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Review Article

Biochemical and Phytochemical Properties of Potato: A Review

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Abstract

Potato contains several biochemical properties such as starch content, ascorbic acid, reducing sugars, non-reducing sugars, total sugars, phenolic content, flavonoids, polyamines, carotenoids, which are highly enviable in the diet because of their favorable effects on human health. The concentration and stability of these chemical compounds are affected by several factors such as cultivars, growing location, cultural practices adopted during cultivation, maturity at harvest, subsequent storage history and other related factors. The advances in analytical techniques have made possible to identify the functions of various biochemical and antioxidant properties of potato tubers. The potatoes are stored and processed into a variety of products before consumption. In the present review, biochemical and antioxidants present in potatoes, factors affecting their content, their stability and health benefits are discussed.

Keywords: Potato, ascorbic acid, Phenolic content, Sugars, Dry matter, Starch Content, Carotene, Flavionoids

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Introduction

Potato is a versatile, carbohydrate-rich food highly popular worldwide and served in a variety of ways. Freshly harvested tubers of potato contain about 80 percent water and 20 percent dry matter. About 60 to 80 percent of the dry matter is starch. Potato is the fourth most important food crop in the world after rice, wheat, and maize, and is the only major food crop that is a tuber. Potato is a very efficient food crop and staple food and produces more dry matter, protein and minerals per unit area in comparison to cereals. Apart from being a rich source of starch, potatoes contain the good quantity of small molecules and secondary metabolites which play an important role in a number of processes. Many of the compounds which present in potato are very important because of their beneficial effects on health and therefore they are highly desirable in the human diet [1]. Nutritional deficiencies are not well known in the countries whose population depends on potatoes as their basic food [2]. One of the global health goals is to increase the availability of nutrients to a large population of the world. A sensible approach to achieving this goal would be to increase the nutritional content of highly consumed crops. Furthermore, potatoes have higher phytonutrient content and are amenable to development through breeding and biotechnology approaches [3]. Antioxidants are substances that reduce or inhibit oxidative processes in human body and food products [4]. Free radicals or reactive oxygen species are very responsible for these degenerative reactions and are associated with many chronic diseases [5]. Fruits and vegetables are precise a very rich source of antioxidant phytochemicals such as polyphenols, anthocyanins and ascorbic acid etc. which are helpful in supplementary the body to neutralize free radicals. Therefore, consumption of a diet high in dietary antioxidants is utmost important, in order to reduce the harmful effects of free radicals. The aim of this review is to retrace the information on various biochemical and phytochemical properties of potato tubers which differ with the cultivar, growing location, cultural practices adopted during cultivation, maturity at harvest, subsequent storage history and other related factors.

Biochemical and phytochemical properties of potato tubers

In addition to supplying energy, potatoes contain a number of health promoting antioxidants such as phenolics, flavonoids, folates, anthocyanins, and carotenoids and biochemical such as starch content, dry matter, ascorbic acid, reducing sugars, non-reducing sugars and total sugar.

Phenol content

Polyphenols comprise over 8000 recognized substances, which can be alienated into groups according to their chemical structure, such as phenolic acids, stilbenes, coumarins, lignins and flavonoids [6]. Polyphenols are renowned as the most abundant antioxidants in our diet [7]. Potatoes are a high-quality source of these compounds. Phenolic compounds play an important role in determining their organoleptic properties and symbolize as a large group of minor chemical constituents in potatoes. These phenolics have a wide range of health providing characteristics [8]. The phenolic content of potatoes was ranged from 530 to 1770 μg /g [9]. Potatoes were well thought-out the third most important source of phenols after apples and oranges [10]. The presence of lignin, coumarins, anthocyanins and flavones, tannins, monohydric phenols and polyhydric phenols present in potatoes [11]. Mattila and Hellstrom (2007) reported caffeic acid derivatives i.e., chlorogenic acid as the main phenolic constituents in potatoes [12]. The phenolic compounds are present in both the skin and flesh of potatoes, whereas, the concentration being higher in the skin than the flesh. The fresh pulp and skin of potatoes contain 30 to 900 mg/kg and 1000–4000 mg/kg, respectively of chlorogenic acid and minor amounts of other phenolic acids between 0 and 30 mg/kg [13]. Purple and red skinned tubers contained twice the concentration of phenolic acids as white skinned tubers. Tuber flesh contained lower concentrations ranging from 100 to 600 μg of phenolic acids and 0 to 30 μg of flavonoids. It was also reported that concentration of phenolic acids was three to four times in purple or red fleshed cultivars than that of white-fleshed cultivars. The prime phenolic acids were reported to be chlorogenic acid, protocatechuic acid, vanillic acid, and p-coumaric acid. The skin portion of potato tubers is the richest in phenols, which is discarded as waste during potato processing and can be used for ‘value addition' in different food products [14].

About 11 species of *Solanum* are cultivated but most of the potato varieties cultivated throughout the world belong to the species *Solanum tuberosum*. The nutrient content of potatoes was reported to be influenced by a number of factors, variety being the most important [15]. Andre *et al*., (2007) observed an eleven-fold variation in the total phenolic content in Andean potato landraces [16]. Navarre *et al*. (2009) found a fifteen-fold difference in their phenolic content using hundreds of potato genotypes [14]. White fleshed potato varieties were reported to contain the lower amount of phenolics (less than 4 mg/g dry weight) as compared to purple fleshed wild species (more than 5–6mg/g dry weight). An anthocyanin content of up to 7 mg/g fresh weight in the skin and 2 mg/g fresh weight in the flesh was reported by Lewis *et al*. (1998) amongst 26 potato cultivars with colored flesh [17]. Jansen and Flamme (2006) analysed 31 potato genotypes with coloured flesh and found a lower range of 0.5 to 3 mg/g fresh weight in the skin and up to 1 mg/g fresh weight in the flesh [18], while cultivars Brown, Culley, Yang, Durst, novel anthocyanins acylated with caffeic acid in purple sprouts of a Norwegian potato cultivar [19]. Eichhorn and Winterhalter (2005) identified major anthocyanins present in four pigmented potato cultivars [20]. Jansen and Flamme (2006) analyzed 27 potato cultivars and observed that the average anthocyanins content was the highest in the skin (0.65 g/kg fresh weight) [18]. The corresponding values for whole tubers and flesh were 0.31 g/kg fresh weight and 0.22 g/kg fresh weight, respectively. The average anthocyanin content was higher in violet colored potatoes and lower in red colored potatoes.

