Studies on the Parameters of Potato Processing

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Abstract

Potato (*Solanumtuberosum*) popularly known as 'The king of vegetables', has emerged as fourth most important food crop in India after rice, wheat and maize. Indian vegetable basket is incomplete without Potato. Being one of the world's major agricultural crops it is consumed daily by millions of people from diverse cultural backgrounds.

Potatoes are grown in approximately 80% of the countries across the world with an annual production in excess of 300 million tons/year, a figure exceeded only by wheat, maize and rice (Moyano, 2008).High dry matter, edible energy and protein content of potato makes it nutritionally a superior vegetable as well as staple food not only in our country but also through-out the world. It is therefore an essential part of breakfast, lunch and dinner worldwide. Though a short duration crop (90-110 days) yet it produces more quantity of dry matter, edible energy and edible protein than cereals like rice (140-150 days) and wheat (100-120 days) and may prove to achieve the nutritional security of the nation It finds bulk usage in Indian savory & snack food industry for the production of chips, fries, aloolacchha, papads and extruded snacks. The main utilization of processed potatoes includes table stock (31%), frozen French fries (30%), chips and shoestrings (12%), and dehydrated items (12%).Thus, this review attempts to discuss about the important parameters in the processing of the potato with an aim to develop a better understanding .

INTRODUCTION

POTATO (*Solanumtuberosum*) has been an important food source consumed in many different forms by all the ancient civilizations across the globe (Suryawanshi, 2008). People used to dehydrate potato during excess produce to use them during scarce period (Woolfe, 1987). As per the data provided by APEDA for 2012-2013 Uttar Pradesh is the largest potato producing state with a production of about 14,695 thousand tons (around 34% of the total production in India), followed by West Bengal (22.82% of the total production), Bihar (14.85% of the total production) (National Horticulture Board, 2012-2013). India stands out to be amongst one of the largest potato producing countries and ranks fourth in area with 14 lakh hectares and thus the third largest country in the world in production of potato after China and Russian federation with a production of 294.94 lakh tons and production of 17.86 tons per hectare (Suryawanshi, 2008). Great advancements are being made in the arena of potato processing to develop a whole new platform for an attractive and nutritious range of products. The total demand of processed potato products is estimated to rise from 0.7 million tons in 2010 to 7.3 million tons in 2050 (Singh B. , 2013). There are various parameters which play a very important role in the processing of the potato and can be summed under two main categories (1)

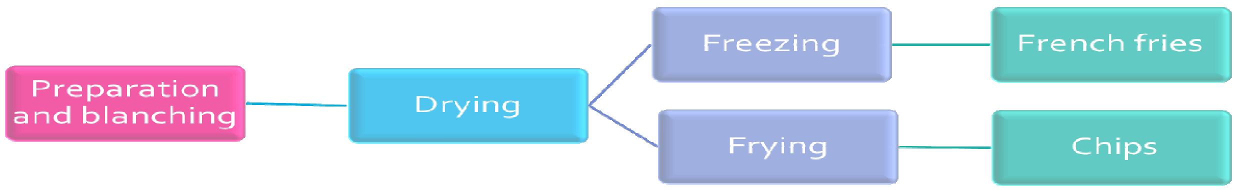
Physicochemical Parameters such as reducing sugar, dry matter content, starch content, storage conditions, and storage temperature;(2) Processing Parameters such as temperature of blanching, frying, slicing thickness, frying time, oil absorption and free fatty acids.

