J Food Sci Technol (November 2020) 57(11):3955–3965
https://doi.org/10.1007/s13197-020-04424-3

ORIGINAL ARTICLE

Biochemical and functional attributes of raw and boiled potato flesh and peel powders for suitability in food applications

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Revised: 21 March 2020 / Accepted: 3 April 2020 / Published online: 11 April 2020

Abstract Four different potato cultivars, namely, Kufri Chipsona 1 and Kufri Frysona (processing purpose), Kufri Jyoti and Kufri Bahar (table purpose) were converted into flesh and peel powder (raw and after boiling) and studied for their respective biochemical and functional attributes to get an idea of possible dynamics of their utilization in different food formulation as bioadditives. The 16 variants of powder obtained retained less than 10% moisture content and demonstrated 'very good' to 'fair' flowability. Peel powders recorded a higher total mineral, fiber, phenolic contents and total antioxidant activity than the flesh powders which were significantly affected by boiling. Among raw and boiled flesh powders, highest reducing and total sugars were recorded for Kufri Bahar while least was observed in Kufri Chipsona 1. Colour coordinate showed that boiling imparts brightness to flesh powder while peel powder got darkened. Boiling of the tubers resulted in an increase in the resistant starch ($\sim$ 29% maximum) and flavour ($\sim$ 180% maximum) component. Peel exhibited a total glycoalkaloid content in the range of 0.75 (Kufri Frysona) to 1.7 mg/100 g (Kufri Bahar) that is well within the acceptable limits. Rheological study of the flesh powders revealed a reduction of about 11–18 °C in pasting temperature and about 87–90% in peak viscosity, setback, breakdown value and final viscosity upon boiling. This study revealed that the traditional processing method such as boiling can significantly modify the techno-functional characteristics of potato flesh and peel powders which can further govern their end use in various food formulations.

Keywords Potato cultivar · Peel powder · Flesh powder · Resistant starch · Glycoalkaloid · Rheology

Introduction

Potato is categorized as the third main crop for human nutrition that helps to combat poverty and malnutrition in developing countries (Marwaha et al. 2010). India ranks second in potato production next to China, producing 12.0% of the total world potato production (Anonymous 2017). Majority of potato is harvested during February–March in the plains in India. The progressive rise in temperature thereafter and the erratic and costly distribution of cold storage facilities cause considerable economic loss to the farmers (Marwaha et al. 2010). To prevent the postharvest losses, potatoes can be processed into various value added products. Analysis pattern of Indian processing industry suggests that demand for processing quality potatoes over next 40 years will rise at the fastest pace for French fries (11.6%) followed by potato flakes/powder (7.6%) and potato chips (4.5%). The actual demand for processing potatoes is expected to rise from 2.8 million

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tonnes in 2010 to 25 million tonnes during the year 2050 (Bandana et al. 2016).

In industry, Indian cultivars Kufri Chipsona 1 and Kufri Frysona are being exploited for potato chips and French Fries making, respectively. Also, Kufri Jyoti and Kufri Bahar are the two most widely used table purpose cultivars. Among the different processing techniques, potato drying is one of the viable techniques that can be practiced at the farm level during glut to yield a product that can be stored for prolonged periods and eventually be incorporated into other food formulations. Strategies for addition of potato flour as a bio-additive to impart thickness and colour or improve flavour in various products is being explored. Potato peel, the major and unavoidable waste of potato processing industries, is also a good source of nutritional and pharmacologically important compounds such as dietary fibre, phenolics and glycoalkaloids (Schieber and Saldaña 2009). Therefore, its incorporation in food products would be a natural way of delivering valuable bioactives into the human body. Studies show that potato dietary fibre is able to bind bile acids in vitro and can be part of the mechanism that lowers plasma cholesterol (Camire et al. 1993). In addition, high intake of dietary fibre has a positive impact on blood glucose profile (Raigond et al. 2017). This peel is obtained as a by-product from industries where either raw potato (chips industry) or boiled potatoes (*aloo* mash industry) are being processed. Depending on the peeling process, i.e. abrasion, steam or lye peeling, the amount of waste can range between 15 and 40% of the amount of processed potatoes (Arapoglou et al. 2010). When discarded, it is an environmental pollutant owing to its high biological oxygen demand (BOD) (Sell 1992). The utilization of this by-product can substantially reduce the waste disposal problem of the potato industries and additionally help in enriching the food matrices with physiological active compounds. However, the utilization strategies need to be supplemented by adequate data revealing techno-functional properties of raw or boiled flesh and peel powders, the two major ways by which potatoes are presently processed in industry. Scanty reports are available on the potential of boiling to modify biochemical and functional properties of potato flesh as well as peel powder. In the present endeavor, the influence of cultivar and boiling method for powder preparation, both from flesh and peel, on the various quality attributes have been studied for their possible utilization in various food formulations.