The number of potato varieties known to mankind is vast and to be estimated approximately 5000 [21]. Singh *et al*. (2005) estimated highest total phenols in Kufri Jyoti (67.4 mg) followed by Kufri Chandramukhi (51 mg) but no significant difference was found (46-46.9 mg) in phenol content of potato variety Kufri Ashoka, Kufri Lavkar, Kufri Sutlej and hybrid JH-214 [22]. In a post-harvest study of potato, Uppal *et al*. (1987) noticed varietal differences in phenol content, which increased during storage [23]. Similarly, Ezekiel and Singh, (2007) noticed that phenol content increased during early storage period and decrease subsequently and they further observed higher phenol content at higher storage temperature [24]. Kumar and Ezekiel (2009) stated that the changes in phenol content in tubers stored at room temperature (26-40°C) did not show any consistent trend when tubers of cultivar Kufri Chipsona 1, Kufri Bahar and Kufri Jyoti were stored for 90 days at room temperature (26-40°C) conditions [25]. After 120 days of storage, Ezekiel *et al*. (2011) recorded higher phenol content than that at the time of loading. Storage generally increases total phenols content in potatoes but little change or a decrease in phenols content after storage have also been reported in some studies [26]. Ezekiel and Singh (2007) recorded that the total phenolic content in four potato cultivars stored for 180 days at 4, 8, 12, 16 and 20 °C. Total phenols increased after storage and the increase was higher at 4 and 16 °C [27]. The total phenols in potato tubers continued to increase up to 271 days of storage at 6 °C but at 20 °C, it decreased after 220 days of storage [27]. Potatoes of two cultivars grown at four locations in the North Indian plains did not show the significant difference in total phenols content up to 115 days of storage at 4 and 10 °C [28]. Kumar and Ezekiel (2009) found that total phenolic content in the peels and flesh of three Indian potato varieties

decreased after 90 days of storage at 2–4 °C, 10–12 °C and in heap storage, a traditional method of storage [25]. The decrease in the peels was minimum at 2–4 °C and maximum in heap storage. Use of irradiation to inhibit sprouting of potato tubers also causes an increase in the total phenols content. Potatoes treated with 0.1 and 0.5 kGy doses of γ-rays and stored for 180 days showed higher total phenols content as compared to untreated potatoes [28]. Increase in total phenols content in irradiated potatoes after storage at 5 and 20 °C [29]. Effect of storage of potatoes was also studied at 4 or 20 °C for 110 days on phenolic content [30]. There was not any significant difference in total phenolic content, chlorogenic acid, caffeic acid and vanillic acid were observed after storage at 4 or 20 °C. There was an increase in rutin, p-coumaric acid and quercetin dehydrate contents after storage at 4 or 20 °C. When 4 °C stored potato tubers were reconditioned for 10 days at 20 °C, there was a significant increase in total phenolic content, chlorogenic acid, caffeic acid, rutin, vanillic acid, p-coumaric acid, and quercetin dehydrate levels. Stushnoff *et al*. (2008) analyzed total phenolics from 8 potato genotypes after 112 and 263 days of storage at 5 °C. Two genotypes showed the sharp rise in total phenolic content after storage, four genotypes showed the increase to a lesser extent whereas, the two genotypes showed little change [31]. Rosenthal and Jansky (2008) observed that stored tubers had higher levels of antioxidant activity than fresh tubers [32]. Jansen and Flamme (2006) recorded that the anthocyanin content of potato tubers in 14 cultivars immediately after harvest and after 135 days of storage at 4 °C and 86% relative humidity, and they did not find any significant change in anthocyanin content of potato tubers [18]. The fact that cold storage had no significant effect on the anthocyanin content of potatoes indicates that there is no risk of degradation of these compounds during storage of potatoes over a longer period. Potatoes are stored at 4 °C in cold storage in countries such as India [33].

Flavonoids

The Range of flavonoids content in potatoes varies from 200 to 300 μg / g fresh weight [17]. The flavonoids, in order of profusion, were reported to be catechin, epicatechin, eriodyctiol, kaempferol and naringenin [34]. Flavonoids such as anthocyanins present in substantial amounts in pigmented flesh potatoes and range vary between 5.5 and 35mg/100 g fresh weight in potato tubers [35]. Purple or red fleshed potato cultivars had two times the flavonoid concentration than that of white-fleshed cultivars and their concentration was significantly higher in skin, impending 900 mg in purple-fleshed and 500 mg in red-fleshed types per 100 g fresh weight [17]. Anthocyanin pigments lie in the periderm of potatoes and impart different colors to their skin i.e., purple being the most common color. The pigmented potatoes may serve as a potential source of natural anthocyanin pigments since these are low expenditure crops [18] and also an influential source of antioxidant micronutrients [36]. The purple fleshed potatoes had privileged anthocyanins as compared to red-fleshed potatoes. The purple and red fleshed potatoes could be used as narrative sources of natural colorants and antioxidants by the food industry for better human health [37]. Chu *et al*., (2000) found that the flavonoids and flavones extracts had high scavenging activities toward oxygen free radicals [38]. Potatoes showed 94% scavenging activity towards hydroxyl radicals and almost complete inhibition of superoxide radicals along with anions. The various biotechnological and transgenic approaches have shown that it is possible to markedly increase the phenolic content, anthocyanins and flavonoid contents of potato tubers [39].

Phytonutrients content of potatoes is influenced by environmental conditions and developmental stage. Potatoes harvested at a young developmental stage had higher concentrations of some phytonutrients such as folate and chlorogenic acid than mature potato tubers [40, 14]. Total carotenoids content was found to be higher in immature potato tubers and it decreased with tuber maturity [41, 42]. "Baby potatoes" or immature potatoes contain higher amounts of phytonutrients than mature potatoes. Reyes *et al*., (2004) observed that the anthocyanins and total phenolic content in tubers decreased with tuber growth and maturity but total yield per ha of these compounds increased throughout the time [37]. Harvesting at later maturity stages maximized total yield of potatoes, anthocyanin, total phenolic content and minimized glycoalkaloid content, thus increasing the commercial and nutritional value of purple and red flesh potatoes. Jansen and Flamme (2006) determined the anthocyanin content of tubers from plants grown at two doses of nitrogen fertilizers i.e. 100 and 200 kg/ha and found no significant difference [18]. Kotikova *et al*. (2007) investigated the influence of different fertilization levels with different doses of N, P, K and Mg nutrients [41]. The application of fertilizers did not bring any significant changes in anthocyanin and carotenoids content of potato tubers. It was suggested that application of synthetic fertilizers make the nitrogen available, which is utilized for growth but not allocated for the production of secondary metabolites such as phenolic content. Faller and Fialho (2009) compared organically grown potato tubers with conventionally grown potato tubers and there was no any significant difference in their soluble and hydrolyzable polyphenolic content [43]. Rosenthal and Jansky (2008) also

