, using high-resolution mass spectrometry in positive ionization mode,

**Fig. 3** Diffractogram of tray-dried and vacuum oven-dried potato peel powder



having a mass spectrum  $m/z$ : 355.10373 as parent ion and base peak, and a retention time of 10.198 min, which might correspond to a CQA. Glycoalkaloids were also present and was observed using high resolution mass spectrometry in positive ionization mode; the ions at  $m/z$  868.50745 and  $m/z$  398.34314 were attributed to protonated  $\alpha$ -solanine and solanidine with a retention time of 15.041 min and 27.9 min, respectively. The HPLC-HRMS also led to the identification of flavonoids components such as rutin, quercetin and phloretin having a retention time of 14.992 min, 14.925 min and 9.892 min, respectively.

### Effect of drying on the colour of potato peel powder

The colour was analyzed by using CIE  $L^* a^* b^*$  values. The results showed that the drying method had affected the colour of potato peel powder significantly.

The  $L^*$  value of vacuum oven-dried PPP ( $60.37 \pm 0.64$ ) was low as compared to tray-dried PPP ( $64.49 \pm 0.73$ ) indicating that the vacuum oven-dried sample is darker in colour.

The  $a^*$  value of tray-dried PPP ( $5.08 \pm 0.04$ ) was lower in contrast to vacuum-oven dried PPP ( $6.32 \pm 0.07$ ) indicating that vacuum-dried powder is towards more red in nature.

The  $b^*$  value of tray-dried PPP ( $15.61 \pm 0.03$ ) was lower in contrast to vacuum-oven dried powder indicating that vacuum-dried PPP ( $20.25 \pm 0.04$ ) is yellower in nature.

The results clearly indicates that drying technique affected the colour of potato peel powder.

### Pre-compression properties

The bulk density of a sample gives a measure of its heaviness, and it is typically determined by particle size. The elimination of entrapped air from the vacuum areas led to the increase in the density of the peel powder after tapping. Flowability can be represented by Carr Index (CI) and Hausner ratio. They are used to give an indication of good and poor flowability. The angle of repose is also frequently

employed as a measure of bulk solids' flowability, which is the material's ability to flow smoothly and evenly via hoppers, silos, feeders, or conveyors. These properties were determined to assess the potential for tablet-making process. The Pre-compression properties for TPPP, VPPP, Tray-dried potato peel granule along with croscarmellose sodium (TPP-CS) and Vacuum oven-dried potato peel granule along with croscarmellose sodium (VPP-CS) are mentioned in Table 2. The pre-compression properties of TPPP and VPPP indicated that they do not possess ideal flowability properties. The pre-compression properties of TPP-CS and VPP-CS suggested that the flowability properties has been improved significantly as compared to their counterparts. Wet granulation led to the origination of granules which causes a reduction in surface area and cohesive forces thus improving flowability (Xie et al. 2012).

Schiano et al. (2018) observed that the flowability is directly proportional to size of the granules for all materials i.e. as size of granules increased, the flowability also increased. Croscarmellose sodium (used as a binder) improved the adhesion between particles which further facilitates agglomeration. Additionally, it will ensure that the tablets will be uniform in size and shape. Granulation produces large and particles which has similar diameter throughout.

### Post-compression properties

Both prepared tablets contained 300 mg of Vacuum oven-dried potato peel powder and tray-dried potato peel powder respectively.

The colour for both the samples was light brown as no other excipient was added (Fig. 4). Magnesium stearate was incorporated as lubricant so that the ejection force can be reduced which will contribute to a smooth, break-free tablet ejection. This is because it lowers the friction between the tablet and the die metal surface.

