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ORIGINAL ARTICLE

Variation in biochemical parameters in different parts of potato tubers for processing purposes

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Abstract The present study was conducted to estimate the variation in bio-chemical parameters among eight different parts *viz.* bud end cortex, bud end medulla, central cortex, central medulla, pith, stem end cortex, stem end medulla and peel of potato tuber of processing varieties. Concentration of dry matter, reducing sugar, sucrose and starch content were higher in cortical region than in medullar region of stem end, bud end and central portion. Variety Kufri Chipsona-1 had maximum dry matter content in stem end cortex (SEC 30.34 %), followed by Kufri Frysona (SEC 27.71 %). Mean reducing sugar values were comparatively more in bud end cortex (BEC 111.3 mg/100 g Fresh Weight) and lowest in stem end medulla (SEM 44.05 mg/100 g FW). Bio-chemical contents varied considerably within different parts of tuber as well as in different genotypes. The information generated in this study can help processors for effective utilization of potato for various types of processing products viz., chips and French fries.

Keywords Quality distribution · Bud end · Stem end · Pith · Central medulla · Potato

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Introduction

Potato (*Solanum tuberosum* L.) is one of the principal tuber crops of the world and is a valuable component of our diet. India is the second largest producer of potatoes globally. Over the years potato has become a most promising food crop together with wheat, rice and maize. It is capable of producing over twice as much dry matter and calories per unit area and time as compared to wheat, rice and maize. Presently, global potato sector is undergoing major changes in developed countries. Potatoes are currently processed into value-added products to meet the demand especially for the fast food and convenience food industries. Analysis of past experience and 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 % Annual Compound Growth Rate, ACGR) followed by potato flakes/powder (7.6 %) and potato chips (4.5 %). The actual demand for processing potatoes will rise from 2.8 million t in 2010 to 25 million t during the year 2050 at an ACGR of 5.61 %. The recent expansion of the potato processing industry in most developing countries has created a demand for specialized varieties for chips, frozen fries and potato flour/starch/flakes. The colour of potato chips is the first quality parameter evaluated by consumers and is critical for the acceptance of the product. Low sugar level (<100 mg per 100 g fresh weight), high dry matter (>20 %), starch content and phenol content are important parameters that are closely looked at by processors in order to meet their quality standards. The structure and composition of parenchyma cells play a crucial role in determining processing quality of the finished product. Parenchyma cells make up the principal tissue of potato tubers and their structure and composition is dependent upon number

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of factors such as cultivar, climatic conditions and edaphic factors (Faulks and Griffiths 1983). The higher dry matter or solids content of tubers results in higher recovery of chips, lower oil absorption, lesser energy consumption and imparts a crispy texture to the product. The reducing sugars play a critical role in determining the colour of fried products which develops during frying at high temperatures due to the '*Maillard reaction*' between reducing sugars and free amino acids present in the tubers. Besides, affecting the colour and flavour of fried products, Maillard reaction has also been related to the formation of acrylamide, which is considered a potentially carcinogenic compound. Sucrose also plays important role in determining the quality of potatoes after storage and serves as a substrate for reducing sugar production via the storage activated invertase enzyme. In addition to the discoloration of fried products, tubers show enzymatic discoloration and after-cooking darkening. Enzymatic discoloration occurs due to phenolic compounds when the potatoes are peeled, cut or injured. Previous reports were based on are about the biochemical composition of whole tuber. Significant differences in chip quality as a result of varying composition of tuber too has been reported (Kumar et al. 2004). Composition of potato tubers can vary in different areas of production, among tubers on the same plant and in tissues from different parts of each tuber (Weaver et al.1978a). Physical and chemical characteristics of potato tubers vary from one variety to another and within the same variety depending upon many factors during growth (Sengul et al. 2004). It has been reported that potato characteristics are different among different varieties, but tubers of the same variety or of the same plant can also vary in specific components. Compositional variations have also been reported from the stem to the bud end of the tuber. The stem end, the point of attachment of the tuber to the plant, is higher in dry matter than the bud end (Artschwager 1924). These intrinsic variations are crucial to French fry quality, especially texture (Mohr 1972). Excess food produced by the potato plant is transported to the medulla through the vascular ring. Distribution pattern of bio-chemical parameters in different parts of tuber may influence the quality of end product (Murniecea et al. 2011). For example, low dry matter in pith region is attributed to droopy French fries (Sayere et al. 1975). French fry quality is also dependent on compositional and anatomical variations within the tuber (Sharma et al. 1959) as the potato flesh is comprised of various tissue types, namely the cortex, located below the periderm or skin, are vascular storage parenchyma and the pith which is located in the centre of the tuber. A vascular ring comprising mainly of xylem and phloem conducting vessels which separates the cortex from the vascular storage parenchyma. Dry matter distribution within the tuber varies from one tissue type to another, with pith tissue containing relatively few starch granules and cortical tissue packed with starch granules (Reeve 1967). Generally reducing sugar levels are higher at the basal end than at the apical end (Kunkel and Gardner 1958). Only sucrose is uniformly distributed among the different parts of the tuber (Weaver et al. 1978b). Besides this, excessive nitrogen fertilization reduces starch, dry matter and sugar contents in potato tubers (Simanaviciene et al. 2001) or leads to delayed maturity and affecting poor tuber quality (Peshin and Singh 1999) as well. Temperature and photoperiod during the growing season affect sugar and dry matter content of potatoes and ultimately affect the chipping quality (Burton 1989). Soil temperatures of below 8–12 °C (Arrenguin and Bonner 1949) or above 25–30 °C increase sugar content (Timm et al. 1968). Understanding the distribution of bio-chemical parameters within the tuber is an important prerequisite for more target specific strategies to enhance the product quality. Therefore in this study an attempt was made to estimate the variations of biochemical constituents i.e. dry matter, reducing sugar, sucrose, phenol and starch content in different parts of potato tubers so as to understand their influence on the colour of processed products viz., chips and French fries.

