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ORIGINAL ARTICLE

Process standardization and storability of calcium fortified potato chips through vacuum impregnation

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Abstract Processed potato products such as potato chips are widely consumed among vulnerable (children and teenager), therefore can be used as an ideal carrier for targeted nutrient's delivery i.e. macronutrient calcium. The present study was carried out to standardize the process for development of calcium fortified potato chips through vacuum impregnation technique and to explore the acceptability of developed product through storage study of 3 months period at ambient storage conditions (~ 250 °C, 51% RH) in LDPE (low density polyethylene) packaging. Fortification of potato chips was done at 15 mm Hg vacuum pressure with GRAS fortificant of calcium (calcium chloride, E509) using different combinations of blanching time, vacuum time, and restoration time as per Box–Behnken design of response surface methodology. optimization was done on the basis of fortified calcium content as well as hardness of the end product. Results showed optimized process conditions (calcium chloride at 1.05% level, blanching for 1.69 min, vacuum exposure for 14.99 min, and rest time of 15.80 min) can fortify potato chips at 700 mg/100 g of calcium level with acceptable sensory attributes. The standardized product was also evaluated for its structural attributes through surface electron microscopy, flavor (umami) compounds along with shelf life. The developed fortified product has 4.5 and 7.1 times higher calcium content than its control and commercial counterparts respectively. Storage studies parameters (FFA value, PV value, sensory attributes and non enzymatic browning) showed that the fortified potato chips were acceptable up to 60 days of storage at ambient condition. Thus, calcium fortification through vacuum impregnation technique for a widely acceptable potato based snacks can be helpful in changing the perception of consumers for potato based snacks from the category of 'Junk food to Healthy food'.

Keywords Vacuum impregnation (VI) · Fortification · Potato chips · Calcium · Flavor

Introduction

Potato (*Solanum tuberosum* L.) ranks fifth in terms of human consumption and fourth in the worldwide production (Burlingame et al. 2009). Lots of processed potato products are available in the market in the form of chips, fries, dehydrated chips, dice, waris, papad, flakes, wedges and granules etc. Among all the processed potato products, potato chips comprise 85% of total Rs 2500 crore salty snack business in India (Raigond et al. 2015). The sector has been expanding with the production of potato chips from 0.38 Million Tones (MT) in 2006–2007 to 0.61 MT in 2010–2011 and is expected to increase further to 3.55 MT by the year 2050 (Singh et al. 2014). Moreover, in India, potatoes chips and fries are highly popular among the children who are vulnerable (4–17 years) for mineral deficiency. Affordable price, easy availability, wide consumption by the vulnerable, especially children are the considerable factors which make chips and fries an ideal

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carrier for mineral fortification. In particular, calcium is a fundamental mineral for the human body and primarily responsible for growth and maintenance of skeleton system and hence categorized as a macronutrient (Joshi et al. 2016).

In recent years, the interest in calcium has intensified because low calcium intake has been reported to be associated with osteoporosis, hypertension and many more disorders (Life Extension Update 2010). Globally, an inadequate consumption of calcium over an extended period of time has been found to induce calcium deficiency risk among 3.5 billion people globally (Kumssa et al. 2014). Most of the people fulfill their calcium demand from dairy products. However, concerns like lactose intolerance, dietary fat, cholesterol and other related allergies, among some individuals, have led to switch their preferences from dairy to non-dairy products. Thus, the difference between recommended and actual calcium intake compel the manufacturers to market an increasing number and variety of calcium–fortified products (Konar et al. 2015).

In today's scenario, fortification through impregnation process performed at atmospheric pressure or under vacuum conditions or by a combination of both has emerged as a useful tool for incorporation of targeted compounds into the porous structure of fruits and vegetables without disrupting their cellular structure (Anino et al. 2006). It is based on the application of a vacuum pressure which allows to remove gases entrapped into the capillaries and to impregnate them with a desired external solution after the rest of atmospheric pressure (Tiwari and Thakur 2016). Vacuum impregnation (VI) has been identified as an innovative method to enrich foods not only with nutritional and functional components but also with the innovative sensorial ingredients. It also helps in inhibiting the biochemical and microbial degradation of the product (Derossi et al. 2010). VI treatments have also been reported as fast as well as low energy costs processes and an ideal non-thermal method for food fortification (Tiwari and Thakur 2016). Earlier also, vacuum impregnation technique has been tried for zinc enrichment of potato tuber (Erihemu et al. 2015) and ascorbic acid enrichment of whole potato tuber (Hironika et al. 2011) due to its porous nature.

In the present study, author shave attempted to enrich calcium content of potato chips by vacuum impregnation technique and to investigate the effects of various process variables such as fortificant (calcium) concentration, blanching time, vacuum time, and rest time on calcium fortification of potato chips. To inspect the effect of calcium impregnation on the developed product's quality attributes; texture, flavor, SEM observation, sensory analysis, and shelf life studies have also been conducted. Besides, effect of calcium impregnation on acrylamide content of developed product was also determined keeping earlier findings of advantages of calcium enhancement on acrylamide reduction in fried snacks in view (Salazara et al. 2014).