CHEMICAL COMPOSITION OF POTATO

Various factors which determine the chemical composition of potato include variations due to different cultivars, location of cultivation, difference in the agricultural practices, maturity at harvest and subsequent storage history. Water constitutes around 75%, starch around 22.6% and fiber around 0.4% in the fresh produce ((NHB), 2012-2013) .On the other hand starch makes up 65-80% of the dry matter content of the potato tuber, which has a calorific value of 120 calories per 150grams or one potato (M.R.Freedman,2011) and about 21% amylose, 75% amylopectin, 0.1% protein and 0.08% phosphorous (Pedreschi F. &., 2002). Potatoes with high solids content (20-22%) are preferred during chip and French fries processing, because they result in better texture, higher yields and lower oil absorption in the finished product(Lisinska, 1989). The content of reducing sugars is closely related to the final color of the fried potatoes(Singh R. D., 1976)as low reducing sugar content minimizes the color development during frying, which is generated by the Millard or non-enzymatic browning reaction(Lisinska, 1989). The two important factors that influence sugar content of potatoes during post-harvest storage are variety and storage temperature. Varieties respond differently to the storage temperatures and different varieties accumulate reducing sugars within themselves in different duration of time. Some varieties stores at moderate temperatures accumulate enough reducing sugar (glucose and fructose) within two weeks of storage to cause dark colored chips (Watada, 1955). Other varieties are capable to withstand storage at low temperature and can be reconditioned at higher temperature to produce acceptable chip color (Murphy & Goven, 1967). Storage temperature between 8.9 and 12.8°C (48 to 54 ° F) are favorable for maintaining for maintain most potato varieties in nearly optimum conditions for chipping(Ohad& Wright, 1971;1954).Potato chips are very thin slices (1.27-1.78 mm thick) of sliced raw potatoes that are fried to a final oil content of 33-38% wet basis(Moreira, 1999).
The various varieties of potato grown in India includes Kufrijyoti, grown in hills of Himachal Pradesh is one of the earliest varieties with the phenotypic drawback containing less amount of dry matter content (nearly 17 to 19.6%)(S.V. Singh1, Kumar, Kumar, & Pandey, 2009), waxy texture and discoloration of the cooked product. Kufri chipsona-3, a variety developed by the C.P.R.I. (Central Potato Research Institute) has high dry matter content (nearly 22.8%)(S.V. Singh1, Kumar, Kumar, & Pandey, 2009) and its round shape provides an additional quality parameter for chipping, thus suitable for processing. Kufri chipsona-1, another variety is identified for the chipping industry because of higher dry matter content (nearly 19.3%) and oblong shape. For the production of French-fries a new outstanding variety KufriFrysona characterized by long shape and high dry matter content is a popular choice. Some other varieties with such positive characteristics are Lady Rosetta (dry matter content of around 23.65%) (S.V. Singh1, Kumar, Kumar, & Pandey, 2009) and Atlantic but these varieties are not developed in India (Abbasi, Masud, Gulfraz, Ali, & Imran, 2011).

Potato chips have an oil content that ranges from 33-38% giving the product a unique and desirable texture-flavor combination (Moreira, 1999). Snack food manufacturers produce traditional chips made by thinly slicing fresh potatoes or from potato dough formed into potato chip shapes for further processing. Shape and thickness can be varied to meet marketing needs, but thickness is usually in the range of 50-60 thousandth of an inch. Potato chips are very thin slices (1.27-1.78 mm thick) of sliced raw potatoes are fried to a final oil content of 33-38% wet basis (Moreira, 1999).

Some potato processing plants use blanching prior to frying to improve the color of the chips. The blanching solution is heated to 65°-95°C and blanching takes around 1min. Excessive water is then removed and potato slices are fried in a continuous fryer, where they remain from 1.5-3 minutes at170°-190°C, until the moisture level is less than 2% (Moyano, 2008).