Materials and methods

Procurement of raw material and chemicals

Four potato varieties, namely, Kufri Chipsona-1 and Kufri Frysona (processing purpose), Kufri Jyoti and Kufri Bahar (table purpose) were procured from CPRI-C, Modipuram, Uttar Pradesh. The cultivars were grown using standard package of practices. Chemicals were procured from Sigma and Merck India Pvt. Ltd.

Pretreatments and development of potato flour

Potatoes of all four varieties were either used raw or used after boiling to prepare the potato flour. The tubers were sorted to remove bruised tubers and cleaned under running water to remove adhered soil particles. Boiling was carried out in a pressure cooker for 10 min to soften the tubers. Both raw and boiled tubers were peeled, and the flesh and peel were dried separately in a cabinet drier (Macro Scientific Works Pvt. Ltd., New Delhi) at 70 °C for 6–7 h. Size reduction of the dried mass of both the flesh and peel was done using a grinder (Inalsa Make), passed through BSS sieve no. 36 and stored in LDPE pouches under dry conditions for later use.

Biochemical parameters of raw and boiled potato flesh and peel flours

Moisture, total ash and crude fibre content

The moisture and ash contents of the potato flesh and peel powder were determined by the method of Ranganna (2007). Moisture was analyzed by gravimetric method using hot air oven (Macro Scientific Works Pvt. Ltd., New Delhi) while ashing was done in muffle furnace (Widsons Scientific Works, New Delhi). Crude fibre content was determined by digesting the sample in acid and alkali solution through a raw fibre extractor (Velp Scientifica make) as described by Ranganna (2007).

Reducing and total sugars

Reducing and total sugars were estimated by the method described by Lane and Eynon (1923).

Total phenols and total antioxidant (AOX) activity

For total phenol determination in potato flesh and peel (raw and boiled), 2 g of sample was crushed in 80% ethanol, and centrifuged (Sigma, Germany). The supernatant was used to determine the total phenolic content (expressed in mg of gallic acid equivalents (GAE)/100 g of extract) and total AOX activity (Apak et al. 2004) by measuring the absorbance of the developed colour in a spectrophotometer (Spectra Max M2, Molecular Devices, USA) at 760 and 450 nm, respectively.

Colour

The colour of powders obtained from flesh and peel of potato tubers (raw and boiled) in terms of CIE L*, a*, b* coordinates was noted using a hand held colour Tec-PCM (Cole-Parmer, Germany). The index L* measures the lightness co-efficient and ranges from 0 (black) to 100 (white). Hunter a* indicates a hue of red (for positive values) and green (for negative values) on the horizontal axis. Similarly, on the vertical axis positive b* indicates yellow and negative b* represents blue. Calibration was done by using black and white tiles before evaluation.

Resistant starch

Resistant starch of the raw and boiled potato was determined using the protocol of Raigond et al. (2017). Dry potato sample (0.1 g) was digested in pepsin and pancreatic α-amylase solution. The solution was centrifuged (Remi Make, New Delhi) followed by addition of distilled water and potassium hydroxide to the residue. After incubation pH (Eutech Instruments, Mumbai) was adjusted to 4.75 using HCl followed by addition of amyloglucosidase. The reaction mixture was incubated and centrifugation (Remi Make, New Delhi). Glucose was determined using glucose-peroxidase assay kit (Sigma). Resistant starch was calculated as glucose × 0.9.

Glycoalkaloids

Potato peel was analyzed for glycoalkaloid content using the method of Singh et al. (2016). To 10 g of ground peel sample, 21 mL of solution containing water, acetic acid and sodium bisulphate in 95:5:0.5 ratio was added. After dilution, the mixture was centrifuged at 5000 rpm for 10 min. The C18 extraction cartridge was conditioned with 5 mL acetonitrile and with 5 mL water: acetic acid: sodium bisulphate solvents. Ten millilitre of supernatant was washed with 4 mL of water: acetonitrile (85:15 ratio) and the glycoalkaloids were eluted out with 4 ml of mobile phase (acetonitrile: phosphate buffer) through an RP-18 column at a temperature of 35 °C with a flow rate of 1.5 mL/min. in HPLC (Merck, Hitachi).