Materials and methods

Variety selection

Kufri Chipsona -1 was procured from CPRI Regional Station Modipurum, Uttar Pradesh, India. Kufri Chipsona-1 was selected on the basis of low phytate:ascorbate ratio (0.42:1) (Joshi et al. 2016). This cultivar was grown during winter (2014–2015, Rabi season) at CPRIC, Modipuram, India using the standard package of practices (Kumar et al. 2007). After skin curing, potato tubers were stored at elevated temperature (10–12 °C) storage chambers using sprout suppressant Isopropyl N-(3-chlorophenyl) Carbonate(CIPC)till being utilized for fortification(Singh et al. 2004). The peels (upper 1.5 mm layer) were removed manually using a ceramic knife. Chips were made using a commercial chips cutter (Make: Felix wafer maker Slim, Om Appliances, Rajkot, India) with an average thickness of 1.67 ± 0.058 mm as measured by Vernier Caliper.

Fortificants and carrier

Food grade Calcium chloride (E509) because of its high bioavailability (≥ 90%), water solubility and neutral effect on taste and color of the product, has been used as a fortificant and procured from Titen Biotech Limited, Delhi-110033. For this fortificant, potato chips were used as a carrier. The standard RDI values (www.lenntech.com/recommended-daily-intake.html 2015) of mineral was based on 2000 cal intake (4–17 years of age) therefore, research work has been planned in such a manner that the targeted level (21% RDI for calcium) of calcium for potato chips can be achieved by consuming 30 g serving in accordance with Recommended Amount Customarily Consumed (RACC).

Vacuum impregnation process

The vacuum was created in a closed chamber and raw potato chips were placed in a single layer on the perforated base. When the constant vacuum level (15 mm Hg) for a pre-defined period was achieved, raw chips were immediately exposed to fortificant solution (calcium chloride) of particular concentrations in the ratio of 1:4 (w/v) to the predefined rest time at atmospheric pressure.

Mineral content estimation

Calcium content of control, commercial, and experimental potato chips were estimated by Atomic Absorption Spectrophotometer (Shinadzu AA700) using wet ashing procedure as described by Raghuramulu et al. (2003).

Texture analysis

Potato chips were evaluated for texture characteristics by Texture analyzer (Stable Micro System, UK). On a hollow planar base, a chip was placed for analysis. The force was applied to the sample by using a cylindrical probe of 0.25 mm diameter at a constant speed of 1 mm/s until the sample was cracked. To determine the texture characteristics of the chips, force-deformation data were recorded. The maximum force of break was indicated as the hardness of chips (Aguilera et al. 2004). The pre-test speed, test speed, post-test speed, distance, trigger type, data acquisition rate and load cell were set at 1.0 mm/s, 1.0 mm/s, 10 m/s, 3 mm, Auto-10 g, 500 pps and 5 kg, respectively.

Experimental design

Response surface methodology (RSM) was used for process optimization and product development. A four-factor three level Box–Behnken design was used to evaluate the combined effect of four independent variables i.e. calcium concentration, blanching time, vacuum time, rest time coded as X_1, X_2, X_3, X_4 respectively on impregnation level of calcium in potato chips. The minimum and maximum values for calcium concentration, blanching time, vacuum time and rest time were varied from 1 to 5%, 0 to 2 min (at (72 °C), 5 to 15 min, 10 to 20 min respectively, keeping constant solid to liquid ratio of (1:4 w/v) during whole experiment (Table 1). To see the effect of blanching, zero min blanching was also kept as a level in the experimental study.

The response value of the experimental design was calcium content (mg/100 g) and hardness (N) of potato chips. A total of 27 runs (trials) were carried out and the responses were taken by repeating each trial thrice to see the change in responses (Table 2).

The response function was partitioned into linear, quadratic, and interactive components Eq. (1).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_1 + \sum_{i=1}^{k} \beta_{ii} X_2 + \sum_{i>1}^{k} \beta_{ij} X_i X_j \quad (1)$$

where Y is the response; X_1, X_2, are input variables; β_0 is the intercept; β_1 are linear coefficient; β_{ii} are quadratic coefficients; β_{ij} are interaction coefficients.

Statistical analysis

The statistical evaluation has been performed by running analysis of variance (ANOVA) and regression calculation using SAS (version 11). Each factor had three levels which were coded as − 1, 0 and 1. The central points (coded as 0) for each factor were 3% calcium chloride, 1 min blanching time, 10 min vacuum time and 15 min rest time. Surface plots and equations have been derived from STATISTICA Version 5.0 software.

Structural changes through SEM

Structural changes in potato chips before and after fortification were observed through Surface Electron microscopy (SEM-EVO 18, Zeiss model). The sample size of 1X 1 cm was placed on sputter coated with gold–palladium plating (of surface thickness 15–28 nm) at 3 millibar vacuum and 15 million volt current for 180 s. After time completion, SEM observation was taken using to evaluate the structural difference in fortified chips compared to Control chips.

Flavor analysis

For extraction of major flavor compounds i.e. 5′-nucleotides or umami compounds, chilled 5% perchloric acid (10 ml) was added to 0.5 g of the powdered potato chips. Remaining experimental conditions and mobile phase were kept the same as optimized by Raigond et al. (2015) for calculating the major flavoring compounds (AMP + GMP).