ROLE OF REDUCING SUGAR IN COLOR DEVELOPMENT

One of the basic parameters for defining the quality of potato chip is the color formation among several others such as yield, texture and oil absorption. The most accepted color of the chip is light brown color (Smith, 1955). Therefore, to meet the preference of the consumer and to produce a superior product, quality parameters are important to the grower and the processor and must be well understood by both to maintain acceptable chip color throughout the chipping season. The basic reason for the discoloration of chip is due to the changes in the reducing sugars content prior to harvest or during the storage time. To make fried or dehydrated products the reducing sugar content should be less than 100mg/100gram (fresh weight of chips) and less than 200mg/100gram (fresh weight of French fries)(Kumar, 2011). Certain changes in the color occur due to the varietal differences or due to the environmental factors (Smith, 1955). Majority of the potato crop is grown in sub-tropical climates in India. The sub-tropical growth and such environmental conditions may result in different storage behavior in regard to the sugar development (Kumar, 2011). Growing season temperatures, soil moisture, fertilization, sucrose content and tuber maturity at harvest are some of the factors that affect the resulting sugar accumulation in newly harvested tubers (Akeley, 1955),(Mareček, Frančáková, Bojňanská, Fikselová, AndreaMendelová, & Ivanišová, 2013). Effect of storagetemperature is important in particular at affecting the levels of reducing sugars-glucose andfructose, which if at higher contents significantly contribute to the deterioration of friedpotato products. Thus it is very important to understand the relationship between the sugar accumulation and storage temperature (Singh, 1976).Various studies have shown that the reducing sugar development in the Indian potato varieties decreases initially and then increases by various folds in different varieties (Kumar, 2011). On comparing various varieties after storage for 35 days it has been determined that the increase in the reducing sugar content of Kufri Chipsona-1 was by 16 folds, in Kufri Chipsona-3 by 8 folds and in Kufri Jyoti it was by 8 folds respectively(Kumar, 2011). It has been determined that the respiration burst due to the change in the storage conditions causes the increase in the utilization of the reducing sugars. Later the respiration rate decereases with the decrease in the storage temperature but at 5°C the respiration is stimulated. Thus, there is a brief respiration burst followed by a subsequent decrease in the respiration rate to a new steady state (Amir J Kahn, Isherwood & Kumar,1973;1977;2011). The differences in chemical composition due to varietal difference affect the quality of the chip (Hoover & Miller, 1963;1975).Varieties respond differently to storage temperatures. Some varieties stored at the most favorable temperatures may accumulate enough reducing sugars (glucose and fructose) within two weeks of storage to cause dark colored chips (Watada, 1955). Sucrose is a non-reducing sugar which is present in the potato in the maximum amount at the time of harvest (Appleman, 1926);(Work & True, 1981). This non-reducing sugar does not directly participate in the Maillard reaction but it certainly does act as an intermediate product for the formation of reducing sugars from starch (Isherwood, 1973)(Kumar, 2011). At lower temperature of storage the invertase inhibitor becomes inactivated thus the invertase activity increases resulting in cleavage of sucrose into reducing sugars(Pressey& Kumar, 1970;2011). In case of Indian varieties it has been determined that statistically excessive reducing sugar accumulated within 12 to 17 days of storage(Kumar, 2011). Short term storage of the potato at low temperature (less than 10°C) resulted in maximum amount of sucrose present in it but the prolonged storage at this low temperature, decreasesthe sucrose content and increases the reducing sugar content (Samotus, 1974).This shift basically occurs due to the conversion of the sucrose into glucose and fructose in the presence of the enzyme invertase as observed in Kufrijyoti – 181mg/100gram and Kufrichipsona 1 and 3 – 98.6 & 88.0 mg /100gram(Kumar, 2011). The advantage of above mentioned processing varieties is that the starch does not convert into reducing sugars very easily at ambient storage temperatures and tubers remain free from discoloration after cooking (Sangha, 2007). Due to high dry matter, low reducing sugars and low phenols, the varieties Kufrichipsona and Lady Rosetta are highly suitable for making chips and French fries. (Indian Potato Varieties, Technical Bulletin No.51, 1999).