The thickness of VPP-CS was  $3.69 \pm 0.27$  mm whereas for TPP-CS it was  $3.36 \pm 0.17$  mm. The diameter of the tablet should be 8 mm or less and should not exceed 22 mm

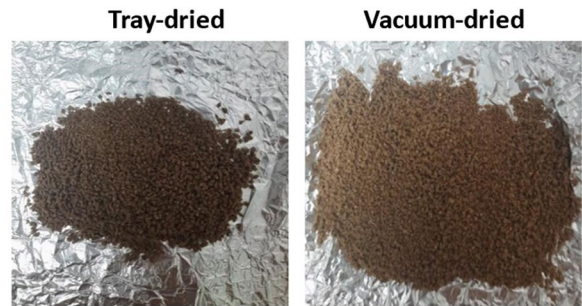
**Table 2** Pre-compression properties of powders and granules

Properties	TPPP	VPPP	TPP-CS	VPP-CS
Bulk density(g/ml)	$0.581 \pm 0.007^c$	$0.60 \pm 0.006^d$	$0.408 \pm 0.005^{bc}$	$0.415 \pm 0.004^{ac}$
Tapped Density(g/ml)	$0.763 \pm 0.003^b$	$0.807 \pm 0.007^c$	$0.442 \pm 0.012^d$	$0.474 \pm 0.006^a$
Angle of Repose	$38.55^0 \pm 1.04^c$ (Good)	$35.03^0 \pm 1.20^d$ (Fair)	$31.22^0 \pm 0.322^{bc}$ (Good)	$32.42^0 \pm 0.560^{ac}$ (Good)
Carr Index	$23.85^a$ % (Passable)	$25.6^b$ % (Passable)	$7.75^c$ % (Excellent)	$12.44^d$ % (Good)
Hausner ratio	$1.310^a$ (Passable)	$1.345^a$ (Passable)	$1.084^a$ (Excellent)	$1.142^a$ (Good)

Values with different superscripts in a row within the group differ significantly at  $P \leq 0.05$

**Fig. 4** Images of potato peel powder after wet granulation and compression

After wet granulation  
using 3% croscarmellose  
sodium



After compression with  
1% magnesium stearate as  
lubricant



(Rahman et al. 2021). The diameter of both tablets was within the prescribed range. The tablet's diameter and shape affect esophageal transit, administration methods such as fluid use and patient positioning (Team and Team 2023).

The hardness of the tablets was between  $11.5 \pm 0.7$  and  $13.7 \pm 1.5$  kg/cm<sup>2</sup> for VPP-CS and TPP-CS respectively. The maximum permissible limits for hardness range between 5–8 kgf (Dulla et al. 2018). However, a force between 4 and 10 kg is also regarded enough (Dulla et al. 2018). These results indicate that the tablet will not chip or crack easily but the hardness of both the samples is not within the prescribed range recommending that it will not dissolve easily. However, dissolution studies should be performed to further validate it.

The friability ranged from 0.83% to 0.85% for VPP-CS and TPP-CS respectively. The maximum limit for friability should be less than 2% for tablets formed by direct compression (BP 2009). The friability test results, which were less than 2%, demonstrate its exceptional resistance to breaking. This means that the tablets could handle shocks and vibrations during handling, transportation, and storage without affecting their quality (Momoh et al. 2013).

## Conclusion

The aim of this study was to utilize red potato peels, analyzing its bioactive components and formulating tablets from the peel using different drying techniques. The proximate composition of both peel powders revealed that drying techniques significantly affect the composition. The red potato peel powder was characterized to study its structure, function, and crystallinity. The extracted

polyphenols which were subjected to phytochemical screening showed that potato peel powder exhibits high content of polyphenols. This implied that red potato peel powder can be beneficial to human health as it has a high antioxidant capacity. The analysis for pre-compression properties was done which showed that both the potato peel powders do not exhibit 'Excellent' flow characteristics. This implies that potato peel powder cannot be solely used for tablet formation. The incorporation of 3% croscarmellose sodium into each red potato peel powder increased the flowability properties significantly. However, tray-dried granules flowability properties were found better as compared to vacuum oven-dried granules. The overall study suggests that potato peel has a lot of beneficial bioactive compounds however, the potential of potato peel in terms of treating specific diseases needs to be further investigated with the help of quantitative and dissolution studies.