Flavour

Powdered potato flesh/peel samples (0.5 g) were ground in liquid nitrogen and extracted by adding 5% perchloric acid in an ice bath for 1 min. The extracts were centrifuged (Remi Make, New Delhi) at 10,000 rpm at 4 °C for 10 min. Potassium carbonate (5 mol/L) was added to 8 mL supernatant to bring the pH (Eutech Instruments, Mumbai) to 6.5. The solution was again centrifuged for 10 min at 6000 rpm and the supernatant obtained was filtered through 0.45 μm. Twenty microlitre of the extract was injected into the HPLC (Merck, Hitachi) for analysis equipped with RP-18 column, at a temperature of 35 °C using potassium phosphate buffer (pH 7.0):acetonitrile in 80:20 ratio as mobile phase at a flow rate of 1.2 mL/min (Raigond et al. 2014a).

Functional attributes of the potato flour

Bulk and tapped density

Bulk and tapped densities of the dried powders were determined by method given by Goula et al. (2004).

Water absorption capacity and oil absorption capacity

Water absorption capacity was measured by the method documented by Medcalf and Gilles (1965) while the method described by Beuchat (1977) was used to determine the oil absorption capacity of the powders. The weight of water or oil absorbed by 1 g of powder was calculated and expressed as water/oil absorption capacity.

Flowability

Flowability was evaluated in terms of Carr index (CI) using following expression (Carr 1965):

$$\mathrm{CI} = [(\text{Tapped density} - \text{bulk density})/\text{Tapped density}] \times 100$$

where, less than 15% CI indicates 'very good' flowability, 15–20% indicates 'good' flowability and > 20% indicates 'fair' flowability of the powder.

Rheological properties potato flesh and peel powders

A small amplitude oscillatory rheological measurement was made for potato flesh and peel powders, with a dynamic rapid viscoanalyser (Super3 model, Newport Scientific, Australia). The strain was set at 1.5%. The potato flesh and peel powders were subjected to frequency sweep testing in a range of 0.1–20 Hz at 40 °C. The dynamic rheological properties were determined for the flours. Cooked pastes of 10% (w/w) concentration were loaded on the ram of the rheometer and covered with a thin layer of low-density silicone oil (to minimize evaporation losses). Viscosity profiles of flour samples were recorded using suspensions with standard 14% moisture content. A programmed heating and cooling cycle was used whereby the samples were held at 50 °C for 1 min, heated to 95 °C at 9 °C/min, held at 95 °C for 4 min, cooled to 50 °C at 9 °C/min and held at 50 °C for 1.5 min. Parameters recorded were pasting temperature, final viscosity and setback value.

Statistical analysis

Statistical analysis was conducted using SPSS for Windows (ver. 17.0). Three replications were taken for each attribute studied. One-way analysis of variance was carried out for comparison of biochemical and functional attributes of potato flesh and peel powders at 5% significance level.

Results and discussion

Moisture content

Moisture of dried powders affects their stability during storage and thus, it is desirable to maintain it below 10%. The moisture content of the powders obtained from raw and boiled potato flesh and peel is shown in Table 1. Significant ($p \leq 0.05$) variation in the moisture content of powders of both flesh and peel were observed with the varieties studied. Dried flesh of raw potatoes retained a moisture content of 3.06 (Kufri Frysona) to 5.73% (Kufri Bahar). A similar range of 3.57–4.01% moisture has been reported by Raj et al. (2011) in flours made from different potato cultivars. Peel powders from raw potatoes on the other hand showed moisture in the range of 5.40–5.66%. Powders obtained from boiled substrate yielded slightly higher moisture content after dehydration both in case of flesh and peel (Table 1). Murayama et al. (2015) have also reported higher moisture values (10.36%) for the potato flour prepared from boiled counterparts.

Ash

Ash content of any flour is an indicative of its overall mineral content. As shown in Table 1, a significant ($p \leq 0.05$) influence of cultivar on the ash content of the flours was observed. Higher ash content was recorded for both raw and boiled flesh flours of table purpose varieties (Kufri Jyoti and Kufri Bahar). Boiling of tubers did not show any specific pattern in the ash content of the obtained flours. Peel powders recorded a higher ash percentage than the flesh powders indicating their higher mineral content. In general, boiling of tubers resulted in a decrease in the mineral content of the peel powders, may be due to their diffusion into the tuber or loss as a result of leaching. Our results are quite high as compared to those reported by Higley et al. (2003) who reported ash content of flour from mealy and waxy potato cultivars to be 4.15 and 4.55%, respectively on dry weight basis. This variation may be attributed to the inherent compositional difference of the studied varieties compared to the supported study.