Acrylamide content analysis

Fortified and control potato chips have been evaluated for acrylamide content as per method reported by Andrzejewski et al. (2004) and Roach et al. (2003). Two columns (Atlantics dC18 and AQASIL C18 column) with different lengths have been used for better chromatographs separation by eliminating possible interferences.

Table 1 Independent variables and their coded and actual values used for optimization

Independent variable	Units	Symbol	Code level		
			− 1	0	1
Calcium salt concentration	%	X_1	1	3	5
Blanching time	Min	X_2	0	1	2
Vacuum time	Min	X_3	5	10	15
Restoration time	Min	X_4	10	15	20

Table 2 The Box–Behnken design and experiment data for mineral impregnation in potato chips

Treatments	Independent variable				Dependent variable	
	X_1 calcium (%)	X_2 blanching time (min)	X_3 vacuum time (min)	X_4 restoration period (min)	Calcium (mg/100 g)	Hardness (newton)
1	1 (− 1)	1 (− 1)	10 (0)	15 (0)	615.71	447.96
2	5 (+ 1)	1 (− 1)	10 (0)	15 (0)	2449.94	591.01
3	1 (− 1)	2 (+ 1)	10 (0)	15 (0)	812.54	342.17
4	5 (+ 1)	2 (+ 1)	10 (0)	15 (0)	2471.74	505.20
5	3 (0)	0 (0)	5 (− 1)	10 (− 1)	326.64	625.92
6	3 (0)	0 (0)	15 (+ 1)	10 (− 1)	574.44	407.99
7	3 (0)	0 (0)	5 (− 1)	20 (+ 1)	469.94	501.44
8	3 (0)	0 (0)	15 (+ 1)	20 (+ 1)	861.10	536.94
9	3 (0)	0 (0)	10 (0)	15 (0)	800.34	561.15
10	1 (− 1)	0 (0)	10 (0)	10 (− 1)	132.24	360.39
11	5 (+ 1)	0 (0)	10 (0)	10 (− 1)	802.74	447.96
12	1 (− 1)	0 (0)	10 (0)	20 (+ 1)	66.64	415.75
13	5 (+ 1)	0 (0)	10 (0)	20 (+ 1)	848.94	443.96
14	3 (0)	1 (− 1)	5 (− 1)	15 (0)	1395.54	545.52
15	3 (0)	2 (+ 1)	5 (− 1)	15 (0)	1220.64	312.00
16	3 (0)	1 (− 1)	15 (+ 1)	15 (0)	1427.14	543.64
17	3 (0)	2 (+ 1)	15 (+ 1)	15 (0)	1879.0	412.22
18	3 (0)	0 (0)	10 (0)	15 (0)	598.74	348.99
19	1 (− 1)	0 (0)	5 (− 1)	15 (0)	297.44	562.79
20	5 (+ 1)	0 (0)	5 (− 1)	15 (0)	950.94	466.88
21	1 (− 1)	0 (0)	15 (+ 1)	15 (0)	115.24	452.54
22	5 (+ 1)	0 (0)	15 (+ 1)	15 (0)	1147.74	476.40
23	3 (0)	1 (− 1)	10 (0)	10 (− 1)	1504.84	321.01
24	3 (0)	2 (+ 1)	10 (0)	10 (− 1)	1483.0	425.74
25	3 (0)	1 (− 1)	10 (0)	20 (+ 1)	1820.74	407.05
26	3 (0)	2 (+ 1)	10 (0)	20 (+ 1)	443.2	533.29
27	3 (0)	0 (0)	10 (0)	15 (0)	1696.84	448.66