Materials and methods

Crops of four processing varieties Kufri Chipsona-1, Kufri Chipsona-3, Kufri Frysona, Kufri Surya along with two table varieties Kufri Jyoti and Kufri Pukhraj were raised during 2013–14 at Central Potato Research Institute Campus, Modipuram, India (29.1° N latitude, 77.92 ° E longitude, and an altitude of 237 m above mean sea level (amsl) following the recommended package of practices. The mean minimum and maximum temperature values were 10.3 and 21.5, respectively. Recommended fertilizer dose for table potatoes (150:80:100 NPK $kgha^{-1}$) and a higher dose (270:80:150 NPK $kgha^{-1}$) for processing cultivars was applied. The crop was irrigated by furrow irrigation 25 mm CPE (cumulative pan evaporation) level by flood irrigation, the method commonly used in the region to avoid and abiotic stress on the crop. Crop was harvested at their chemical maturity (90–110 days, depending on variety) and tubers were graded, processing grade (> 45 mm) potato tubers (about 15 tubers per replication) for analysis purpose from each replication were selected randomly. The analysis was performed in three replicates.

Sampling

Tubers were first washed and then air dried, peel was removed with the help of hand peeler. After peeling, a one centimeter thick slice was cut longitudinally from the centre of potato tuber from bud end to stem end (Fig. 1). Then this slice was divided lengthwise into three pieces of equal length. Centre

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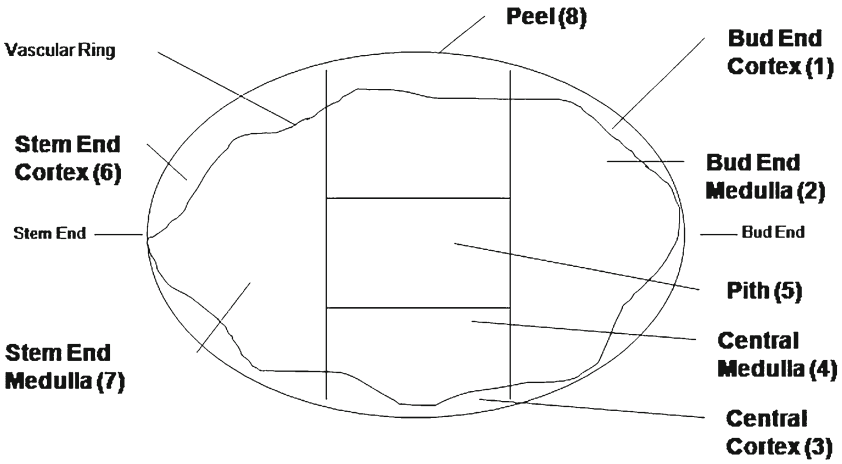

Fig. 1 Diagrammatic presentation of different parts of potato tuber

portion was again cut width-wise into three portions, of which central region was taken as pith. The pieces from bud end, stem end and centre portion (excluding pith) was divided separately into cortex and medulla with the help of a fine blade in sunlight for demarcation of vascular ring. These portions were then finely chopped and pooled separately (in triplicate) for further analysis of dry matter content and biochemical parameters viz. reducing sugar, sucrose, phenol and starch contents.