Crude fibre

Potato peels constitute about 2.5 g per 100 g of total dietary fibre (Al-Weshahy and Rao 2012). Fibre percentage in peels is dependent on the peeling method with abrasion peeling of potatoes resulting in less dietary fibre and more starch as compared to the steam peeling (Camire et al. 1997). We observed a non-significant variation in the crude fibre content of the flours of raw flesh and peel. As expected, crude fibre content in the potato flesh powder was quite low as compared to the peel powders. Powder from flesh of boiled Kufri Chipsona 1 recorded the highest crude fibre percentage whereas peel powder of boiled Kufri Frysona recorded the maximum crude fibre content. The values we obtained are slightly lower than those shown by Avula and Singh (2009) who reported a dietary fibre content of 10.6% for potato flour on dry weight basis. Interestingly, boiled peel powder showed an enhancement in the crude fibre content of all the cultivars. This might be due to the non-adherence of the starchy flesh to the boiled peel versus the raw peel.

Reducing and total sugars

Reducing and total sugars ranged from 0.24–1.03% and 1.03–1.43%, respectively in all the flesh powders with powder made from cultivar Kufri Chipsona 1 showing minimum and Kufri Bahar showing maximum sugars (Table 1). Raj et al. (2011) have reported reducing sugar in a higher range of 0.412–1.864%. This may be attributed to non-conversion of starch to sugars in the freshly harvested tubers we collected directly from the field that further resulted in lower sugars in the dehydrated powder from respective varieties. Boiling of the tubers led to a decrease in the reducing and total sugar content in the powders developed. The reduction in values upon boiling may be as a result of the water soluble nature of these sugars. Among raw and boiled flesh powders, highest reducing and total sugars was recorded in Kufri Bahar while least was observed in Kufri Chipsona 1. Flesh of processable varieties showed lesser reducing sugars as compared to the table varieties. This is owing to the inherent genetic

Table 1 Biochemical attributes of potato flesh and peel powders

Variety	Moisture (%)		Ash (%)		Crude fiber (%)		Reducing sugars (%)		Total sugars (%)		Total phenols (mg GAE/100 g)		Total AOX activity (µmole Trolox/g)		L*		a*		b*	
	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled
Flesh powder																				
Kufri Chipsona 1	3.85	4.90	11.09	12.27	2.51	3.90	0.28	0.24	1.09	1.03	124.00	90.8	8.33	8.16	49.87	47.15	4.45	5.42	17.8	21.57
Kufri Frysona	3.06	4.40	10.57	12.36	3.00	2.77	0.34	0.27	1.14	1.08	135.26	95.8	8.97	8.93	52.51	56.12	4.86	3.88	13.12	19.15
Kufri Jyoti	4.66	6.67	15.6	15.18	2.74	2.68	0.71	0.67	1.23	1.08	143.66	99.73	8.78	6.98	40.42	49.96	3.68	4.75	13.65	19.32
Kufri Bahar	5.73	5.67	21.57	20.73	2.27	2.68	1.03	1.00	1.43	1.08	154.13	114.40	9.84	9.63	39.46	49.88	4.4	5.54	7.91	21.72
CD ($p \leq 0.05$)	1.26	1.47	4.11	1.85	ns	0.52	0.15	0.03	0.41	0.02	12.01	11.71	0.89	ns	2.62	ns	0.53	1.09	3.06	ns
Peel powder																				
Kufri Chipsona 1	5.40	6.13	15.60	11.91	7.88	10.83	nd	nd	nd	nd	379.16	109.13	13.82	11.90	40.69	35.24	4.41	4.85	18.79	19.50
Kufri Frysona	5.46	6.20	13.88	8.33	8.22	13.11	nd	nd	nd	nd	245.00	108.06	21.83	14.35	40.73	37.26	5.39	7.09	20.59	19.38
Kufri Jyoti	5.66	7.53	16.02	13.88	8.89	10.07	nd	nd	nd	nd	282.08	105.13	21.23	20.30	37.90	32.51	5.04	5.00	18.22	17.86
Kufri Bahar	5.40	6.13	17.69	16.03	7.90	12.80	nd	nd	nd	nd	393.95	112.73	36.85	31.55	35.80	32.41	5.43	3.79	20.86	17.80
CD ($p \leq 0.05$)	ns	ns	ns	1.83	ns	1.42	nd	nd	nd	nd	83.20	ns	1.31	0.67	ns	2.21	ns	0.29	ns	ns

Values are mean of triplicate readings

nd not determined, *ns* non-significant makeup of the varieties that have been bred for reduced sugar content for use in processed products with low browning incidence.