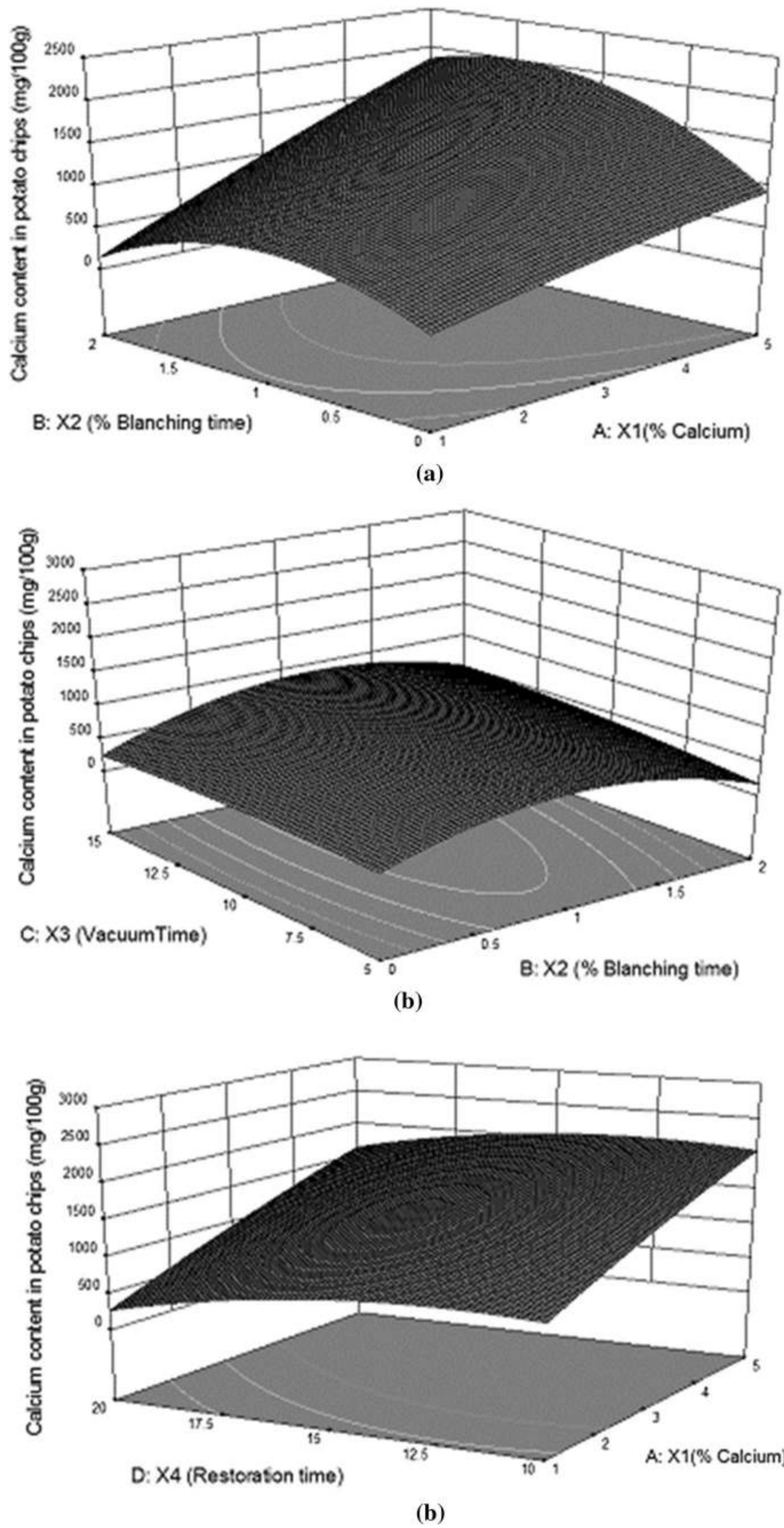
Storage study

Fortified potato chips in comparison with control were evaluated for their shelf life using various parameters such as rancidity (free fatty acids and peroxide value), color and sensorial scores using standard methodologies given by Ranganna (2007) and Larmond (1977), respectively. To evaluate the sensory properties of the fortified potato chips on 9 points Hedonic scale for its color, texture, taste, flavor and overall acceptability, a semi-trained panel of 25 members have been asked to evaluate the sample in comparison with control (Larmond 1977).

Results and discussion

The results of 27 experiments run showed that the range of calcium impregnation varied from 66.42 to 2449.94 mg/100 g, while hardness values varied from 321 to 591 N under predefined combinations of process variables (Table 2). The regression analysis indicated that the calcium content of potato chips was a function of calcium concentration of impregnation solution followed by blanching time. However, the effect of vacuum time and rest time was found to be non-significant.

Fig. 1 Effect of **a** blanching time and calcium concentration, **b** vacuum time and blanching time and **c** restoration time and calcium concentration on calcium impregnation of potato chips



Effect of process variables on calcium impregnation

Effect of blanching time

It was observed that the blanching time was a quadratic function for calcium impregnation in chips i.e. with the increase in blanching time, calcium concentration in potato chips increase initially but decreased later on (Fig. 1a). Maximum level of impregnation was achieved at the blanching time of 1.5 min. It may be due to the fact that 1.5 min blanching time was sufficient for porosity enhancement in potato chips which resulted in an effective impregnation process. In favor of the findings, Alzamora et al. (2005) described that the blanching treatment often produces profound structural alterations (swelling of cell walls, disruption of membranes, etc.) which affects mass transport phenomena, resulting in the extensive uptake of solute inside the cytoplasm of parenchyma cell properties. However, a sharp decrease was also observed when blanching time was increased from 1.5 to 2 min. Such negative effect of prolonged blanching was also observed by Bellary and Rastogi (2014) on banana slices due to gelatinization of starch. The potato slices were also prone for starch gelatinization.

Effect of vacuum time

Vacuum time within the range from 5 to 15 min used in the present study, did not show any significant effect on impregnation process in potato chips (Fig. 1b). However, it was also observed that 7.5 min vacuum time at 15 mm Hg vacuum pressure was sufficient to remove air from the potato pores.

Effect of calcium concentration

The effect of calcium ion concentration was more direct i.e. as the calcium concentration increased in the solution, impregnation level or calcium content in the chips also increased linear manner (Fig. 1a, c). This linear behavior of fortificant concentration was also observed by Joshi et al. (2016)

Effect of rest time

Figure 1c showed that rest time also had the positive effect on impregnation process but was statistically non-significant ($p \leq 0.05$). It was observed that with increase in rest time from 10 to 15 min, the calcium content increased and reached approximately 220 mg/100 g of potato chips (Fig. 1c). The highest level of impregnation was achieved at 15 min of rest time followed by slight decrease corresponding to 20 min. This showed that rest time of 15 min was sufficient to fill the vacuum treated pores with the solute solution. The findings were corresponded well with the report of Mujica-Paz et al. (2003) that in rest time when vacated porous capillaries are immersed in a physiologically active compounds concentrated solution at atmospheric pressure, the impregnation solution penetrates the intercellular spaces by capillary action and pressure gradient.