did not find any consistent effect of production system on antioxidant activity in tubers [32]. Effect of location for crop growth on phytochemicals content has been studied by several researchers. Ezekiel *et al*. (2008) did not find any significant differences in the total phenolic content of potatoes of two varieties grown at three locations in the North Indian plains having similar altitude but varying in temperatures during crop growth [28]. Location of crop growth i.e., coastal area and plains did not have a significant effect on the anthocyanin content of potato tubers [18]. It was concluded that the level of anthocyanin was not affected by the environmental conditions and it was primarily dependent on the genotype. Potatoes grown at two locations differing in altitude showed no significant difference in the total carotenoids content [41]. However, a significant effect of location on anthocyanin and total phenolics was observed by Reyes *et al*. (2004) [37]. The anthocyanins and total phenolic content of potato tubers were enhanced when tubers were grown in a location with cooler temperatures and longer days with higher solar radiation and 2.5 and 1.4 times, respectively, higher anthocyanins and total phenolic content were found under such conditions. It appears that temperature during crop growth can affect the phytochemicals content. Potatoes were grown at 3 locations varying in altitude viz, 203, 960 and 1250 masl. Higher anthocyanins content were observed at the higher elevation, however, total carotenoids were not affected [35]. Andre *et al*. (2009) determined the effect of environment and genotype on polyphenols content and in vitro antioxidant capacity of native Andean potatoes and observed a high stability in the ranking of cultivars across environment in terms of phenolic content and antioxidant capacity, indicating that these Andean cultivars could be used in breeding programmes for improving the phenolic content [44]. Conflicting results have been reported with respect to year of crop growth. Jansen and Flamme (2006) compared the anthocyanin contents in tubers of 23 cultivars grown during two years and found that there was no significant difference between years in the anthocyanin content of tubers although the weather conditions during plant growth were different during the two years (the weather during summer was cool and wet during one year and warm and dry during the next year) [18]. Kotikova *et al*. (2007) found that year of cultivation had a significant effect on total carotenoids content [41]. Stushnoff *et al*. (2008) observed environmental conditions produced the year to year variation in total phenolics levels [31]. Rosenthal and Jansky (2008) observed the significant effect of the year. They determined antioxidant levels in tubers of 14 specialty potato clones grown at four production sites i.e., two conventional, two organics for two years [32]. Year of cultivation showed significant effect on antioxidant activity higher in 2006 than in 2005 and attributed the increased levels of antioxidants to cooler late season temperatures in 2006. Chemical haulm desiccation was reported to have no significant effect on the concentration of antioxidants [45].

Folate

Potatoes do not have high folate content, but they are a major source of folate due to their higher consumption. Potatoes supply about 10% of the total folate intake of the people in European countries such as Netherlands, Norway, and Finland [46]. Folate concentration in potato varies between 12 and 37 μg /100 g fresh weight [47]. The range of Folate content was reported 11 to 35 μg/100 g fresh weight in more than 70 potato cultivars, wild species and highly developed hybrids [48]. It has also been reported that yellow fleshed potatoes rich source of folate. Antioxidants such as ascorbic acid were also reported to shelter folates against oxidative degradation [49].

Kukoamines

Kukoamines are conjugated polyamine and they are considered to have health promoting possessions, which are yet to be well established. Kukoamines in potato tubers was firstly reported by [50]. Further studies on these compounds are desired to understand their stability, beneficial effects and various roles in other functions. These polyamines have been recommended to play a role in the regulation of starch biosynthesis [51] and making the potato tubers disease resistant [52].

Carotenoids

Potatoes are the rich source of carotenoids, which are lipophilic compounds and synthesized in plastids from isoprenoids [53]. Lutein, violaxanthin, zeaxanthin, and neoxanthin are the major carotenoids present in potatoes and β-carotene are present in trace amounts. The orange and yellow flesh colored tuber is due to zeaxanthin and lutein, respectively. Potato cultivars with white flesh contained fewer carotenoids as compared to cultivars with yellow or

orange flesh. Total carotenoids content was reported in the range of 50–350 μg/100 g fresh weight and 800–2000 μg/100 g fresh weight, respectively, in white and yellow fleshed potato cultivars [54]. Some of the research workers have been able to increase carotenoids content considerably using transgenic approaches. Ducreux *et al*. (2005) conducted an experiment to increase tuber carotenoids content from 5.6 to 35 μg / g dry weight of *cv*. Desiree by over expressing a bacterial phytoene synthase. They also observed the large increase in the levels of individual carotenoids, β-carotene, and lutein [55]. It was recorded that 50% of the recommended daily allowance of vitamin A can be met by consuming 250 g of carotenoids enriched genetically engineered potatoes [56]. Morris *et al*. (2004) have been reported more than 20 fold of carotenoid concentrations in potato germplasm. Breithaupt and Bamedi (2002) studied that the carotenoid pattern of four yellow-fleshed and four white-fleshed German potato cultivars (Solanum tuberosum L.). The carotenoid pattern was dominated by violaxanthin, antheraxanthin, lutein, and zeaxanthin, which were present in different ratios, whereas neoxanthin, β-cryptoxanthin, and β-carotene were only minor constituents. Andean potatoes provide a rich and varied source of carotenoids [57]. Andre, Ghislain, *et al*. (2007) recorded a range of 3 to 36 μg/g dry weight for total carotenoids among 74 Andean landraces [58]. In another study, Andre, Oufir, *et al*. (2007b) screened 24 Andean cultivars and identified genotypes containing a high concentration of lutein (1.12–17.69 μg/g dry weight) and zeaxanthin (18 μg/g dry weight) and β-carotene (2 μg/g dry weight) [59].

Dry matter and Starch Content

The dry matter content of potato varied with genotype [60, 61]. The increase in dry matter is undoubtedly a heritable character but is also affected by a number of environmental factors [62, 63]. Kumlay *et al*. (2002) observed that dry matter content of potato increased bit by bit from the first sample date, though at last sampling date (harvest time), the dry matter content was almost stable [64]. Kumar and Ezekiel (2006a) investigated two early maturing potato cultivars, viz. the Indian variety Kufri Lavkar and the exotic variety Atlantic, for dry matter content changes during tuber growth and observed that relatively the poor processing cultivar Kufri Lavkar maintained lower dry matter as compared to Atlantic throughout the growth and irrespective of the tuber size [65]. Ezekiel and Rani (2006) recorded the dry matter content of 33 potato genotypes tubers from 16.3 to 26.2% [66]. It was observed that the physiologically mature tubers had maximum dry matter content [67]. Ezekiel and Singh (2007) recorded a little change in dry matter content of potato during storage, and among the varieties, they recorded higher dry matter content in Kufri Sindhuri and Kufri Chipsona 1 [24]. On the other hand, Kumar *et al*. (2005) observed that Kufri Chipsona 2 had considerably higher dry matter content (22.7%) than Kufri Chipsona 1 (21.2%) [68]. Asmamaw *et al*. (2010) reported a progressive reduction in dry matter content with the increase in storage time. They also reported that the cultivars with high dry matter content maintained better quality than the cultivars with lower dry matter content [69]. The dry matter content increased during storage and this increase was considerable 120 days after storage [26]. Dry matter percentage of potato increased with increasing lifting period and tuber size in respect of increasing the storage period [70]. The instant reason of sugar end is a modification in the tuber from starch production to starch decomposition and rapid activity of enzyme ‘acid invertase' which convert sucrose to the reducing sugars (fructose and glucose) [71]. High dry matter and starch content in autumn might be due to the higher translocation of photosynthesis and synthesis of starch under low temperatures and short day condition during growth [72]. During potato tuber development phase, chemical maturity (chemical accumulation) is followed by physiological maturity (dry matter accumulation). In a post-harvest study of potato, [60] and Lana *et al*. (1970) observed that starch content varied with genotype [61]. Kumar *et al*. (2005) observed that starch content was positively correlated with specific gravity (r= 0.77) and dry matter content (r= 0.79) [68]. Kumlay *et al*. (2002) observed that starch content of potato increased gradually from the first sample date, but at last sampling date (harvest time), the starch content of potato was almost stable [64]. According to Feltran *et al*. (2004), the starch content had a positive correlation with a specific gravity of potato [73].