EFFECT OF STORAGE TEMPERATURE ON POTATO

Potato held at varied storage conditions causes various changes in regard to sugar concentration within it (Rogers, 1937). It has been understood that the storage of potato at low temperature such as 2°C causes no sprouting in the potato and thus helps attain prolonged storage period.However the activation of the invertase enzyme at the same temperature results in the conversion of the starch into sugar (Isherwood, 1973). Presence of a higher percentage of starch and low concentration of reducing sugar and invertase enzyme in potato has been determined at the time of harvest but with the exposure to a temperature of 4.4°C a rapid increase in the concentration of invertase enzyme activity ocuurs resulting in an increase in reducing sugar content due to starch conversion (Pressey, 1969).The main factor that affects reducing sugar content is the temperature in the storage area. If the temperature falls during more than 10 days to below 2 ° C, the decomposition of starch is accelerated (Mareček, Frančáková, Bojňanská, Fikselová, AndreaMendelová, & Ivanišová, 2013). The temperature for storage around 12-14°C provides a reconditioning period for the conversion of the reducing sugar back to the starch form before the chip formation (Singh,1976)(Work & True, 1981);(Singh Brajesh, Ezekie R, Kumar Dinesh, 2008).Reducing sugar level is kept in terms of impact on the quality of fried products at an acceptable level. The modest increaseoccurs at the end of the storage period due to aging of tubers(Marecek& Macugova, 2008). At such high temperatures of storage, there occurs a major draw back, the respiration activity of the potato increases at these temperatures resulting in potato sprouting. Therfore in order to control sprouting effect the usage of antisprouting chemicals is done. Optimum storage conditions and temperature at field site mark a noticeable influence on acryl amide formation since less sugar development will lead to lesser non-enzymatic reaction at the time of cooking(Haase, Matth¨aus, && Vosmann, 2003)

ROLE OF ANTISPROUTING CHEMICALS

Sprouting causes increased weight loss and may impede airflow through the potato pile. Reduced airflow often leads to increased pile temperatures and disease problems.Thus the antisprouting chemical like chlorpropham (CIPC Treatment) is used to spray the potato at the time of storage which causes no sprouting at the required storage temperature of 12-14°C. It is a chemical which is manufactured by the United Phosphorus Ltd, Mumbai(Singh Brajesh, Ezekie R, Kumar Dinesh, 2008). The method of spraying the chemical on the potato in the cold storage is known as fogging which is done twice during the whole span of the storage, initially when the potato is brought at the cold storage and then a repeat after a duration of 60 days(Kleinkopf G. E, 2003). The antisprouting chemical interferes with the metaphase of the cell division cycle which cannot complete itself, thus results in no sprouting (Coleman W.K, 2001). Other than the chlorpropham other anti-sprouting agents such as Peppermint and spearmint oils, clove oil which is marketed as Biox-C in United States and hydrogen peroxide are also used. The advantage of using these anti sprouting suppressants such as peppermint causes fewer problems with culinary and palatability concerns. Mint oil applications do not cause any significant processing quality changes such as altering tuber sugar profile or fry-color(Kleinkopf G. E, 2003).