As far as the whole model is concerned, the model was significant ($p \leq 0.05$) having F value 8.43 and R-square 0.907. The value of adequate precision which measures signal to noise ratio was 10.8 (≥ 4.0). This shows that the model can be used to navigate the design space.

Level optimization and validation

Mean optimized values for calcium chloride concentration, blanching time, vacuum level and rest time were 1.05%, 1.69 min, 14.99 min, 15.80 min, respectively with 90% of confidence limit. The developed potato chips using optimized conditions can be considered as good source of calcium with overall acceptability scores (≥ 8.1 on 9.0 points Hedonic scale vs. 8.0 of control preparation, Table 3). In comparison, fortified potato chips had calcium 4.5 and 7.1 times higher than that of control and commercial counterparts respectively.

Texture analysis

One of the important criteria for deciding the overall acceptability of any food product by the consumers is the texture. Joshi et al. (2016) reported that average fracturability (hardness) of commercially available chips (Lay's classic salted) was 456.03 N. The effect of impregnation on the hardness characteristics of potato chips were also evaluated and summarized in Fig. 2a, b.

From Fig. 2a, it has been observed that with increase in calcium concentration, firmness also get increased. Present findings were in agreement with those reported by Luna-Guzman and Barrett (2000) and Saftner et al. (2003) that calcium chloride treatment improves the firmness and the quality of freshly cut cantaloupes and honeydew, respectively. Therefore, increase in the concentration of calcium in potato disc by vacuum impregnation led to overall increase in hardness/firmness of the product. However, rest time had non-significant effect on the hardness of potato chips. Figure 2a strongly validates the fact that calcium ions were the principle agent responsible for textural hardness or fracturability of the potato chips.

From Fig. 2b it was observed that blanching significantly enhanced the hardness of plant tissue after frying. Van Loon et al. (2005) reported that blanching improves the texture of plant tissues due to gelatinization of starch

Table 3 Effect of fortification on the sensory evaluation of potato chips

Chips	Taste	Flavor	Color	Texture	Overall acceptability
Control	7.96 ± 1.09[a]	8.07 ± 1.11[a]	7.95 ± 1.31[a]	8.20 ± 1.17[a]	8.04 ± 1.01[a]
Fortified chips	8.14 ± 1.33[a]	7.32 ± 1.12[a]	8.36 ± 1.06[ab]	8.68 ± 1.29[a]	8.10 ± 1.07[ab]

[a,b]Values with the different letters within the same column are significantly different at $p < 0.1$. Mean ± SD (n = 56). 1–9 scale: 1 = dislike extremely. 9 = Like extremely