Total phenolic content and total antioxidant capacity

Plant polyphenols play a role in the defense mechanism against pathogens. Therefore, almost 50% of phenolics are located in the peel and adjoining tissues and decrease toward the center of the potato tuber (Friedman 1997). It is evident from Table 1 that total phenolic content is higher in peel powder in comparison to the flesh powder irrespective of cultivar or treatment. Bandana et al. (2016) have also documented higher phenolics in the peel region of the tubers studied. A reduction in the total phenolic content of the flesh and peel powders was observed post boiling (Table 1). This may have resulted owing to the water soluble nature of the phenolics and their leaching into the boiling water. Similar observations were reported by Tierno et al. (2015) wherein they found retention of only 45–74% total phenolics after boiling. Phenolic compounds contribute to antioxidant activity and protect plants against various biotic and abiotic stresses. As a result, their presence in human diet prevents degenerative diseases (Im et al. 2008). Hence, incorporation of the phenolic enriched potato peel into the foods can act as a source of these beneficial phenolics in addition to the fibre content they possess.

Based on our results, we observed that potato peel had higher total antioxidant (AOX) activity as compared to the flesh portion of the tubers (Table 1). Tubers exhibiting higher total phenolic content also showed correspondingly higher total AOX activity. In potato cultivars, contribution of total phenols to total AOX activity was reported to be up to 58–82% (Reddivari et al. 2007). Powders prepared from boiled tubers showed a slight reduction in the total antioxidant activity. This can be supported by the fact that phenolics, the major contributor to the total AOX activity are water soluble and might have leached out during boiling.

Colour

Colour of the flesh and peel powders of the raw and boiled potato tubers were measured in L*, a* and b*coordinates and are presented in Table 1. The lightness parameter ‘L*’ of the raw flesh powder varied significantly ($p \leq 0.05$) with the cultivar studied. Also, we observed brighter flour of processable varieties as compared to the table purpose ones as supported by comparable low reducing sugar content in these varieties. All powders prepared from boiled potato flesh showed slightly higher L* values irrespective of cultivar indicating that boiling has improved the color of potato flours. Such results may be due to the browning causal polyphenol oxidase enzyme inactivation (Murayama et al. 2015). Higher b* indicates higher yellow color which is again attributed by inactivation of the browning enzymes. Overall, after boiling an increase in a* for both the powders was observed. However, in case of flesh powder an increase in L* and b* coordinates indicated brighter colour whereas a decrease in these values depicted the darker tinge of peel powder upon boiling. This might be attributed to the higher level of phenolics present in the peel portion of the tuber as discussed previously.

Resistant starch

Potato starch has a tendency to develop resistant starch by induced physical and chemical modifications (Raigond et al. 2017). Varietal differences were observed among the content of resistant starch for raw and boiled potato flours (Table 2). The varieties, Kufri Chispona 1 and Kufri Frysona that are used for processing yielded lower values for resistant starch (0.85 and 0.99 g, respectively) compared to the table varieties, Kufri Bahar and Kufri Jyoti (1.2 and 1.03 g, respectively). Raigond et al. (2017) have also reported a variation in resistant starch content amongst the potato genotypes due to the genetic variability. Higher resistant starch content in a particular cultivar is indicative of its lower digestibility. Boiling of the tubers resulted in an increase in the resistant starch content. This may be attributed to the fact that boiling followed by cooling leads to an increase in the resistant starch content. Our results are in accordance with those reported by Raigond et al. (2014b) that boiling followed by cooling leads to enhancement of resistant starch content in tubers.