Ascorbic acid

Apart from a supply of energy and high-quality protein, a potato has also been documented as an important source of vitamin and minerals and also as a valuable source of scurvy preventive Vitamin C, more commonly known as ascorbic acid. Ascorbic acid being anti-oxidant also enhances the absorption and internal transport of dietary iron and zinc from other plant sources as it is a strong reducing agent in plant metabolism. Potato tubers reported to contain up to 46 mg of ascorbic per 100g tubers on the fresh weight basis and its availability depends on the variety, maturity status and the environmental conditions under which crop is grown. Ascorbic acid concentration in freshly harvested

peeled raw tubers ranged from 22.2 to 121.4 mg/100 g on a dry weight basis and from 6.5 to 36.9 mg/100 g on a fresh weight basis, which decreased with the increase in storage period in tubers of all the varieties. However, Ezekiel and Rani (2006) recorded that the ascorbic acid value increased up to 30 days of storage and then decreased up to 120 days of storage. Ascorbic acid concentration in freshly harvested peeled raw tubers ranged from 22.2 to 121.4 mg/100 g on a dry weight basis and from 6.5 to 36.9 mg/100 g on a fresh weight basis, which decreased with the increase in storage period in tubers of all the varieties [66]. In a study, Singh *et al*. (2005) assessed that ascorbic acid although was numerically maximum in Kufri Chandramukhi (16.9 mg), but statistically, it was on par with hybrid JH-214, Kufri Jyoti and Kufri Ashoka [22]. Finlay *et al*. (2003) observed a statistically significant difference in total ascorbate concentration among the genotypes both at harvest and after storage, which decreased during storage in all the genotypes [101]. However, Ezekiel and Rani (2006) recorded that the ascorbic acid value increased up to 30 days of storage and then decreased up to 120 days of storage [66]. Burgos *et al*. (2009) determined the ascorbic acid concentration of tubers in 25 Andean potato varieties grown in three environments and found a significant variation due to genotype, environment, and interaction of genotype and environment [74].

Sugars

The sugar level in potato during suberization and at harvest is largely dependent on cultivar [76]. Low sugar content is a desirable character for processing purpose. Sucrose content at the time of harvest is an indicator of the chemical maturity of the tuber. The higher values of sucrose in potato tuber at the time of harvest indicate its immaturity. The sucrose content at harvest is very important because when hydrolyzed by invertase it results in accumulation of reducing sugars making the potatoes unfit for processing [72].Increase in total sugars or a particular sugar and dry matter is a heritable character but is also affected by a number of environmental factors [63]. The sugar level in potatoes during tuberization and at harvest is largely dependent on cultivar. Quantity and kind of sugars in particular cultivar are inherited characteristics [75].

Different varieties were tested for processing; all the new varieties contained more than the acceptable limits (0.25%) of reducing sugars for processing. though they can be processed into French fries as they had less than 0.5 percent of reducing sugars [72]. The reducing sugar ranged from 13.2 mg/100 g fresh weight in cv. Atlantic to 35.7 mg/ 100g fresh weight in heat tolerant hybrid HT/92-621 during the early autumn crop. The values were 110.7 in FL-1533 to 263.8mg/100g fresh weight in Kufri Chipson-2. At Sadabad the sucrose values ranged from 103.76 in Kufri Jyoti to 192.51 mg/100g fresh weight in Kufri Chipson-2. The maximum values of sucrose in Kufri Chipsona-2 indicated its immaturity at the time of harvest [76]. At harvesting stage, both sucrose and glucose contents need to be at lower level. The variety ‘Millennium Russet' contained the minimum average sucrose contents during both years of trial, indicating that this variety was chemically more mature at harvest in contrast to Umatilla and Defender [77]. The higher acceptable limit of reducing sugar content is 150 mg/100g fresh weight Varieties used for the production of potato chips were usually low in reducing sugars. A major decrease in the reducing sugar content was observed with an increasing underwater weight [78]. The reducing sugar content in the hybrid HT/92-621 was far lower (19.21-61.56mg/100g fresh weight) than the higher limit of acceptable values for chips (<0.25 percent) or French fries (<0.5%). The mean sucrose values in the hybrid HT/92-621 were similar to cv. Kufri Chipsona -1 and were considerably lower than Kufri chipsona-2 [65].

Both glucose and sucrose accumulation were normally much lower in 2003 compared to 2002 during an experiment. Chipeta, Cherry Red, and Durango Red had the minimum sugar of the seven cultivars [67]. The potato variety Kufri Jyoti had high levels of reducing sugars 75.7-240.7 mg/100g fresh it and produced unacceptable chips of dark color. Conversely, processing varieties contained higher dry matter content 19.3-23.3 percent lowers content of reducing sugars 21.0- 57.7 mg/100g fresh weight [79]. Kumar and Ezekiel (2006b) assessed two early maturing potato cultivars, viz. the Indian var. Kufri Luvkar and the exotic var. Atlantic, for sucrose, changes during tuber growth and noted that relatively, the poor processing var. Kufri Luvkar maintained higher sucrose content as compared to Atlantic throughout the growth and irrespective of tuber size. They obtained a negative correlation between free sugars vis-à-vis crop duration and tuber size [80]. The increase in reducing sugar contents took place subsequent to increase in sucrose content. Storage also induced a marked increase in sucrose content [24]. The different genotypes had different content of reducing sugars [60, 61].

A mature potato had a lower content of reducing sugars [78]. Kumar and Ezekiel (2006b) evaluated two early maturing potato cultivars, viz. the Indian cv. Kufri Luvkar and the exotic cv. Atlantic, for reducing sugars changes during tuber growth and noted that comparatively, the poor processing cv. Kufri Luvkar maintained the higher content

of reducing sugars (43.74 mg/100 g on fresh weight) as compared to cv. Atlantic (14.68 mg/100 g on a fresh weight basis) throughout the growth and irrespective of the tuber size but this increase in the content of reducing sugars took place subsequent to increase in sucrose content [80]. Storey (2007) reported that potato tubers contained 0.01-0.6% reducing sugars on fresh weight basis [81]. Ezekiel and Singh, (2007) reported that reducing sugars increased during storage and out of the seven varieties grown at Modipuram, only Kufri Chipsona 1 showed lower reducing sugars [24].

Upon handling, the glucose content changed less markedly than sucrose but its level appeared slightly higher at most intervals as compared to control values. Storage also induced a marked increase in the sucrose content. Pandey *et al*. (2008) evaluated two potato varieties for reducing sugars and found that the tubers of Kufri Himsona had lower levels of reducing sugars and variety Kufri Jyoti higher reducing sugars (206.7 mg/100 g on fresh weight) [82]. Also according to Shabba *et al*. (2007), the quantity and kind of sugars in particular cultivar are the inherited characteristics. Potato accumulated a lot of sugars under conditions of high-temperature storage (Singh and Verma, 1979). An increase in total sugars or a particular sugar is indubitably a heritable character but is also affected by a number of environmental factors [62, 63]. The sugar level in potato tubers during tuberization and at harvest is largely dependent on cultivar [75].