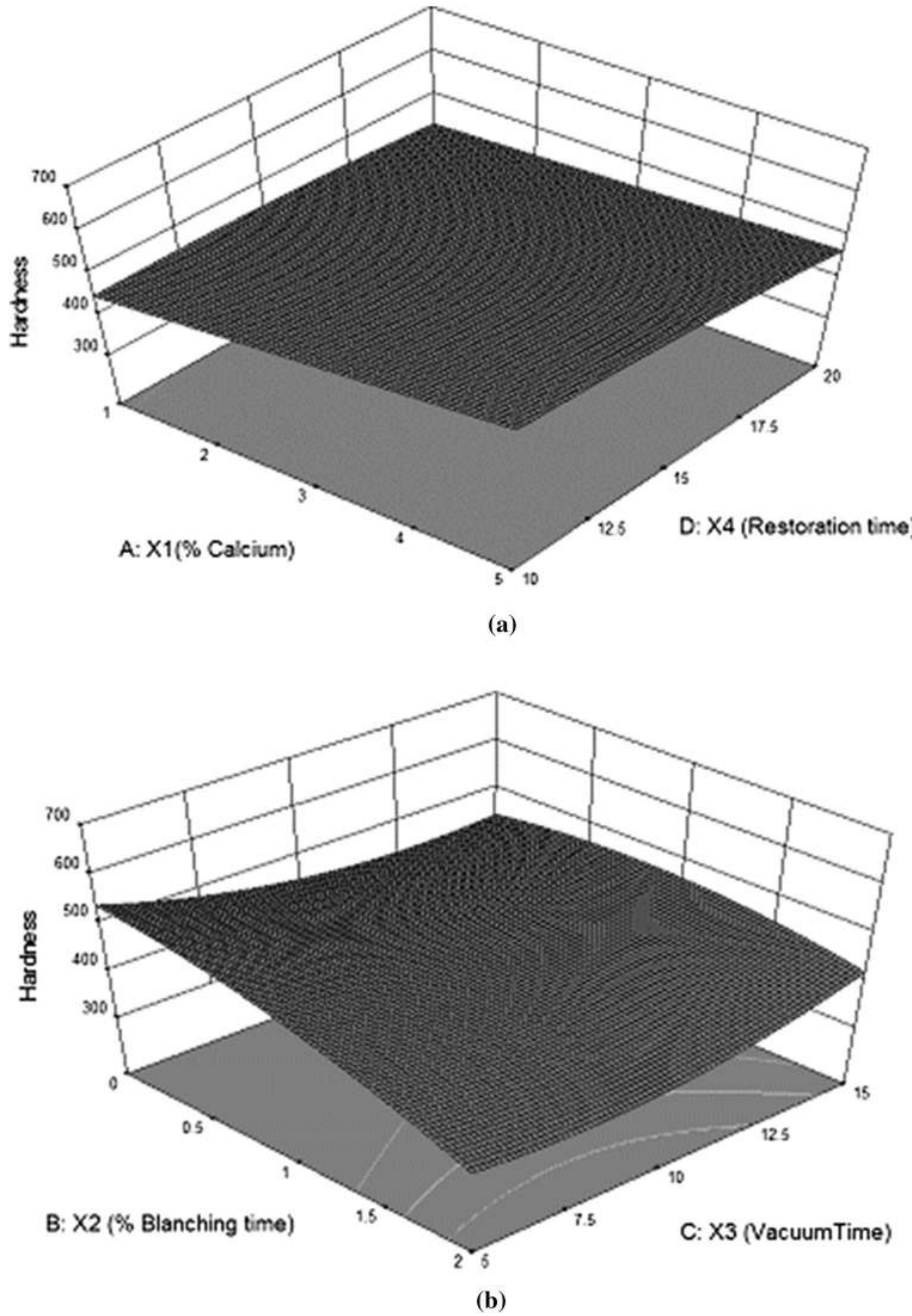


Fig. 2 Effect of **a** calcium concentration and restoration time and **b** blanching time and vacuum time on hardness of potato chips

which reduced oil uptake during frying. Aseidu-Larbi (2010) also stated that blanching and frying have been found to increase the dry matter content, due to loss of non-fibre substances, thus leading to the increased firmness of the product. As described above, blanching led to starch gelatinization and frying of gelatinized starch led to the development of crispiness in potato chips. Therefore, the desired crispiness was the result of gelatinization of starch. Besides above-mentioned reasons, low-temperature blanching, in the range of 55–75 °C, has also been reported to improve the firmness of cooked vegetables and fruits (Verlinden et al. 2000).

Texture profile analysis (TPA)

The force–displacement curve showed a jagged appearance with several fracture events, typical of crispy food (Taniwaki and Kohyama 2012). In order to compare objectively the behavior of the fortified chips, specific parameters were extracted from the force curves. The parameters evaluated were: (1) the number of total force peaks, which are an index of the jaggedness of the curve and crispiness of the product; (2) the maximum force peak, which are related with hardness of the product. At an optimized condition, fortified potato chips had 455 N firmness in terms of maximum hardness. While total no of peak force was 20, reflecting the crispiness of the developed product. Research in the literature also favor the current findings that average firmness of commercial available chips (Lay's classic salted) was 456.03 N with 21 positive peaks (Joshi et al. 2016) (Table 4). In the light of this observation, it can be concluded that fortified potato chips were at par with commercially available chips in terms of firmness and crispiness.

Correlation between blanching and solid loss and oil absorption capacity

Blanching treatment has been reported to produce profound structural alterations (swelling of cell walls, disruption of membranes, etc.) which affects mass transport phenomena, resulting in the extensive uptake of solute inside the cytoplasm of parenchyma cells (Alzamora et al. (2005). Current study corresponded well with the above mentioned statement by reflecting more fortification level at higher blanching time (Table 2). Alternatively, blanching is also reported to cause more oil absorption which is well observed through current study (Fig. 3b of SEM analysis), that can result loss in crispiness. But in the present study, oil absorption is more, although the crispiness remained the same. Calcium deposition in the wall of potato cells due to enhanced porosity led hardness unchanged in the potato chips. Present findings were in agreement with those reported by Luna-Guzman and Barrett (2000) and Saftner et al. (2003) that calcium chloride treatment improves the firmness and the quality of freshly cut cantaloupes and honeydew, respectively. Furthermore, blanching and frying are reported to increase the dry matter content due to loss of non-fiber substances leading to firmness of the product.

As described above, blanching led to starch gelatinization and frying of gelatinized starch led to the development of crispiness in potato chips. Therefore, the desired crispiness was the result of starch gelatinization. In the light of observation presented, it is concluded that even though in fortified potato chips, cell surface seems smoother than those of control chips (Fig. 3b) due to the more oil absorption, but have no effect on the desired crispiness of the same.

Flavor compound

Raigond et al. (2015) reported that the potato chips of different brands in the market showed the presence of flavor compounds concentration ranged from 5.9 to 9.8 µg/g FW. The flavor compound (Umami/5′-nucleotide) was found to be 8.8 and 2.51 µg/g FW in control and calcium-fortified potato chips which is approximately four times lesser than the commercially available chips. Umami compounds have been reported for acceptability of bland potato products such as boiled, roasted potatoes (Raigond et al. 2014). Except for umami flavor, additional salt and different flavoring agents are also required for potato chips acceptability. This may be the reason behind unavailability of bland taste potato snacks in the market.