EFFECT OF FRYING ON OIL UPTAKE IN FRIED POTATO

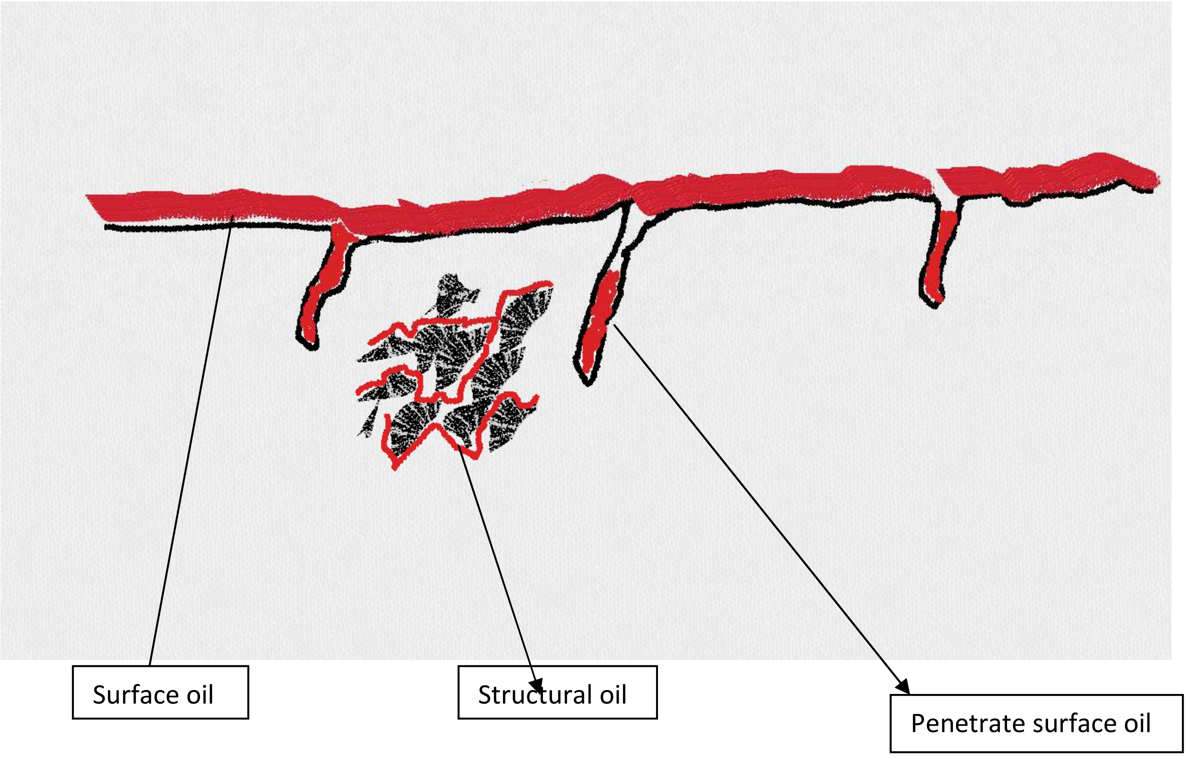
Deep-fat frying is a complex unit operation involving high temperatures, significant micro structural changes both to the surface and the body of the chip and simultaneous heat and mass transfer resulting in flows of water vapor (bubbles) and oil in opposite directions at the surface of the piece(Bouchon, 2001). In case of these fried products the most desirable feature is the formation of a composite structure: a dry, porous, crisp and oily outer layer or crust, and a moist cooked interior or core. The crust is the result of several alterations that mainly occur at the cellular and sub-cellular level, and are located in the outermost layers of the product. Potato chips are very thin pieces (1.27–

1.78mmthick) of potatoes fried to final oil and moisture contents of -35% and 1.7%, respectively (Moreira, 1999).

On the other hand the French-fries which also have a large market share, represent a composite structure formed by two regions: (i) an external dehydrated and crispy region where oil is located; and (ii) a humid and cooked core region free of oil. The external crust is very similar to the structure of a fried potato slice or potato chip (Pedreschi, 2002). The final oil and moisture content of French - fries is about 15% and 38%, respectively (Aguilera,2000;Saguy,2003).

Nowadays the consumers are becoming health concious and therfore these deep-fat fried products need to be processed in a manner which fulfills the sensory and health aspects of the consumer. Hence, in order to make the products healthy, the property of the fried product to take up oil at the time of frying or cooling period has to be managed. Technologies have to be implemented for the end-product to have a low oil content(Bouchon, 2001). Numerous studies done to determine the mechanism of the oil upake by the product show the evidence that maximum oil absorbtion occurs after frying, during the cooling period (Ufheil, 1996).It has been stated that the oil absorption mechanism can be divided into three components:(1) structural oil (STO), which represents the oil absorbed during frying;(2) penetrated surface oil (PSO), which represents the oil suctioned into the fried potato during cooling after removal from the fryer; and(3) surface oil (SO), which is the oil that remains on the surface(Bouchon, 2001). PSO constitutes the maximum amount in the total oil (TO) during the frying. When the slices were removed from the fryer, a higher temperature difference develops between the surface and the interior, which, in turn, generates a higher negative pressure in the pore space leading to more oil penetration into their microstructure during cooling. This fact confirms that the oil absorption is principally a surface phenomenon (Aguilera, (2000).(Gamble, Rice, & Selman, 1987) found that moisture loss and oil uptake were interrelated and were both linear functions of the square root of frying time. They made the hypothesis that the oil entering the slice would lie in the voids left by the escaping water.