Biochemical estimations

Dry matter content was determined by drying finely chopped tuber pieces in oven first at 70 °C for six hours and then at 65 °C till constant weight (Uppal 1999). The reducing sugars were estimated quantitatively by Nelson Somoyogi method given by Sadasivam and Manikam (1996a) based on the principal that reducing sugars when heated with alkaline copper tartarate reduce the copper from cupric to cuprous state and thus cuprous oxide is formed. When cuprous oxide is treated with arsenomolybdic acid, the reduction of molybdic acid to molybdenum blue takes place. During estimation of reducing sugars, interfering compounds like soluble proteins were removed by precipitating using saturated potassium oxalate solution, filtering and in next step by using lead acetate solution and finally centrifuging. To the supernatant (0.2 ml) alkaline copper tartarate reagent was added and the content was boiled for 10 min, cooled and 1 ml of arsenomolybdate reagent was poured. The blue colour developed was photometrically measured at 620 nm. Sucrose was analysed according to the anthrone method (Van Handel 1968). To 0.1 ml of the 80 % ethanol extract 0.1 ml of 30 % aqueous potassium hydroxide was added and kept in a boiling water bath for 10 min. The samples were cooled and 3.0 ml of anthrone reagent was added and kept at 40 °C for 10 min. The absorbance was read at 620 nm. Sucrose of known concentration was used as standard. Both the methods for reducing sugars and starch estimation have been followed (Kumar and Ezekiel 2004) recently. The phenol contents were determined based on the reactions where, phenols react with phosphomolybdic acid in Folin-Ciocalteau reagent in alkaline medium and produce blue coloured complex. Phenols were extracted in 80 % ethanol. After centrifuging, supernatant was evaporated to dryness and volume was made to 1 ml. To the extract, Folin-Ciocalteau reagent (1 N) was added followed by addition of 2 ml of sodium carbonate (20 %). Blue coloured complex was measured for its absorbance at 650 nm (Sadasivam and Manikam 1996b) against a reagent blank. For extraction of starch, sample (500 mg) was treated with 80 % alcohol to remove sugars and then starch was extracted with perchloric acid (52 %). After centrifugation, supernatants were again treated with perchloric acid and volume was made to 100 ml. Extract (0.2 ml) was taken and 4 ml of anthrone was added and boiled. After cooling, the intensity of green to dark green colour was measured at 630 nm (Thimmaiah 2004).

Statistical analyses

All the analysis was performed in three replicates using complete randomized block design. The data were analysed using MSTAT 4.0C software (Gomez and Gomez 1984). The significant of means was compared using the Tukey's HSD test ($p < 0.05$). Different letters have been used to indicate significant differences.

Result and discussion

Dry matter content Distribution of dry matter has been shown in Table 1. Dry matter content varied greatly with a range of 13.78–30.34 %. Among test varieties, Kufri Chipsona-1 had significantly high dry matter content in stem end cortex (SEC 30.34 %), followed by central cortex (CC 28.34 %) portion. Likewise, similar trend of accumulation of dry matter was noticed in Cv. Kufri Chipsona-3 (SEC 25.27 and CC 25.09 %), Kufri Frysona (SEC 27.71 and CC 27.17 %), Kufri Surya (SEC 23.84 and CC 21.20 %) and

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Table 1 Distribution of dry matter (%) in different parts of tuber

Tuber portion	Kufri Chipsona-1	Kufri Chipsona-3	Kufri Frysona	Kufri Surya	Kufri Jyoti	Kufri Pukhraj
BEC*	25.18^{e}	21.84^{hi}	22.92^{g}	17.28st	16.97^{tu}	16.10^{v}
BEM	21.21^{ij}	18.41^{opq}	18.95^{no}	16.40^{uv}	14.42^{z}	$13.85^{[z}$
CC	28.34^{b}	25.09^{e}	27.17^{c}	21.20ij	18.99^{no}	17.76^{qrs}
CM	26.35^{d}	21.66^{hij}	23.83^{f}	20.32^{klm}	17.32st	15.93^{vwx}
Pith	18.23^{pqr}	17.69^{rs}	17.41st	14.80^{yz}	14.94^{yz}	$13.78^{[z}$
SEC	30.34^{a}	25.27^{e}	27.71^{bc}	23.84^{f}	20.40^{kl}	19.99^{lm}
SEM	23.65^{f}	22.20^{h}	21.75^{hi}	20.96^{jk}	19.64^{mn}	18.36^{opqr}
Peel	18.32^{opqr}	18.77^{op}	18.33^{opqr}	15.24^{xy}	15.98^{vw}	15.28^{wxy}