The accumulation of sucrose in large quantities in tubers stored at high temperature or farm stores had been reported earlier [83, 72]. In potato, more than 65% of the maximal sucrose accumulation occurred within 5 days of storage since potato increased its ability to produce sucrose as the storage period increased [71]. Zhitian *et al*. (2002) observed that the sucrose concentration in potato increased early in storage and then remained constant [84]. Kumar (2011) studied the development of cold-induced sweetening and its relation with phenolic content of the tuber in three Indian potato varieties, viz. Kufri Chipsona 1, Kufri Chipsona 3, and Kufri Jyoti and observed that the reducing sugars decreased in an initial phase of storage, followed by the continuous increase to unacceptably higher levels after around two weeks of storage [85]. The reduction in reducing sugars at high temperature might be due to low activities of invertase or synthesis of invertase inhibitors [86]. Potato storage in ordinary rooms, traditional heaps, etc. at the relatively higher temperature (25-30ºC) showed very little increase in reducing sugars [23]. The exotic cultivar Atlantic and Frito-Lay 1625 showed negligible accumulation of reducing sugars and invertase activities as compared to Indian cultivar Kufri Luvkar and Kufri Jyoti during storage at 6°C for 90 days, and there was a general trend of decline in content of reducing sugars and invertase activity at higher temperature (20°C) of storage [87]. When mature tubers were stored at relatively high temperature, the concentration of reducing sugars remained low [88]. The freshly harvested mature tubers of a few Indian potato cultivars contain low level of reducing sugars [89]. The glucose concentration increased early in storage and then remained constant [84]. Kumar *et al*. (2003) monitored potato tubers of Kufri Chipsona 1, Kufri Chipsona 2 and Atlantic-harvested in the first week of February for changes in reducing sugars and sucrose content for 40 days at room temperature and noticed that reducing sugars decreased after 20 days of storage [90].

Potato accumulated a lot of sugars under conditions of high-temperature storage [91]. An increase in total sugars or a particular sugar is indubitably a heritable character but is also affected by a number of environmental factors [62, 63]. The sugar level in potato tubers during tuberization and at harvest is largely dependent on cultivar [75]. Also according to Shabba *et al*. (2007), the quantity and kind of sugars in particular cultivar are the inherited characteristics [67].

Advances in Analytical Techniques

For the quantification of individual phenolic compounds, HPLC-DAD (diode array detector) analysis was done by Andre *et al*., 2009 [44]. The pH differential method can be used for measuring Anthocyanins (Giusti &Wrolstad, 2001). The various detector methods like HPLC/DAD/MS and HPLC-DAD/ESIMS/MS have been used for the identification of anthocyanins and anthocyanidins [92, 93]. Bonierbale *et al*. (2009) developed near infrared reflectance spectroscopy calibrations and found this to be a low-cost method useful for the characterization of potato germplasm for the estimation of total carotenoids and zeaxanthin concentrations. This method is particularly useful to scientists and researchers for screening a large germplasm collection [94]. Oxygen Radical Absorbance Capacity (ORAC) is a measure of the capacity of an antioxidant to delay the oxidation of a target molecule. Brown in 2008 stated that Hydrophilic Oxygen Radical Absorbance Capacity (H-ORAC) is used for hydrophilic anthocyanins, and lipophilic-Oxygen Radical Absorbance Capacity (L-ORAC) is used for detecting lipophilic carotenoids [54]. Starch from sugar-free pellet obtained after the extraction of total sugar is estimated by using the method of Clegg (1956)

[95]. The content of non-reducing sugar is obtained by subtracting the values of reducing sugars from that of total sugars and multiplying the value with 0.95 [96]. Reducing sugars are estimated by using a method of Somogyi (1945) [97]. The total sugar is estimated by using the method of Yemm and Willis (1954) [98]. Ascorbic acid content is estimated by using the method given by AOAC (1980), which is based on the reduction of 2, 6 dichlorophenol indophenols (2, 6-DCPIP) by ascorbate. Total phenolic content is generally estimated using the method of Swain and Hillis (1959) [99] or Folin Ciocalteu assay (Singleton & Rossi, 1965) [100].

Conclusions

The research in potato chemistry has established various facts about the biochemical and phytochemical properties that there is a lot more in potatoes than starch. Phytochemicals content and various biochemicals in potatoes can be enhanced by emerging various new cultivars from available germplasm high in these compounds. Natural colorant and antioxidant present in purple and red flesh potatoes can be used for developing functional nutraceuticals compounds. Considering the large quantities of potatoes are consumed throughout the whole world so potatoes could be a very good vehicle for addressing some health related problems. All the biochemical and phytochemical properties of potatoes above discussed greatly depend on the cultivars, various agronomic cultural practices, pre-sowing conditions and post-harvest conditions. The processing quality attributes depend upon the level of certain biochemical compounds like dry matter, starch content, sugar level, ascorbic acid, phenol content etc. Pigmented potatoes may also serve as a prospective source of natural anthocyanins for use in the food industry and processing industries since the cost of production of potatoes is relatively low as compared to other horticultural crops. In addition, a potato is a high yielding crop and the cultural and storage practices are well established.

References

[1] Katan, M. B., & De Roos, N. M. (2004). Promises and problems of functional foods. Critical Reviews in Food Science and Nutrition, 44, 369–377.

[2] McCay, C. M., McCay, J. B., & Smith, O. (1987). The nutritive value of potatoes. In W. F. Talburt, & O. Smith (Eds.), Potato processing (pp. 287–332). New York: Van Nostrand Reinhold.

[3] Nzaramba, M. N., Bamberg, J. B., & Miller, J. C., Jr. (2007). Effect of propagule type and growing environment on antioxidant activity and total phenolic content in potato germplasm. American Journal of Potato Research, 84, 323–330.

[4] Tamuly, C., Saibia, B., Hazarika, M., Bora, J., Bordoli, M.J. and Sahu, O.P. Correlation between phenolic, flavonoid, and mineral contents with antioxidant activity of underutilized vegetables, International Journal of Vegetable Sciences, 19(1), 2013.

[5] Babbar, N., Oberoi, H. S., Uppal, D.S. and Patil, R.T. Total phenolic content and antioxidant capacity of extracts obtained from six important fruit residues, Food Research International, 44, 2011, 391-396.

[6] Ross, J. A., & Kasum, C. M. (2002). Dietary flavonoids: Bioavailability, metabolic effects, and safety. Annual Review of Nutrition, 22, 19–34.

[7] Manach, C., Scalbert, A., Morand, C., Remesy, C., & Jimenez, L. (2004). Polyphenols: Food sources and bioavailability. The American Journal of Clinical Nutrition, 79, 27–747.

[8] Bravo, L. (1998). Polyphenols: Chemistry, dietary sources, metabolism and nutritional significance. Nutrition Reviews, 56, 317–333.

[9] Al-Saikhan, M. S., Howard, L. R., & Miller, J. C., Jr. (1995). Antioxidant activity and total phenolics in different genotypes of potato (Solanum tuberosum L.). Journal of Food Science, 60, 341–343.

[10] Chun, O. K., Kim, D. O., Smith, N., Schroeder, D., Han, J. T., & Lee, C. Y. (2005). Daily consumption of phenolics and total antioxidant capacity from fruit and vegetables in the American diet. Journal of the Science of Food and Agriculture, 85, 1715–1724.