Hence, in addition to quantitative aspects, water loss can become an explanatory variable for transformation and oil uptake in particular because water escape is at the origin of a very diverse material phenomena such as the creation of cavities (Vitrac, 2000).



EFFECT OF FRYING TEMPERATURE AND PERIOD ON PRODUCT QUALITY

Understanding about the role of reducing sugar in color development we now correlate the temperature and frying period. The frying temperature depends on the type of product, its size and composition, and varies from 120°C to 190°C. High oil temperatures (160–190°C) enable rapid heat transfer, rapid browning and short frying time. For this reason, putting too large an amount of cold food into hot fat is detrimental to product quality and process efficiency because it causes a dramatic decrease in fat temperature and longer cooking time. An increase in oil temperature triggers an increase in dehydration and coupled reactions speeds. Therefore, high temperatures limit frying time. However, for the same residual content of water the effect of frying temperature is marginal as temperatures between 140°C and 190°C have been observed to have no influence on oil absorption (Gamble, Rice, & Selman, 1987). However, the incitation of limiting oil temperature in order to limit its degradation motivated the study of frying temperatures below 140°C. The works showed that a temperature such as 120°C resulted in longer frying time and higher oil uptake for the same residual water content (Pedreschi F. &., 2002),(EJ & IS., 1994), (Bouchon& Pyle, 2003). This phenomenon can be explained by the higher oil uptake during frying caused by the longer frying time, weaker opposite water flows or by the development of different crust structures (i.e. a different porosity more likely to enhance oil uptake). Indeed, during frying at a very low oil temperature, such as 120°C, crusts exhibit a low level of firmness that lets the oil penetrate easily into the product (Blumenthal, 1991),(Bouchon& Pyle, 2003).At temperatures up to 60°C, browning is normally a zero-order reaction (A **zero-order reaction** proceeds at a rate independent of the concentration of reactants and will not speed up or slow down, respectively). At higher temperatures, a plot of brown pigments versus time will curve upwards since the reaction rate depends on a single reactant and the value of the exponent is one in a first order reaction(Moyano, 2008).Higher frying temperatures accelerate the cooking of the core and hardening of the crust, resulting in French fries with harder crusts (Moyano, 2008).

EFFECT OF BLANCHING ON CHIP QUALITY

Blanching is a treatment at a temperature range between 65 to 90°C causing inactivation of enzymes. Recent studies show that a compound called acrylamide is generated as a side reaction of the Maillard reaction. The amino acid asparagine and reducing sugars (fructose and glucose) are the key components of the Maillard reaction in fried potatoes (Mott ram &Wedzicha, 2002). Asparagine provides the backbone of the acrylamide molecule, while reducing sugars are the e△ential co-reactants in the formation of the N-glycoside intermediates, which lead to the formation of acrylamide. Fried products, especially French fries and crisps, belong to the food category with probably the highest concentration of acrylamide recorded so far. The reason for this strong susceptibility to acrylamide formation is the abundance of free asparagine present in potato (Zyzak, et al., 2003),(Pedreschi, et al., 2007). Since the non-enzymatic reaction is dependent on oil temperature and frying time, a successive increase in the temperature from 150 to190°C results in a redder and darker product. Now the process of blanching helps in reducing the acrylamide formation by reducing the Eof French fries, probably due to the leaching out of reducing sugars previous to frying and inhibiting non-enzymatic browning reactions resulting in lighter and less red French fries (Pedreschi, Kaack, & Granby, 2006). The potential for acrylamide formation is strongly related to the sugar content such as glucose and fructose(Biedermann, Biedermann-Brem, Noti, & Grob, 2002).For instance, some authors reported that the reduction of the sugar content by blanching or soaking could decrease acrylamide concentration by about 60% in potato chips (Haase, Matth¨aus, &Vosmann, 2003),(Pedreschi, Kaack, &Granby, 2006).