Glycoalkaloids in peel

Potatoes contain nitrogenous steroidal glycosides in their peel, commonly known as glycoalkaloids that are produced under stress conditions. The main constituents of these are α-chaconine and α-solanine. In general, glycoalkaloids concentration should be less than 200 ppm (Singh et al. 2016) owing to its anti-nutritional nature. In the present work, we observed a total glycoalkaloid content in the range of 0.75 (Kufri Frysona) to 1.7 mg/100 g (Kufri Bahar) in the peels (Table 2). Singh et al. (2016) performed cluster analysis of the 41 Indian potato cultivars and grouped all the four varieties we studied (Kufri Chipsona 1, Kufri Frysona, Kufri Jyoti and Kufri Bahar) in cluster 1 having the least glycoalkaloid content with mean value of 1.10 mg/100 g. Ostry et al. (2010) found that for peeled potatoes, the average content of glycoalkaloids could vary from 1.0 to 45.0 mg/kg, wherein the peeling reduces the

Table 2 Resistant starch, glycoalkaloid and flavour content of the raw and boiled potato powders

Variety	Treatment	Resistant starch[a] (%)	Glycoalkaloids[b] (mg/100 g)	Flavour[a] (μg/g)
Kufri Chipsona 1	Raw	0.85	1.44	5.5
	Boiled	1.1	1.47	5.9
Kufri Frysona	Raw	0.99	0.75	5.24
	Boiled	1.05	0.76	12.7
Kufri Jyoti	Raw	1.03	0.86	3.16
	Boiled	1.2	0.83	8.84
Kufri Bahar	Raw	1.2	1.7	3.5
	Boiled	1.34	1.61	6.5
CD for raw powder ($p \le 0.05$)		0.101	0.094	ns
CD for boiled powder ($p \le 0.05$)		0.033	0.042	1.56

Values are mean of triplicate readings; ns: non-significant

[a] Estimated in flesh powder

[b] Estimated in peel powder

glycoalkaloid content by 60–96%. Boiling resulted in non-significant reduction in the content of glycoalkaloid in both processing and table purpose potato varieties due to its thermo-stable nature.

Flavouring compounds

The adenosine glucoside is the predominant flavouring compound of potatoes and its concentration may vary according to the genotype. Higher flavor was detected in processing varieties, Kufri Chipsona 1 and Kufri Frysona. This is the reason that makes them suitable for use in processed products. Variation in flavor attribute is reported to be a function of genotype, storage environment and the biochemical reactions that lead to their production (Jansky 2010). Boiling resulted in an increase in the flavor component of the potatoes. This may be attributed to the release of the volatile compounds from the complex starch matrix of the potatoes. Previously, Gupta et al. (2015) also reported baked Kufri Chipsona 1 to possess excellent flavour followed by baked Kufri Frysona and Kufri Bahar.

Functional properties of potato flesh and peel powder

Bulk and tapped density

Bulk density is a measure of heaviness of a flour sample, and is generally affected by particle size. The bulk density of potato flesh flours was higher compared to their respective peel flours owing to the higher dry matter content of the flesh portion of the tubers (Table 3). Also, we observed a reduction in the bulk density of the flours obtained from boiled fleshes and peels. This reduction in bulk density post boiling might be as a result of loss of solubles and reduction in the bulk of the flours. Also, it indicates that boiling resulted in non-alignment of flour particles that become difficult to pack (Egbuonu and Nzewi 2014). An increase in the density of the peel powder was observed after tapping (Table 3) owing to the removal of entrapped air from the void spaces. It also showed a decrease with the boiling treatment given to tubers.

Water absorption capacity (WAC)

Water absorption capacity is one of the most important functional properties in food processing that is closely related to texture of the developed product. Hence, powder of processing cultivar, Kufri Chipsona 1 is more suitable for incorporation in products requiring enhanced viscosity such as soups and gravies since potato flour obtained from these raw tubers had maximum WAC (6.64 g/g). Boiling resulted in a decrease in the WAC (Table 3) which might be attributed to the swelling of starch granules as a consequence of imbibition of water molecules during gelatinization and also a slight increase in the resistant starch content (from 0.85 to 1.34%) that prevents water absorption (Sajilata et al. 2006). In general, WAC of peel powders was lower than flesh powders but varied non-significantly with the potato cultivar (Table 3). This may be attributed to the higher insoluble fibre in the peel. Variation in WAI of potato flours with respect to variety has been previously reported by Jeddou et al. (2017).