[11] Talburt, W. F., Schwimmer, S., & Burr, H. K. (1987). Structure and chemical composition of the potato tuber. In W. F. Talburt, & O. Smith (Eds.), Potato processing (pp. 11–46). New York: Van Nostrand Reinhold.

[12] Mattila, P., & Hellstrom, J. (2007). Phenolic acids in potatoes, vegetables, and some of their products. Journal of Food Composition and Analysis, 20, 152–160.

[13] Lewis, C. E., Walker, J. R. L., & Lancaster, J. E. (1999). Changes in anthocyanin, flavonoid and phenolic acid concentrations during development and storage of coloured potato (Solanum tuberosum L.) tubers. Journal of the Science of Food and Agriculture, 79, 311–316.

[14] Navarre, D. A., Shakya, R., Holden, M., & Kumar, S. (2010). The effect of different cooking methods on phenolics and vitamin C in developmentally young potato tubers. American Journal of Potato Research, 87, 350–359.

[15] Toledo, A., & Burlingame, B. (2006). Biodiversity and nutrition: A common path toward global food security and sustainable development. Journal of Food Composition and Analysis, 19, 477–483.

[16] Andre, C. M., Oufir, M., Hoffmann, L., Hausman, J. F., Rogez, H., Larondelle, Y., & Evers, D. (2009). Influence of environment and genotype on polyphenol compounds and in vitro antioxidant capacity of native Andean potatoes (Solanum tuberosum L). Journal of Food Composition and Analysis, 22, 517–524.

[17] Lewis, C. E., Walker, J. R. L., Lancaster, J. E., & Sutton, K. H. (1998). Determination of anthocyanins, flavonoids and phenolic acids in potatoes. I: Coloured cultivars of Solanum tuberosum L. Journal of the Science of Food and Agriculture, 77, 45–57.

[18] Jansen, G., & Flamme, W. (2006). Coloured potatoes (Solanum Tuberosum L.) —Anthocyanin content and tuber quality. Genetic Resources and Crop Evolution, 53, 1321–1331.

[19] Fossen, T., Øvstedal, D. O., Slimestad, R., & Andersen, Ø. M. (2003). Anthocyanins from a Norwegian potato cultivar. Food Chemistry, 81, 433–437.

[20] Eichhorn, S., & Winterhalter, P. (2005). Anthocyanins from pigmented potato (solanum tuberosum L.) varieties. Food Research International, 38, 943–948.

[21] Burlingame, B., Mouille, B., & Charrondiere, R. (2009). Nutrients, bioactive non-nutrients and anti-nutrients in potatoes. Journal of Food Composition and Analysis, 22, 494–502.

[22] Singh, R.K., Marwaha, R.S., Sharma, J. and Singh, S., 2005. Antioxidant status and tuber yield in different potato cultivars. Potato Journal, 32(3): 199-200.

[23] Uppal, D.S. and Verma, S.C., 1987. Role of invertase in the accumulation of sugars in potato tubers stored at different temperature. In: Abstract of 10th Triennia Conference, EAPR, Aalborg, Denmark, pp. 32-33.

[24] Ezekiel, R. and Singh, B., 2007. Changes in contents of sugars, free amino acids and phenols in four varieties of potato tubers stored at five temperatures for 180 days. Journal of Food Science and Technology, 44(5): 471-477.

[25] Kumar, D., & Ezekiel, R. (2009). Changes in glycoalkaloids and phenolic contents inpotato tubers stored under different conditions. Journal of Food Science and Technology, 46, 480–483.

[26] Ezekiel, R., Singh, B., Kumar, A., Mehta, D. and Dutta, R., 2011. Processing quality of potatoes at different low holding temperature. Indian Journal of Horticulture, 68(3): 408-412.

[27] Ezekiel, R., Paul, V., Singh, B., Peshin, A., & Shekhawat, G. S. (2000). Effect of low temperature, desprouting and gibberellic acid treatment on little tuber formation on potatoes during storage. Journal of Indian Potato Association, 27, 13–23.

[28] Ezekiel, R., Singh, B., and Datta, P. S. (2008). Chipping quality of γ-irradiated potatoes of three Indian cultivars stored at 8, 12 and 16 °C. Journal of Food Science and Technology, 45, 36–43.

[29] Mondy, N. L., & Gosselin, B. (1989). Effect of irradiation on discolouration, fenouls and lipids of potatoes. Journal of Food Science, 54, 982–984.

[30] Blessington, T., Nzaramba, M. N., Scheuring, D. C., Hale, A. L., Reddivari, L., & Miller, J. C., Jr. (2010). Cooking methods and storage treatments of potato: Effects on carotenoids, antioxidant activity, and phenolics. American Journal of Potato Research, 87, 479–491

[31] Stushnoff, C., Holm, D., Thomson, M. D., Jiang, W., Thompson, H. J., Joyce, N. I., et al. (2008). Antioxidant properties of cultivars and selections from the Colorado potato breeding programme. American Journal of Potato Research, 85, 267–276.

[32] Rosenthal, S., & Jansky, S. (2008). Effect of production site and storage on antioxidant levels in speciality potato (Solanum tuberosum L.) tubers. Journal of the Science of Food and Agriculture, 88, 2087–2092.

[33] Gottschalk, K., & Ezekiel, R. (2006). Storage. In J. Gopal, & S. M. P. Khurana (Eds.), Handbook of potato (pp. 489–522). New York: Food Products Press.

[34] Brown, C. R., Culley, D., Yang, C., Durst, R., &Wrolstad, R. (2005). Variation of anthocyanin and carotenoid contents and associated antioxidant values in potato breeding lines. Journal of the American Society for Horticultural Science, 130, 174–180.