Structural effect of calcium impregnation

Figure 3a, b, showed that at 100× magnification, in comparison to control there was no significant difference in the cell structure of fortified potato chips observed. To observe the changes more evidently, SEM images were taken at 500× magnification. Under magnified view, it was perceived from the Fig. 3c, d that granular structure did not differ but there was a deposition of calcium in the periphery of cells in fortified chips. This might be the reason for unchanged mouth feel of fortified chips.

Acrylamide content

In comparison with control (47 µg/kg) nil acrylamide content was found in calcium fortified potato chips. Calcium salts addition has already been reported to reduce the acrylamide formation (Chang et al. 2014). Because of the complete absence of acrylamide content, the developed fortified chips (fulfilling 21% of calcium RDI) would be a more healthy choice for consumers.

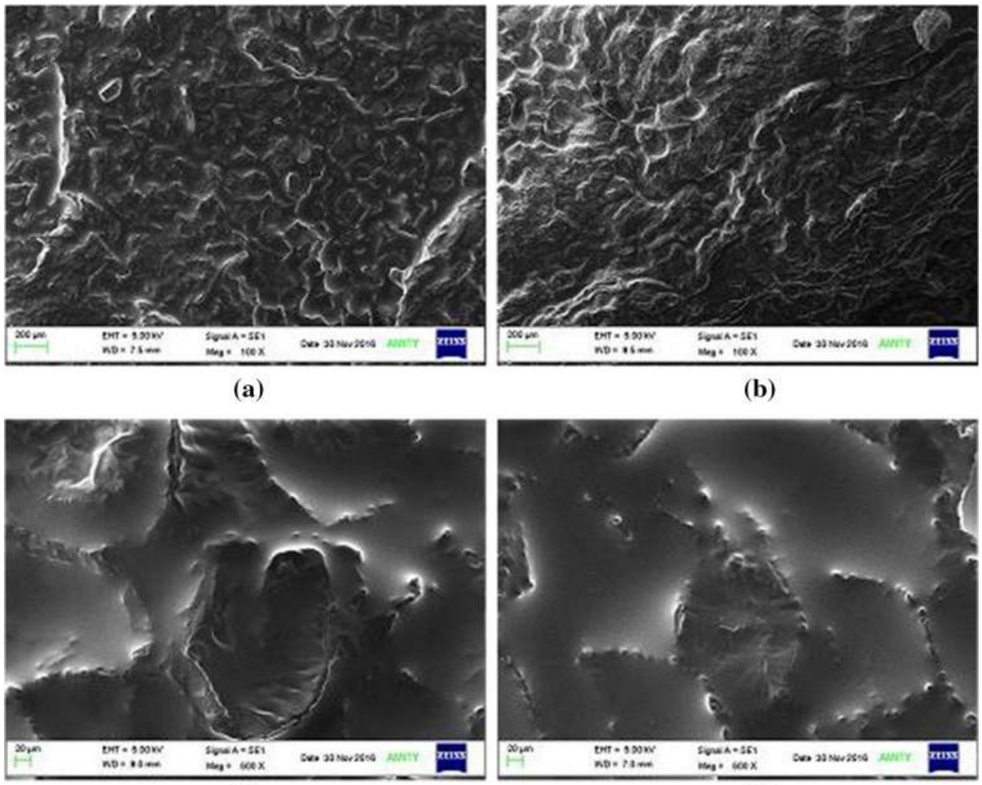


Fig. 3 Structural effect of calcium impregnation in comparison with control. **a** Control chips (×100), **b** calcium fortified chips (×100), **c** control chips (×500) and **d** calcium fortified chips (×500)

Storability

FFA content was increased during storage. Acceptable limit as given by BIS 12575: 2010 for FFA content of Fried Potato Chips is 2% (as % oleic acid). FFA remained lesser than 2% up to 3 months of storage in control as well as fortified chips. However, nil traces of peroxides were observed in both types of chips. The shelf life can further be improved by nitrogen flushing packaging technique since in presence of nitrogen oxidative deterioration can't occur (Marasca et al. 2016). Non-enzymatic browning evaluation showed that color scores, in terms of optical density (OD), for fortified chips were better than that of control. During storage, there has been no significant change observed in terms of color and appearance in both the samples.

Sensory scores have been found to be decreased throughout the storage period. However, control as well as the optimized fortified chips were acceptable till 60 days of storage (Fig. 4). Thus, with Low-density polyethylene (LDPE) packaging, fortified chips can be acceptable well up to 60 days of storage at ~ 25 °C and 51% RH.

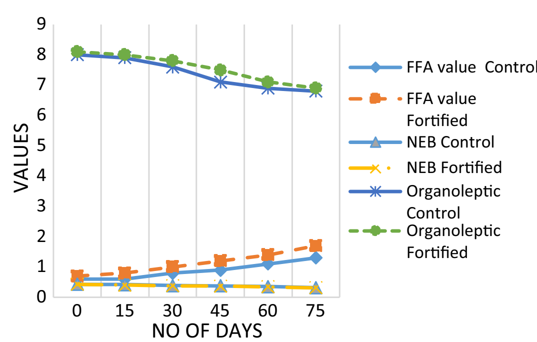


Fig. 4 Shelf life analysis

Fortification confirmation

The developed potato chips using optimized conditions (calcium chloride concentration, blanching time, vacuum level and rest period were at 1.05%, 1.69 min, 14.99 min, 15.80 min, respectively) can be considered as rich source of calcium with acceptable sensory scores (≥ 8.1 on 9.0 point Hedonic scale vs. 8.0 of control preparation) (Fig. 5). In comparison, fortified potato chips had calcium content 4.5 and 7.1 times higher than that of control and commercial counterparts respectively (Fig. 6).