Oil absorption capacity (OAC)

Oil absorption capacity of a flour helps to maintain and improve mouthfeel of the product in which it is used. Varietal variation was observed in OAC of the potato flours with higher OAC obtained for peel powder in comparison

Table 3 Functional qualities of powders prepared from raw and boiled potatoes

Variety	Bulk density (g/mL)		Tapped density (g/mL)		Water absorption capacity (g/g)		Oil absorption capacity (g/g)		Flowability (%)	
Treatment	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled	Raw	Boiled
Flesh powder										
Kufri Chipsona 1	0.76	0.76	0.86	0.90	6.64	5.74	2.05	2.10	11.53	16.42
Kufri Frysona	0.75	0.70	0.85	0.88	5.97	5.43	1.94	1.95	12.48	19.99
Kufri Jyoti	0.74	0.71	0.90	0.82	5.08	5.98	2.01	1.86	18.51	13.09
Kufri Bahar	0.76	0.65	0.87	0.80	5.00	4.85	1.74	2.05	12.82	17.59
CD ($p \leq 0.05$)	ns	0.02	0.03	0.04	2.24	0.13	0.18	0.03	3.26	4.14
Peel powder										
Kufri Chipsona 1	0.59	0.48	0.68	0.62	5.51	5.48	2.33	2.46	13.64	23.69
Kufri Frysona	0.57	0.50	0.67	0.65	4.89	5.92	2.08	2.25	15.16	24.16
Kufri Jyoti	0.57	0.35	0.58	0.65	5.58	6.48	2.22	3.03	18.80	13.10
Kufri Bahar	0.66	0.58	0.80	0.46	2.79	5.01	2.26	2.76	27.87	17.30
CD ($p \leq 0.05$)	0.04	0.03	0.04	0.01	ns	0.30	ns	0.08	6.82	4.78

Values are mean of triplicate readings

ns non-significant

to the flesh powder (Table 3). This may be as a result of higher oil uptake by the crude fibre present in the peel portion. Slight increase in the oil absorption index was observed after boiling of the tubers, for both flesh and peel powders. Similar trend was observed by Onuegbu et al. (2013) for boiled upko seed flour. Processing purpose varieties, Kufri Chipsona 1 and Kufri Frysona, flesh powders demonstrated higher OAC as compared to table purpose varieties. High OAC of food materials helps in better retention of flavour in the developed end products and hence these cultivars are supposed to be good for flavour expression in processed potato products. The OAC we got for peel powder was in accordance with the values reported by Jeddou et al. (2017).

Flowability

Flowability is an important handling property of flours and can be expressed as Carr Index (CI). Predominantly, the range of flowability was less than 20% for all powders (Table 3) indicating 'very good' flowability characteristics as described by Carr (1965). In case of raw tubers, Kufri Jyoti flesh powder yielded maximum flowability value (18.51%), while the highest flowability was observed for powder of Kufri Frysona (19.99%), in boiled tubers. In case of peel powders, although a non-significant variation existed in flowability for raw powders, but the same varied significantly ($p \leq 0.05$) after boiling the tubers (Table 4). A maximum of 27.87% flowability was observed for peel powder of raw Kufri Bahar while boiled peel of Kufri Frysona showed the maximum value (24.16%) indicating 'fair' flowability characteristic.

Rheological properties of raw and boiled potato flesh and peel flours

For use in particular food application, texture is a key determinant that requires potato to maintain a desired feel through a heating process. Cooked potato structure is influenced by starch content, starch granule size, pectic substances and other minor components (Ormerod et al. 2002). RVA analysis of flours demonstrated significant ($p \leq 0.05$) differences among the gelatinization behaviours of the potato cultivars studied and the treatment applied (Table 4). Higher peak viscosity was observed for potato flours obtained from processing varieties, Kufri Chipsona 1 and Kufri Frysona. This might be attributed to the higher starch content of these varieties as compared to the table purpose varieties (Higley et al. 2003). This also showed that the flours from these varieties had greater ability to hold water and swell without bursting (higher thickening power) compared to the table purpose varieties, as confirmed by the WAC we recorded for these flours. Boiling of the tubers resulted in significant ($p \leq 0.05$) reduction in the peak viscosities, suggesting that flours from boiled tubers had starch that had been gelatinized thus, unable to form thick gels. Similar observations have been reported by Avula and Singh (2009). Boiling played a major role in influencing the pasting behaviour of potato. The quick swelling of starch granules beyond the reversible

Table 4 Rapid viscoanalyzer data of raw and boiled potato flesh powder

Variety	Treatment	Pasting temperature (°C)	Peak viscosity (cP)	Setback viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)
Kufri Chipsona 1	Raw	68.55	3817.33	1831.67	1932.33	4370.67
	Boiled	51.10	562.67	246.66	163.00	482.67
Kufri Frysona	Raw	69.42	2891.33	2638.00	235.33	3997.67
	Boiled	50.10	1326.67	630.33	660.33	977.00
Kufri Jyoti	Raw	74.65	2011.00	1694.00	304.00	2642.67
	Boiled	63.25	694.67	491.66	196.67	800.67
Kufri Bahar	Raw	68.97	2746.04	3582.00	511.67	5257.67
	Boiled	50.45	506.33	338.33	172.33	574.67
CD for raw powder ($p \leq 0.05$)			ns	177.47	237.44	140.95
CD for boiled powder ($p \leq 0.05$)			77.66	36.87	77.45	69.21