[35] Brown, C. R. (2008). Breeding for phytonutrient enhancement of potato. American Journal of Potato Research, 85, 298–307.
[36] Andre, C. M., Oufir, M., Guignard, C., Hoffmann, L., Hausman, J. F., Evers, D., & Larondelle, Y. (2007). Antioxidant profiling of native Andean potato tubers (Soanum tuberosum L.) reveals cultivars with high levels of β-carotene, α-tocopherol, chlorogenic acid, and petanin. Journal of Agricultural and Food Chemistry, 55, 10839–10849.
[37] Reyes, L. F., Miller, J. C., Jr., & Cisneros-Zevallos, L. (2004). Environmental conditions influence the content and yield of anthocyanins and total phenolics in purple- and red-flesh potatoes during tuber development. American Journal of Potato Research, 81, 187–193.
[38] Chu, Y. H., Chang, C. L., & Hsu, H. F. (2000). Flavonoid content of several vegetables and their antioxidant activity. Journal of the Science of Food and Agriculture, 80, 561–566.
[39] Lukaszewicz, M., Matysiak-Kata, I., Skala, J., Fecka, I., Cisowski, W., & Szopa, J. (2004). Antioxidant capacitymanipulation in transgenic potato tuber by changes in phenolic compounds content. Journal of Agricultural and Food Chemistry, 52, 1526–1533.
[40] Goyer, A., & Navarre, D. A. (2009). Vitamin B9 is higher in developmentally younger potato tubers. Journal of the Science of Food and Agriculture, 89, 579–583.
[41] Kotikova, Z., Hejtmankova, A., Lachman, J., Hamouz, K., Trnkova, E., & Dvorak, P. (2007). Effect of selected factors on total carotenoid content in potato tubers (Solanum tuberosum L.). Plant Soil Environment, 53, 355–360.
[42] Morris, W. L., Ducreux, L., Griffiths, D. W., Stewart, D., Davies, H. V., & Taylor, M. A. (2004). Carotenogenesis during tuber development and storage in potato. Journal of Experimental Botany, 55, 975–982.
[43] Faller, A. L. K., & Fialho, E. (2009). The antioxidant capacity and polyphenol content of organic and conventional retail vegetables after domestic cooking. Food Research International, 42, 210–215.
[44] Andre, C. M., Oufir, M., Hoffmann, L., Hausman, J. F., Rogez, H., Larondelle, Y., & Evers, D. (2009). Influence of environment and genotype on polyphenol compounds and in vitro antioxidant capacity of native Andean potatoes (Solanum tuberosum L). Journal of Food Composition and Analysis, 22, 517–524.
[45] Bouno, V., Paradiso, A., Serio, F., Gonnella, M., De Gara, L., & Santamaria, P. (2009). Tuber quality and nutritional components of "early" potato subjected to chemical haulm desiccation. Journal of Food Composition and Analysis, 22, 556–562.
[46] Navarre, D. A., Goyer, A., & Shakya, R. (2009). Nutritional value of potatoes. Vitamin, phytonutrient and mineral content. In J. Singh, & L. Kaur (Eds.), Advances in potato chemistry and technology (pp. 395–424). Austerdam: Elsevier.
[47] Konings, E. J., Roomans, H. H., Dorant, E., Goldbohm, R. A., Saris, W. H., & van den Brandt, P. A. (2001). Folate intake of the Dutch population according to newly established liquid chromatography data for foods. The American Journal of Clinical Nutrition, 73, 765–776.
[48] Goyer, A., & Navarre, D. A. (2007). Determination of folate concentrations in diverse potato germplasm using a trienzyme extraction and a microbiological assay. Journal of Agricultural and Food Chemistry, 55, 3523–3528.
[49] McNulty, H., & Pentieva, K. (2004). Folate bioavailability. The Proceedings of the Nutrition Society, 63, 529–536.
[50] Parr, A. J., Mellon, F. A., Colquhoun, I. J., & Davies, H. V. (2005). Dihydrocaffeoyl polyamines (kukoamine and allies) in potato (Solanum tuberosum) tubers detected during metabolite profiling. Journal of Agricultural and Food Chemistry, 53, 5461–5466.
[51] Tanemura, Y., & Yoshino, M. (2006). Regulatory role of polyamine in the acid phosphatase from potato tubers. Plant Physiology and Biochemistry, 44, 43–48.
[52] 52. Matsuda, F., Morino, K., Ano, R., Kuzawa, M., Wakasa, K., & Miyagawa, H. (2005). Metabolic flux analysis of the phenylpropanoid pathway in elicitor-treated potato tuber tissue. Plant & Cell Physiology, 46, 454–466.
[53] DellaPenna, D., & Pogson, B. J. (2006). Vitamin synthesis in plants: Tocopherols and carotenoids. Annuual Review of Plant Biology, 57, 711–738.
[54] Brown, C. R. (2008). Breeding for phytonutrient enhancement of potato. American Journal of Potato Research, 85, 298–307.

[55] Ducreux, L. J. M., Morris, W. L., Hedley, P. E., Shepherd, T., Davis, H. V., Millam, S., & Taylor, M. A. (2005). Metabolic engineering of high carotenoid potato tubers containing significant levels of beta-carotene and lutein. Journal of Experimental Botany, 56, 81–89.

[56] Diretto, G., Al-Babili, S., Tavazza, R., Papacchioli, V., Beyer, P., & Giuliano, G. (2007). Metabolic engineering of potato carotenoid content through tuber-specific overexpression of a bacterial mini-pathway. PloS One, 2, e350.

[57] Breithaupt, D. E., & Bamedi, A. (2002). Carotenoids and carotenoid esters in potatoes (Solanum tuberosum L): New insights into an ancient vegetable. Journal of Agricultural and Food Chemistry, 50, 7175–7181.

[58] Andre, C. M., Ghislain, M., Bertin, P., Oufir, M., Herrera Mdel, R., Hoffmann, L., Hauseman, J. F., Larondelle, Y. E., & Evers, D. (2007). Andean potato cultivars (Solanum tuberosum L.) as source of antioxidant and mineral micronutrients. Journal of Agricultural and Food Chemistry, 55, 366–378.

[59] Andre, C. M., Oufir, M., Guignard, C., Hoffmann, L., Hausman, J. F., Evers, D., & Larondelle, Y. (2007). Antioxidant profiling of native Andean potato tubers (Soanum tuberosum L.) reveals cultivars with high levels of β-carotene, α-tocopherol, chlorogenic acid, and petanin. Journal of Agricultural and Food Chemistry, 55, 10839–10849.

[60] Kunkel, R., Gifford, P.F., Edgar, A.D. and Binkey, A.M., 1952. The Mechanical Separation of Potatoes into Specific Gravity Groups. Agriculture Experimental Station Bulletin, No. 422A.

[61] Lana, E.P., Johansen, R.H. and Nelson, D.C., 1970. Variation in specific gravity of potato tubers. American Potato Journal, 47: 9-12.

[62] Burton, W.G., 1989. Yield and content of dry matter: The underlying physiological processes. In: The Potato (Ed. Burton, W.G.). Longman Scientific and Technical, New York, USA, pp. 84-155.

[63] Ezekiel, R., Verma, S.C., Sukumaran, N.P. and Shekhawat, G.S., 1999. A Guide to Potato Processor in India. Technical Bulletin No. 48, Central Potato Research Institute, Shimla, India, pp. 14-39.

[64] Kumlay, A.M., Kaya, C., Olgun M., Dursun, A., Pehluvan, M. and Dizikisa, T., 2002. Comparison of seasonal change of specific gravity, dry matter accumulation and starch content of four potato (Solanum tuberosum L.) varieties. Acta Horticulturae, 579: 255-258.

[65] Kumar, D. and Ezekiel, R., 2006a. Developmental changes in sugars and dry matter content of potato tuber under sub-tropical climates. Scientia Horticulturae, 110(2): 129-134.

[66] Ezekiel, R. and Rani, M., 2006. Oil content of potato chips: Relationship with dry matter and starch content and rancidity during storage at room temperature. Potato Journal, 33: 1-2.

[67] Shabba, M.A., Stushnoff, C., McSay, A.E., Holm, D. and Davidson, R., 2007. Effect of temperature on storage properties, dormancy, soluble sugar content and α-galactosidase activity of seven new potato (Solanum tuberosum L.) cultivars. Journal of Food, Agriculture and Environment, 5(1): 116-121.

[68] Kumar, R., Pandey, S.K. and Khurana, S.M.P., 2005. Keeping quality of potato processing cultivars during room temperature storage. Potato Journal, 32(1-2): 55-59.

[69] Asmamaw, Y., Tekalign, T. and Workneh, T.S., 2010. Specific gravity, dry matter concentration, pH and crisp-making potential of Ethiopian potato (Solanum tuberosum L.) cultivars as influenced by growing environment and length of storage under ambient conditions. Journal of Potato Research, 53(2): 95-109.