BEC*:Bud end cortex; BEM: Bud end medulla; CC: Central cortex; CM: Central medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; PE: Peel

The alphabets given as superscript show the significant differences using Tukey's Honestly significant difference test at 5 % level of significance. (The same alphabets show non-significant differences)

Kufri Jyoti (SEC 20.40 and SEM 19.64 %). Results obtained are in tune with the results (Kumar and Ezekiel 2004) obtained in North Indian plains and under temperate conditions (Weaver et al. 1978a). This data is supported by the fact that dry matter content is also measured as specific gravity and it has been shown to differ among different varieties. Besides that, there is strong link between texture of potato chips/French fries and dry matter content of potatoes. The highest dry matter was found in stem end cortex (30.34 %) followed by central cortex (28.34 %) and products made from these regions may affect product texture owing more to crunchiness. Lowest dry matter was found in pith (13.78 %) and bud end medulla (13.85 %). French fries prepared from this region had drooping texture and if dry matter content is low, chips and French fries would be too soft. Not only this, low dry matter content during the processing of potatoes for French fries and chips would require more energy to vaporize the water. In addition, it also affects the fat content of fried products, while with increase in the dry matter content absorption of fat content is expected to decrease, which is a better criteria for consumer's health. Dry weight determination of potato revealed that the stem end had higher dry matter content than bud end. Dry weight is more in cortical layer, the zone containing the greater part of the vascular system, and decreases towards the centre of the tuber. A study reported that composition of potato varies in different section of each individual tuber (Van Es and Hartmans 1981). In all varieties, higher dry matter was recorded in stem end cortex whereas minimum in pith portion of tuber. Higher dry matter in cortex region could be due to the presence of fibro-vascular bundles in this region and lowest in pith region because this is more or less permeated by water. These findings are in confirmation with results of earlier workers (Kumar and Ezekiel 2004) under North Indian plains. Potatoes of higher solid content or having low moisture contents are considered desirable for processing purpose and product yield are dependent on the amount of water that is lost during process of frying. High dry matter content (>20 %) of tubers is suitable for making chips and French fries that ultimately influences product yield, texture, flavour and oil absorption. In this study it was observed that amongst the test varieties, all processing varieties met specific requirements of chipping/French Fries.

Reducing sugar accumulation Reducing sugar <100 mg/100 g Fresh Weight is considered to be acceptable and is one of the important characteristic for chips/French fry making. The reducing sugars in general were minimum and within the acceptable range in all the processing cultures and in table variety Kufri Jyoti, Whereas, in Kufri Pukhraj the levels were very high (Table 2). Among different varieties, reducing sugar ranged from 8.97 (pith) to 413.4 (bud end cortex) mg/100 g FW. Different concentrations of sugars among different portion suggest that while taking potato for processing purpose or for analysis each portion of tuber should be equally distributed. Pattern of sugar accumulation was found to be different in different varieties**.** However, the differences were found to be non-significant in different portions. Similar results have been reported in literature (Kumar and Ezekiel 2004) under North Indian plains. Contrary to this, a study carried out at North Pacific region, indicated reducing sugars are evenly distributed throughout the potato tubers as compared to the even distribution of sucrose and cortex has been observed to contain highest amount of reducing sugars, with very low levels detection in the stem end region (Weaver et al. 1978b). Studies on problem of sugar-end development indicated that tuber had high starch and reducing sugar content in the basal portion (Weaver et al. 1970). In another study, potato samples indicated fried dark colours on the apical end (Iritani and Weller 1973) than the stem end due to presence of more reducing sugars. Reducing sugars was minimum in pith of Kufri Surya (8.97 mg/100 g FW), central medulla (9.83 mg/100 g FW). Cultivar specific differences too have been reported

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Table 2 Distribution of reducing sugars (mg/100 g fresh weight) in different parts of tuber