Values are mean of triplicate readings

ns non-significant

point made them fragile whereby they are easily broken by stirring, resulting in a decrease in viscosity. Reduction in viscosity is particularly important in the preparation of weaning and supplementary foods. In our sample, boiling resulted in the decrease in pasting temperatures indicating the presence of already gelatinized starch.

A high degree of breakdown was observed for flours of all raw and boiled potato cultivars (Table 4). This is associated with collapse of the swollen starch granules during the heating process corresponding to the release of soluble starch that reassociates during the cooling portion of the RVA graph resulting in a higher setback. Processing varieties showed intermediary setback compared to the two table purpose varieties. Since boiling the potatoes results in starch gelatinization, we observed a sharp reduction in the peak viscosities from the raw counterparts. Hopkins and Gormley (2000) had also previously concluded that boiled potatoes from varieties with low dry matter, such as Kufri Jyoti and Kufri Bahar used in the present study yielded low peak viscosities.

Setback value is the recovery of the viscosity during cooling of the heated starch suspension. When hot starch pastes are cooled, the subsequent increase in viscosity is dependent upon the ability of starch molecules to aggregate during retrogradation. Therefore, high setback value is desirable for products requiring high viscosity and paste stability at reduced temperatures, whereas a low setback indicates the development of soft gel upon cooling (Oduro et al. 2000). As shown in Table 4, we observed maximum setback (3582 cP) for flesh powder of raw Kufri Bahar followed by raw Kufri Frysona 1 (2638 cP). The difference in setback among different flours may be due to the amount and the molecular weight of amylose leached from the granules and the remnant of the gelatinized starch. Setback value has thus been reported to correlate with ability of starches to form hard gel (semi-solid paste). Set back from peak leads to the growth of gel micellar regions, and hence increase in index of retrogradation.

Conclusion

A significant ($p \leq 0.05$) difference of treatment was observed on the techno-functional attributes of the potato flesh and peel powders which further determine their end-use. Raw powders of both flesh and peel exhibited higher WAC, while OAC was found to be more in case of boiled samples. Crude ash, crude fiber content, phenolics and antioxidant capacity were higher in the peel fractions compared to the flesh powders exhibiting their nutritional superiority and therefore their possible use as a functional food ingredient. For almost all product applications, boiled flesh powder was found to be better in terms of lightness in colour, flavor expression and resistant starch content. Boiled samples showed a sharp decline in the pasting temperature, peak viscosity, breakdown value, set back and final viscosity. We concluded that powders with high water absorption and peak viscosity are suitable to act as thickening agents such as raw powder of Kufri Chipsona 1 followed by raw powder of Kufri Bahar. Low pasting temperature such as observed for boiled Kufri Chipsona 1 flesh powder is good for use in baked products. It is further supported by its low reducing sugar content as well as highest b* value (yellowness indicator). Low breakdown value is desirable for development of weaning foods. In this aspect, boiled powder of Kufri Chipsona 1 was the most suitable followed by boiled powder of Kufri Bahar. Of the four varieties studied, both the table varieties (Kufri Jyoti and Kufri Bahar) exhibited higher resistant starch upon boiling that is in tune with the prevailing dietary preferences. Further, they also contain appreciable total phenolics and total antioxidant capacity. Observing the low glycoalkaloid content, it is not wrong to say that peels of both raw and boiled tubers of all the four varieties can be used for fibre enrichment of foods. Boiled powders of Kufri Frysona and Kufri Jyoti would be the best alternates to express best potato flavour in the food whereas raw powders of cultivar Kufri Jyoti and Kufri Bahar can be used in viscous foods without masking the actual food flavour owing to low flavour components. Hence, the study revealed that the traditional processing method such as boiling can significantly modify the techno-functional characteristics of the potato flesh and peel powders.

Acknowledgements This work is part of the Masters Degree Programme of Ahmad Farid Azizi. We wish to acknowledge and thank ICAR for providing financial assistance in the form of India Afghanistan Fellowship during his degree programme.

Compliance with ethical standards

Conflict of interest No potential conflict of interest was reported by the authors.

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