[70] Nipa, J.S., Roy, T.S., Amin, A.K.M.R. and Hasanuzzaman, M., 2013. Effect of lifting time and tuber size on ambient storage performance of potato derived from true potato seed. International Journal of Sustainable Agriculture, 5(1): 1-9.

[71] Sowokinos, J.R., Knoper, P.H., and Varns, J.L., 1987. Influence of potato storage and handling stress on sugars, chip quality and integrity of the starch (Amyloplast) membrane. American Potato Journal, 64: 213-225.

[72] Uppal, D.S., 1999. Effect of storage environments on chip color and sugar level in tubers of potato cultivars. Journal of Food Science and Technology, 36: 545-547.

[73] Feltran, J.C., Lemos, L.B. and Vieites, R.L., 2004. Technological quality and utilization of potato tubers. Scientific Agriculture, 61: 598-603.

[74] Burgos, G., Auqui, S., Amoros, W., Salas, E. and Bonierbale, M., 2009. Ascorbic acid concentration of native Andean potato varieties as affected by environment, cooking and storage. Journal of Food Composition and Analysis, 22(6): 533-538.

[75] Sinha, N.K., Cash, J.N. and Chase, R.W., 1992. Differences in sugars chip color, specific gravity, and yield of selected potato cultivars grown in Michigan. American Potato Journal, 69: 385-389.

[76] Pandey, P.C., Singh, S.V., Pandey S.K. and Singh, B., 2007. Dormancy, sprouting behaviour and weight loss in Indian potato (Solanum tuberosum) varieties. Indian Journal of Agricultural Sciences, 77(11): 715-720.
[77] Sabba RP and AJ Bussan. 2005. Chemical maturity and sugar development in processing russets. Proc. WI Potato Grower Education. Conf. 18:67-73
[78] Tineke, De Wilde, Meulenaer, B.D., Mestdagh, F.D.R., Govaert, Y., Ooghe, W., Fraselle, S.P., Demeulemeester, K., Peteghem, C.V., Calus, A., Degroodt, J.M. and Verhe, R., 2006. Selection criteria for potato tubers to minimize acrylamide formation during frying. Journal of Agriculture Food Chemistry, 54: 2199.
[79] Singh, S.V., Marwaha, R.S., Kumar, D., Kumar, P. and Pandey, S.K., 2009, Suitability of potato varieties grown in north-eastern Indian plains for processing. Potato J., 36 (1-2): 25-34.
[80] Kumar, D. and Ezekiel, R., 2006b. Effect of physiological and biochemical attributes of potato cultivars Kufri Lavkar and Atlantic on their chipping quality. Potato Journal, 33(1-2): 50-55.
[81] Storey, M., 2007. The harvested crop. In: Potato Biology and Biotechnology Advances and Perspectives. Elsevier, Oxford, UK, pp. 441-470.
[82] Pandey, S.K., Singh S.V., Kumar, D., Manivel, P., Marwaha, R.S., Kumar, P., Singh, B.P. and Gupta, V.K., 2008. Kufri Himsona: A chipping cultivar for hill regions of India. Potato Journal, 35(1-2): 1-8.
[83] Verma, S.C., Sharma, T.R. and Verma, S.M., 1974b. Sucrose accumulation during high temperature storage of potato tubers. Potato Research, 17: 224-226.
[84] Zhitian, z., Wheatley, Christopher, C., Corke, H., 2002. Biochemical changes during storage of sweet potato roots differing in dry matter content. Post-harvest Biology and Tachnology, 24 (3): 317-325.
[85] Kumar, D., 2011. Cold-induced sweetening development in Indian potato (Solanum tuberosum L.) varieties. Indian Journal of Biochemistry and Biophysics, 48(2): 123-127.
[86] Pressey, R. and Shaw, R., 1996. Effect of temperature on invertase: invertase inhibitor and sugars in potato tubers. Plant Physiology, 41: 1657-1661.
[87] Peshin, A., 2000. Influence of storage temperature on invertase activity and sugar content in potato (Solanum tuberosum L.) tubers. Indian Journal of Plant Physiology, 5(3): 297-299.
[88] Rubbi, S.F., Sikka, L.C., Quddusur-Rahman, K.M., Kibria, G. and Rezaul-Karim, Q., 1988. Preliminary observations on qualitative biochemical changes in stored potatoes. In: Proceedings of the Triennial Conference of the Asian Potato Association, Kunming, People's Republic of China, 25-26 June 1988, pp. 18-24.
[89] Rai, R.D. and Verma, S.C., 1989. Evaluation of potato cultivars before and after cold storage for chipping. Indian Food Packer, 43: 15-19.
[90] Kumar, D., Ezekiel, R. and Singh, B.P., 2003. Post-harvest and pre-holding changes in sugar content of potatoes. Potato Journal, 30: 1-2.
[91] Singh, M. and Verma, S.C., 1979. Post-harvest technology and utilization of potato. In: Proceedings of the International Symposium of Post-harvest Technology and Utilization of Potato, 30th August to 2nd September, organized by CPRI, Shimla and CIP, New Delhi, India.
[92] Mulinacci, N., Ieri, F., Giaccherini, C., Innocenti, M., Andrenelli, L., Canova, G., et al. (2008). Effect of cooking on the anthocyanins, phenolic acids, glycoalkaloids, and resistant starch content in two pigmented cultivars of Solanum tuberosum L. Journal of Agricultural and Food Chemistry, 56, 11830–11837.
[93] Truong, V. D., Deighton, N., Thompson, R. T., McFeeters, R. F., Dean, L. O., Pecota, K. V., et al. (2010). Characterization of anthocyanins and anthocyanidins in purplefleshed sweetpotatoes. Journal of Agricultural and Food Chemistry, 58, 404–410.
[94] Bonierbale, M., Gruneberg, W., Amoros, W., Burgos, G., Salas, E., Porras, E., & Felde, T. M. (2009). Total and individual carotenoid profiles in Solanum phureja cultivated potatoes: II. Development and application of near-infrared reflectance spectroscopy (NIRS) calibrations for germplasm characterization. Journal of Food Composition and Analysis, 22, 509–516.
[95] Clegg, K.M., 1956. The application of anthrone reagent to the estimation of starch in cereals. Journal of Science and Food Agriculture, 1: 40-44.
[96] Somogyi, M.J., 1952. Notes on sugar determination. Journal of Biology and Chemistry, 200: 245 Somogyi, M.J., 1952. Notes on sugar determination. Journal of Biology and Chemistry, 200: 245.
[97] Somogyi, M.J., 1945. A new reagent for the determination of sugar. Journal of Biology and Chemistry, 160: 61-69.

[98] Yemm, E.W. and Willis, A.J., 1954. The estimation of carbohydrates in plant extracts by anthrone. Journal of Biochemistry, 57: 508-514.
[99] Swain, T. and Hillis, W.E., 1959. The phenolic constituents of Prunus domestica: The quantitative analysis of phenolic constituents. Journal of Food Science and Agriculture, 10: 63-68.
[100] Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungsticacid reagents. American Journal of Enology and Viticulture, 163, 144–158.

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