Tuber portion	Kufri Chipsona-1	Kufri Chipsona-3	Kufri Frysona	Kufri Surya	Kufri Jyoti	Kufri Pukhraj
BEC*	$20.42^{tuvwxyz}$	$33.20^{nopqrstu}$	123.0^{g}	$22.20^{stuvwxyz}$	55.69^{jk}	413.4^{a}
BEM	16.10^{wxyz}	67.20^{ij}	94.34^{h}	16.10^{wxyz}	38.17^{mnopqr}	336.9^{c}
CC	$26.80^{pqrstuvwx}$	55.00^{jkl}	$30.00^{opqrstuvw}$	17.50^{vwxyz}	46.40^{klmn}	290.5^{d}
CM	13.22^{xyz}	66.90^{ij}	74.40^{i}	9.83^{yz}	$27.01^{pqrstuvwx}$	206.5^{e}
Pith	17.70^{vwxyz}	41.50^{klmnop}	$29.90^{opqrstuvw}$	8.97^{z}	$24.51^{rstuvwxy}$	210.4^{e}
SEC	$26.70^{pqrstuvwx}$	19.70^{uvwxyz}	52.60^{jklm}	$22.60^{stuvwxyz}$	35.60^{nopqrs}	390.9^{b}
SEM	$27.00^{pqrstuvwx}$	43.50^{klmno}	$27.90^{pqrstuvwx}$	9.62^{yz}	$26.93^{pqrstuvwx}$	129.4^{fg}
Peel	$35.33^{nopqrst}$	40.20^{lmnopq}	$31.20^{opqrstuv}$	$31.90^{nopqrstuv}$	$25.79^{qrstuvwx}$	141.7^{f}

BEC*:Bud end cortex; BEM: Bud end medulla; CC: Central cortex; CM: Central medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; PE: Peel

The alphabets given as superscript show the significant differences using Tukey's Honestly significant difference test at 5 % level of significance. (The same alphabets show non-significant differences)

(Weaver et al. 1972) suggesting that kind of sugar in a particular cultivar may be due to inherited characteristics (Cunningham and Stevenson 1963).

Sucrose content During processing, harvesting and storage conditions, sucrose is important parameter as it is the substrate of the reducing sugars and that may be hydrolyzed in suitable environmental conditions ultimately leading to the increase of the sugars. Significantly higher sucrose content was recorded in variety Kufri Pukhraj in stem end cortex (188.3 mg/100 g FW). However, non-significant differences were found in central cortex and stem end medulla. The differences in sucrose content in central medullary portions of processing varieties, Kufri Chipsona-1 and Kufri Chipsona-3 were found to be non-significant (Table 3). Pith regions of processing varieties viz., Kufri Chipsona-3, Kufri Frysona and Kufri Jyoti too indicated non-significant differences. The content of the major sugars found in potatoes, viz., glucose, fructose, and sucrose, may vary among good and poor chipping varieties (Miller et al. 1975). Lowest sucrose content was observed in pith (39.31 %) and peel portion (42 %). Higher starch content in stem end cortex combined with high mean dry matter can make them suitable for processing into dried food products even for the industrial production of starch as the high dry matter content is a presumption for high starch content.

Phenol content The distribution of phenols of potatoes has been shown in Table 4. Concentration of phenols was found to be the significantly higher in peels (194.0 mg/100 g FW) of variety Kufri Surya and Kufri Pukhraj (163.5 mg/100 g fresh weight). The differences were found to be non-significant in different tubers portions. Tyrosine and chlorogenic acid are the main phenolic constituents of parenchyma cells (Reeve et al. 1969) and are responsible for undesirable discolouration in uncooked and cooked potatoes. Tubers at maturity were found to contain higher concentration of phenols in stem end portion that at bud end (Lewis et al. 1999). In most of the test

Table 3 Distribution of sucrose content (mg/100 g fresh weight) in different parts of tuber