**Acknowledgements** The authors gratefully acknowledge to Institution of Eminence (IoE) scheme, Banaras Hindu University, Varanasi (U.P.) India, for financial support under the Incentive to Seed Grant under IoE Scheme (Dev. Scheme No 6031 and PFMS Scheme No 3254). Madhukiran R Dhondale acknowledges the funding from PMRF, India under grant number 1102018.

**Author contributions** DT: Investigation, formal analysis, methodology, writing-manuscript, review, and editing. MK: Writing-manuscript, methodology, formal analysis, review, and editing. AKC: Conceptualization, research administration, validation and manuscript review and editing. DK: Formal analysis and supervision. MRD: Formal analysis and supervision.

**Funding** Not applicable.

**Availability of data and material** Not applicable.

**Code availability** Not applicable.

#### Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This article does not contain any studies with human or animal subjects.

**Consent to participate** Not applicable.

**Consent to publication** Not applicable.

#### References

- Ansari Z, Goomer S (2020) Nutritional and pharmacological potential of potato peels: a valuable multi-functional waste of food industry. *Plant Archives* 20:84–87
- Akter M, Anjum N, Roy F, Yasmin S, Sohany M, Mahomud MS (2023) Effect of drying methods on physicochemical, antioxidant and functional properties of potato peel flour and quality evaluation of potato peel composite cake. *J Agric Food Res* 11:100508
- Arun Venkatesh S (2014) Formulation and Evaluation of Bisacodyl Enteric Coated Tablets (Doctoral dissertation, CL Baid Metha College of Pharmacy, Chennai)
- Awogbemi O, Kallon DVV, Owoputi AO (2022) Biofuel generation from potato peel waste: current state and prospects. *Recycling* 7(2):23
- Bouhadjra K, Lemlikchi W, Ferhati A, Mignard S (2021) Enhancing removal efficiency of anionic dye (Cibacron blue) using waste potato peels powder. *Sci Rep* 11(1):2090
- Brahmi F, Mateos-Aparicio I, Garcia-Alonso A, Abaci N, Saoudi S, Smail-Benazzouz L, Boulekbache-Makhlouf L (2022) Optimization of conventional extraction parameters for recovering phenolic compounds from potato (*Solanum tuberosum* L.) peels and their application as an antioxidant in yogurt formulation. *Antioxidants* 11(7):1401
- Daimary N, Eldiehy KS, Boruah P, Deka D, Bora U, Kakati BK (2022) Potato peels as a sustainable source for biochar, bio-oil and a green heterogeneous catalyst for biodiesel production. *J Environ Chem Eng* 10(1):107108
- Dulla O, Sultana S, Shohag Hosen M (2018) In vitro comparative quality evaluation of different brands of esomeprazole tablets available in selected community pharmacies in Dhaka, Bangladesh. *BMC Res Notes* 11:1–5
- Hossain MB, Brunton NP, Rai DK (2016) Effect of drying methods on the steroidal alkaloid content of potato peels, shoots and berries. *Molecules* 21(4):403
- Khanal S, Karimi K, Majumdar S, Kumar V, Verma R, Bhatia SK, Kumar D (2023) Sustainable utilization and valorization of potato waste: State of the art, challenges, and perspectives. *Biomass Convers Biorefin* 1:1–26
- Liang S, McDonald AG (2014) Chemical and thermal characterization of potato peel waste and its fermentation residue as potential resources for biofuel and bioproducts production. *J Agric Food Chem* 62(33):8421–8429
- Makori SI, Mu TH, Sun HN (2022) Profiling of polyphenols, flavonoids and anthocyanins in potato peel and flesh from four potato varieties. *Potato Res* 1:1–16
- Momoh MA, Chime SA, Kenchukwu FC (2013) Novel drug delivery system of plant extract for the management of diabetes: an antidiabetic study. *J Dietary Supplem* 10(3):252–263