ROLE OF OTHER FACTORS DURING HARVESTING AND STORAGE

Out of the six vitamins included in the recommended daily dietary allowance of food, four are present in potato, namely: ascorbic acid, thiamin, riboflavin and niacin. However, the principal vitamin is ascorbic acid, an important antioxidant that is susceptible to heat and light, and is also the index of quality change in the potato tubers during storage (Burlingame B; Mouille R; Charrondiere, 2009). Polyphenols, in addition, are the most common dietary antioxidant(Lachmann J, 2008).Exposure of tubers to light at some stages during the commercial processing and marketing chain is generally inevitable and results in adverse physiological changes within the tuber. These changes include ‘greening’ due to the increase in level of chlorophyll and synthesis of toxic steroidal glycol-alkaloids (predominantly found as α-solanine and α-chaconine) within the marginal tuber layers (Abbasi, Masud, Gulfraz, Ali, & Imran, 2011). Accumulation of both compounds can result in significant financial and food security threats. Contrary to glycol-alkaloids, chlorophyll is safe and tasteless yet green potatoes are considered harmful for consumption. Sweetening is an important physiological change in potato tubers, particularly associated to low temperature storage. The quality of potatoes continues to change as a result of physiological activity owing to the accumulation of reducing sugars and running down of starch (Nourian F; Ramaswamy AC; Kushalappa, 2003).

ROLE OF FREE FATTY ACIDS AND OXYGEN

Heating fats in deep layers, such as in potato chip processing cause less damage than heating to the same temperatures in thin films. This indicates that exposure to oxygen accelerates nutritional impairment. In commercial potato chip industry the frying oils are characterized by free fatty acid value of no greater than 0.60 percent and a decrease in iodine value of no greater that 3.0 percent in 95 % of the processing plants (Talburt, 1959 and 1967).The increased value of iodine indicates an increase in the unsaturated fat content resulting in higher chances of oxidative rancidity or spoilage due to oxygen in the product. Also the presence of low F.F.A indicates less chance of trans-fat formation and rancidity as a higher content of F.F.A in the product will cause hydrolytic rancidity to occur and formation of trans-fat in case of saturated fat content.

CONCLUSION

Potato has been stated as the king of vegetables, therefore it is one of the most important processed vegetables. Frying, dehydration and freeze drying are some important unit operations in the potato processing industry. The phenomenon of oil uptake, formation of acrylamide compound during the Maillard reaction and the increasing reducing sugar content at the time of storage are some impediments which diminish the quality and acceptability of the product. Oil uptake in fried potatoes diminishes as the frying temperature increases. Most of the oil is absorbed when the fried potato pieces are removed from the fryer and penetrate into the microstructure during the cooling process. Acrylamide is a toxic compound (carcinogenic in animals), which is formed during frying mostly by the Maillard reaction mechanism in which asparagine reacts with reducing sugars such as glucose and fructose. Thus the step of blanching prior to the frying is an important step to mitigate the formation of this compound. Since the flavor and taste of fried potatoes depend on the Maillard reaction, the major challenge is to produce fried potatoes with low acrylamide content without affecting their traditional flavor, taste, and other sensorial attributes. There should be low levels of FFA so that minimum amount of trans-fat formation occurs and therefore no hydrolytic rancidity can occur. In regard to post harvest practices, as discussed above, exposure of the tuber to sunlight should be avoided as it causes increase in the levels of chlorophyll and thus deteriorating the taste factor of the product. Also it causes the increase in the synthesis of toxic steroidal glycol-alkaloids which is undesired in the tuber. Along with these mentioned post-harvest practices the storage temperature has to been maintained to the optimum so that no reducing sugar can be formed and also no sprouting should occur. Therefore the usage of CIPC is practiced in the cold storages as mentioned earlier. The storage temperature of 12-14°C is considered the optimum for no sugar development. The oil uptake in the chip varies with the temperature of the frying. The basic temperature range for frying is between 120- 190°C. The frying done at 120°C allows more oil uptake and also increases the frying time. The higher temperature of frying allows the harder crust formation with lower oil uptake.

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