Tuber portion	Kufri Chipsona-1	Kufri Chipsona-3	Kufri Frysona	Kufri Surya	Kufri Jyoti	Kufri Pukhraj
BEC*	94.70^{mnop}	84.50^{pq}	97.40^{mno}	135.5^{fgh}	$102.2l^{mn}$	137.8^{fgh}
BEM	75.70^{qr}	62.00^{s}	79.20^{qr}	85.00^{pq}	$76.52q^{r}$	130.5^{ghi}
CC	110.0^{kl}	105.0^{lm}	136.0^{fgh}	139.0^{efg}	121.8^{ij}	162.1^{bc}
CM	80.10^{qr}	80.10^{qr}	91.20^{op}	119.0^{jk}	92.65^{nop}	148.5^{de}
Pith	39.31^{t}	59.30^{s}	54.90^{s}	96.90^{mno}	53.67^{s}	128.1^{hij}
SEC	109.0^{kl}	93.40^{nop}	154.0^{cd}	168.0^{b}	129.9^{ghi}	188.3^{a}
SEM	85.80^{pq}	77.40^{qr}	94.30^{nop}	142.0^{ef}	$100.3l^{mno}$	161.3^{bc}
Peel	97.80^{mno}	141.0^{ef}	85.00^{pq}	42.00^{t}	72.86^{r}	110.1^{kl}

BEC*:Bud end cortex; BEM: Bud end medulla; CC: Central cortex; CM: Central medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; PE: Peel

The alphabets given as superscript show the significant differences using Tukey's Honestly significant difference test at 5 % level of significance. (The same alphabets show non-significant differences)

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Table 4 Distribution of phenol content (mg/100 g fresh weight) in different parts of tuber

Tuber portion	Kufri Chipsona-1	Kufri Chipsona-3	Kufri Frysona	Kufri Surya	Kufri Jyoti	Kufri Pukhraj
BEC*	63.30^{klmn}	64.10^{jklm}	39.50^{p}	64.10^{jklm}	$59.2l^{mno}$	67.06^{jklm}
BEM	65.20^{jklm}	103.0^{d}	43.10^{op}	85.90^{defghi}	67.88^{jkl}	35.85^{p}
CC	65.90^{jklm}	71.10^{hijkl}	35.80^{p}	62.60^{klmn}	49.89^{gmnop}	75.75^{ghijkl}
CM	36.60^{p}	88.00^{defgh}	41.00^{p}	99.40^{d}	74.00^{ghijkl}	$78.13^{lfghijk}$
Pith	81.30^{efghij}	98.90^{d}	50.10^{mnop}	96.80^{gde}	$79.73^{efghijk}$	$59.8l^{lmno}$
SEC	75.50^{ghijkl}	102.0^{d}	46.70^{nop}	72.70^{ghijkl}	69.30^{ijkl}	67.10^{jklm}
SEM	69.80^{ijkl}	89.30^{defg}	67.80^{jkl}	133.0^{c}	93.26^{def}	88.70^{defg}
Peel	148.0^{bc}	101.6^{d}	147.0^{bc}	194.0^{a}	148.4^{bc}	163.5^{b}

BEC*:Bud end cortex; BEM: Bud end medulla; CC: Central cortex; CM: Central medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; PE: Peel

The alphabets given as superscript show the significant differences using Tukey's Honestly significant difference test at 5 % level of significance. (The same alphabets show non-significant differences)

varieties, cortical portion had lower value of phenol as compare to medullar portion. It has been reported (Samarin et al. 2012) recently that potato peel contains phenolic acids consisting largely of chlorogenic acids.

Starch content A wide variation in starch content was observed. Starch determination of different portions revealed that starch content is remarkably higher in stem end cortex (24.62 %) in variety Kufri Chipsona-1. Similar results have been reported for accumulation of starch (Fedec et al. 1977). Whereas, quantity of starch was lesser in peels (12.64 %) in same variety (Table 5). Starch followed a very similar pattern of distribution of dry matter. The dry matter content and specific gravity reflect the amount of starch present and are used as crude indicators of processing quality. As there is strong correlation between the percentage of starch and low dry matter also tend to have low amount of starch. In all the test varieties highest starch was estimated in stem end cortex except in Kufri Chipsona-3 in which it was highest in central cortex portion of potato tuber. Lowest content of starch was found in peels of all the varieties i.e. Kufri Pukhraj (9.11 %) Kufri Surya (9.20 %), Kufri Chipsona-3 (11.57 %), Kufri Chipsona-1 and Kufri Jyoti (12.63 %). Crisp texture of potato tubers depends mainly upon the starch content that contribute up to 75 % of the dry matter. Owing to high starch content that forms more gelatinization during processing of tubers contributes more texture. Textural changes that take place during frying are suggested to be associated with physical and chemical changes in finished product. At the initial stage of tuber growth starch is found in the cortex and pith storage cells, later the rate of starch synthesis and accumulation increases. Starch in the cortex cells, shown to appear earlier than in the pith cells, suggesting that tubers when 5 mm in size, assimilates are unloaded mainly in the cortex cells and at later stages mostly in to peri-medullary zone rich in phloem (Borzenkova and Borovkova 2003).