- Naqvi SA, Irfan A, Zahoor AF, Zafar M, Maria A, Chand AJ, Ashfaq S (2020) Determination of antimicrobial and antioxidant potential of agro-waste peels. *An Acad Bras Ciênc* 92:1
- Özdikicierler O, Dirim SN, Pazir F (2014) The effects of spray drying process parameters on the characteristic process indices and rheological powder properties of microencapsulated plant (Gypsophila) extract powder. *Powder Technol* 253:474–480
- Pardo RNC, Rojas GMA, Florez LM (2021) Thermal analysis of the physicochemical properties of organic waste to application in the compost process. *Biomass Convers Biorefin* 1:1–13
- Pharmacopoeia B (2009) The commission office London
- Rahman M, Akter K, Sarker MS, Sharna JF, Wahed MII (2021) In vitro comparative quality evaluation of different brands of marketed paracetamol tablets available in Bangladesh. *J Pharm Res Int* 33(38A):26–32
- Sahin-Nadeem H, Dinger C, Torun M, Topuz A, Özdemir F (2013) Influence of inlet air temperature and carrier material on the production of instant soluble sage (*Salvia fruticosa* Miller) by spray drying. *LWT Food Sci Technol* 52:31–38
- Sampaio SL, Petropoulos SA, Alexopoulos A, Heleno SA, Santos-Buelga C, Barros L, Ferreira IC (2020) Potato peels as sources of functional compounds for the food industry: a review. *Trends Food Sci Technol* 103:118–129
- Schiano S, Chen L, Wu CY (2018) The effect of dry granulation on flow behaviour of pharmaceutical powders during die filling. *Powder Technol* 337:78–83
- Singh B, Singh J, Singh JP, Kaur A, Singh N (2020) Phenolic compounds in potato (*Solanum tuberosum* L.) peel and their health-promoting activities. *Int J Food Sci Technol* 55(6):2273–2281
- Singh N, Kamath V, Rajini PS (2005) Protective effect of potato peel powder in ameliorating oxidative stress in streptozotocin diabetic rats. *Plant Foods Hum Nutr* 60:49–54
- Team P, Team P (2023) Quality control tests of tablets or Evaluation of tablets. *PharmaEducation*. <https://pharmaeducation.net/quality-control-tests-of-tablets-or-evaluation-of-tablets/>
- Teow CC, Truong VD, McFeeters RF, Thompson RL, Pecota KV, Yencho GC (2007) Antioxidant activities, phenolic and  $\beta$ -carotene contents of sweet potato genotypes with varying flesh colours. *Food Chem* 103(3):829–838
- Thomas J, Barley A, Willis S, Thomas J, Verghese M, Boateng J (2020) Effect of different solvents on the extraction of phytochemicals in colored potatoes. *Food Nutr Sci* 11(10):942
- Valcarcel J, Reilly K, Gaffney M, O'Brien NM (2015) Antioxidant activity, total phenolic and total flavonoid content in sixty varieties of potato (*Solanum tuberosum* L.) grown in Ireland. *Potato Res* 58:221–244
- Wang S, Lin AHM, Han Q, Xu Q (2020) Evaluation of direct ultrasound-assisted extraction of phenolic compounds from potato peels. *Processes* 8(12):1665
- Xie X, Puri VM (2012) Powder deposition in three parallel-oriented dies of cylindrical and E shapes. *Adv Powder Technol* 23(1):1–7
- Yuksel F, Durmaz A (2022) Evaluation of by-products of potato peel as food additive. *Curr Nutr Food Sci* 18(1):15–21
- Zhang L, Tu ZC, Yuan T, Wang H, Xie X, Fu ZF (2016) Antioxidants and  $\alpha$ -glucosidase inhibitors from Ipomoea batatas leaves identified by bioassay-guided approach and structure-activity relationships. *Food Chem* 208:61–67. <https://doi.org/10.1016/j.foodchem.2016.03.079>

Zhu X, Cheng Y, Chenb P, Pengb P, Liu S, Li D, Ruanb R (2016) Effect of alkaline and high-pressure homogenization on the extraction of phenolic acids from potato peels. *Innov Food Sci Emerg Technol* 37:91–97

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.