Table 5 Distribution of starch content (mg/100 g fresh weight) in different parts of tuber

Tuber portion	Kufri Chipsona-1	Kufri Chipsona-3	Kufri Frysona	Kufri Surya	Kufri Jyoti	Kufri Pukhraj
BEC*	16.63^{ijk}	16.03^{jklm}	17.50^{ghi}	$12.43t^{uv}$	16.93^{hij}	11.81^{uvw}
BEM	16.36^{jkl}	13.53^{qrs}	14.57^{nop}	15.43^{lmn}	16.28^{jkl}	10.07^{xyz}
CC	21.23^{c}	19.08^{de}	20.77^{c}	16.15^{jklm}	20.87^{c}	12.67^{stu}
CM	20.99^{c}	15.90^{klm}	17.88^{fgh}	15.51^{lmn}	19.16^{de}	9.44^{yz}
Pith	14.31^{opq}	12.66^{stu}	13.51^{qrs}	10.93^{wx}	13.81^{pqr}	10.31^{xy}
SEC	24.62^{a}	18.19^{efg}	21.43bc	18.79^{def}	22.37^{b}	14.21^{pq}
SEM	19.46^{d}	16.05^{jklm}	15.24^{mno}	15.74^{klm}	18.02^{fg}	12.74^{stu}
Peel	12.64^{stu}	11.57^{vw}	13.00^{rst}	9.20^{z}	12.63^{stu}	9.11^{z}

BEC*:Bud end cortex; BEM: Bud end medulla; CC: Central cortex; CM: Central medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; P: Pith; SEC: Stem end cortex; SEM: Stem end medulla; PE: Peel

The alphabets given as superscript show the significant differences using Tukey's Honestly significant difference test at 5 % level of significance. (The same alphabets show non-significant differences)

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Conclusion

The colour of the processed products is determined by the chemical composition of the tubers. Compositional factors in tubers influence colour development in processed potato products. Factors influencing chemical composition and controlling factors that affect the final colour quality of the processed product is important. Pattern of distribution of dry matter, reducing sugar, sucrose, phenol and starch in potato tuber dependent on an intersecting set of factors, including the anatomy of the tuber, phloem and xylem loading and unloading and transport mechanism within the tuber. By taking into account the accumulation of different biochemical contents in tubers is an important prerequisite to more targeted approach for improving the levels of desirable constituents through agronomy or breeding. Agronomic interventions are required for uniformity.

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References

Arrenguin LB, Bonner J (1949) Experiments on sucrose formation by potato tubers influenced by temperature. Plant Physiol 24:720–738

Artschwager E (1924) Studies on the potato tuber. J Agric Res 27:809–835

Borzenkova RA, Borovkova MP (2003) Developmental pattern of phytohormone content in the cortex and pith of potato tubers as related to their growth and starch content. J Plant Physiol 50:119–124

Burton WG (1989) Yield and content of dry matter. The underlying physiologlcal processes. In: WG B (ed) The Potato. Longman Scientific and Technical, New York, pp. 84–155

Cunningham CE, Stevenson FJ (1963) Inheritance of factors affecting potato chip color and their association with specific gravity. Potato J 40:253–265

Faulks RM, Griffiths NM (1983) Influence of variety, site and storage on physical, sensory and compositional aspects of mashed potato. J Sci Food Agric 34:979–986

Fedec P, Ooraikul B, Hadziyev D (1977) Micro-structure of raw and granulated potatoes. J Inst Cm Sci Techno Ailment 10:295–306

Gomez KA, Gomez AA (1984) Statistical procedures for agriculture research (second ed). John Wiley & Sons, New York, p. 630

Iritani WM, Weller L (1973) Relative differences in sugar content of basal and apical portions of russet Burbank potatoes. Potato J 50:24–31

Kumar D, Ezekiel R (2004) Distribution of dry matter and sugars within a tuber of potato cultivars grown under short day conditions. Potato J 31:129–134

Kumar D, Singh BP, Kumar P (2004) An review of the factors affecting sugar content of potatoes. Annals Applied Biol 145:247–250

Kunkel R, Gardner WH (1958) Black spot of russet Burbank potatoes. Soc Hort Sci 73:436–444

Lewis CE, Walker JRF, Lancaster JE (1999) Changes in anthocyanin, flavonoid and phenolic acid concentrations during development and storage of coloured potato (*Solanum tuberosum* L.). J Sci Food Agric 79:311–316

Miller RA, Harrington JD, Kuhn GD (1975) Effect of variety and harvest date on tuber sugars and chip color. Potato J 52:379–386

Mohr WP (1972) Soggy-centered French fries. Can Inst Food Sci Technol J 5:179–183

Murniecea I, Karklinnaa D, Galoburdaa R, Santareb D, Skrabulec I, Costad HS (2011) Nutritional composition of freshly harvested and stored Latvian potato (*Solanum tuberosum* L.) varieties depending on traditional cooking methods. J Food Compo Anal 24:699–710

Peshin A, Singh B (1999) Biochemical composition of potato tubers as influenced by higher nitrogen application. J Potato Assoc 26:145–147

Reeve RM (1967) A review of cellular structure, starch and textural qualities of processed potatoes. Econ Bot 21:294–308

Reeve RM, Hautala E, Weaver ML (1969) Anatomy and compositional variation within potatoes II. Phenolics, enzymes and other minor components. Potato J 46:374–386

Sadasivam S, Manikam A (1996a) Estimation of reducing sugars by nelson-somoyogi method. In: Sadasivam S, Manikam A (eds) Biochemical methods for agricultural sciences. Wiley Eastern Ltd, New Delhi, India, pp. 5–6

Sadasivam S, Manikam A (1996b) Phenols. In: Sadasivam S, Manikam A (eds) Biochemical methods for agricultural sciences. Wiley Eastern Ltd, New Delhi, India, pp. 193–194

Samarin AM, Poorazarang H, Hematyar N, Elhamirad A (2012) Phenolics in potato peels: extraction and utilization as natural antioxidants. World Appl Sci J 18:191–195

Sayere RN, Nonak M, Weaver ML, et al. (1975) French fry quality related to specific gravity and solid content variations among potato strip within the same tuber. Potato J 52:73–82

Sengul M, Keles F, Keles MS (2004) The effect of storage condition (temperature, light, time) and variety on the glycoalkaloid content of potato tubers and sprouts. Food Control 15:281–286

Sharma MK, Isleib DR, Dexter ST (1959) Specific gravity of different zones within potato tubers. Am Potato J 35:784–788

Simanaviciene O, Mazvila J, Vaisvila Z. ir kt. (2001) Skirtingais budais apskaiciuotu NPK trąsų normų meslo ir siaudų palyginimas sejomainoje Zemdirbyste: mokslo darbai/LZI, LZUU-Akademija75 p 14–28

Thimmaiah SK (2004) Estimation of starch by anthrone method. In: standard methods of biochemical analysis. Thimmaiah SK (ed). Kalyani Publishers, New Delhi, p. 58

Timm HM, Yamaguchi MD, Clegg BJC (1968) Influence of high temperature exposure on sugar content and chipping quality of potatoes. Potato J 45:359–365

Uppal DS (1999) Quality traits and chipping performance of newly released potato varieties. J Potato Assoc 26:139–142

Van Es A, Hartmans KJ (1981) Structure and chemical composition of potato. In: Rastovski A, Van Es A (eds) Storage of potatoes. Centre for Agricultural Publishing and Documentation, Wageningen, pp. 17–81

Van Handel E (1968) Direct micro-determination of sucrose. Anal Biochem 22:280–283

Weaver ML, Hautala E, Nonaka M, Iritani WM (1972) Sugar end in russet Burbank potatoes. Potato J 49:376–382

Weaver ML, Hautala E, Iritani WM (1970) Studies on sugar end in Russet Burbank potatoes. Abst of paper presented at 54th annual meeting Potato Asso America. American Potato J 47:353

Weaver ML, Timm H, Nonaka M, Sayre RN, Reeve RM, McCready RM, Whitehand LC (1978a) Potato composition: I tissue selection and its effects on solids content and amylose/amylopectin ratios. Potato J 55:73–82

Weaver ML, Timm H, Nonaka M, Sayre RN, Reeve RM, McCready RM, Whiteland LC (1978b) Potato composition: II tissue selection and its effects on total sugar, total reducing sugar, glucose, fructose and sucrose contents. Potato J 55:83–93