Table 4 Textural parameters for fortified and commercial potato chips

Chips Sample	Number of force peaks before breaking	Number of force peaks after breaking	Number of total force peaks	Maximum force (F_{max}) (N)
Commercial Chips	7	14	21	456
Control chips	7	12	19	454
Calcium fortified chips	8	12	20	455

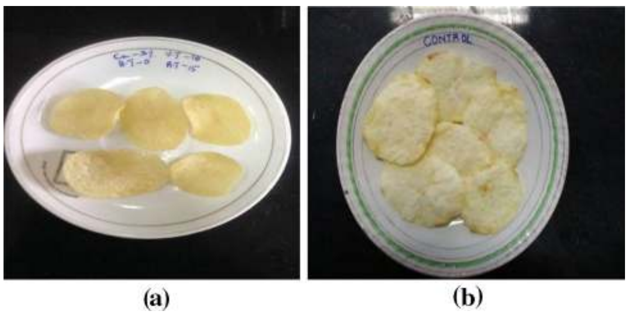


Fig. 5 **a** Calcium fortified potato chips and **b** control chips

Conclusion

The present study showed that using vacuum impregnation technique, it was possible to increase the concentration of calcium in the potato chips from 154.65 mg (control) to 700 mg/100 g (fortified) under predefined process variables of the study. The results indicated that impregnation phenomenon was majorly governed by fortificant concentration followed by blanching time. The fortified chips have 4.5 and 7.1 times higher calcium content than its control and commercial part, respectively. Thus, the developed calcium fortified chips having the shelf life of 2 months at ~ 25 °C and 51% RH in LDPE packaging will be helpful in supplying nutritious potato chips to consumers.

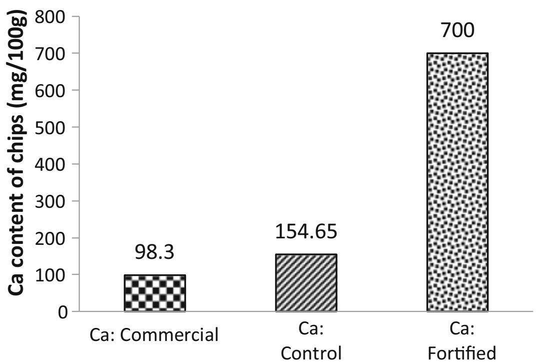


Fig. 6 Comparative chart for mineral content in various types of chips

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References

Aguilera JM, Castro L, Cadoche L (2004) Structure property relationships in starch amorphous model. In: Proceedings of the 14th international drying symposium, Sao Paulo, Brazil, pp 1468–1472

Alzamora SM, Salvatori D, Tapia MS, Lopez-Malo A, Welti-Chanes J, Fito P (2005) Novel functional foods from vegetable matrices impregnated with biologically active compounds. J Food Eng 67:205–214

Andrzejewski D, Roach JAG, Gay M, Musser SM (2004) Analysis of coffee for the presence of acrylamide by LC/MS/MS. J Agric Food Chem 52:1996–2002

Anino SV, Salvatori DM, Alzamora SM (2006) Changes in calcium level and mechanical properties of apple tissue due to impregnation with calcium salts. Food Res Int 39(2):154–164

Aseidu-Larbi AB (2010) Production and storage of minimally processed chips from water yam. Kwame Nkrumah University of Science and Technology, Ghana

Bellary AN, Rastogi NK (2014) Effect of selected pre-treatments on impregnation of curcuminoids and their influence on physico-chemical properties of raw banana slices. Food Bioprocess Technol 7:2803–2812

Burlingame B, Mouille B, Charrondiere R (2009) Nutrients, bioactive non-nutrients and anti-nutrients in potatoes. J Food Compos Anal 22:494–502

Chang KLB, Wang JS, Sung WC (2014) Calcium salts reduce acrylamide formation and improve qualities of cookies. J Food Nutr Res 2(11):857–866. https://doi.org/10.12691/jfnr-2-11-16

Derossi A, Pilli DT, Severini C (2010) Reduction in pH of vegetables by vacuum impregnation: a study on pepper. J Food Eng 99:9–15

Erihemu Hironaka K, Koaze H, Oda Y, Shimada K (2015) Zinc enrichment of whole potato tuber by vacuum impregnation. J Food Sci Technol 52(4):2352–2358

Hironika H, Kikuchi M, Koaze H, Sato T, Kojima M, Yamamoto K, Yasuda K, Mori M, Tsuda S (2011) Ascorbic acid enrichment of whole potato tuber by vacuum impregnation. Food Chem 127:1114–1118

Joshi A, Rudra SG, Sagar VR, Raigond P, Dutt S, Singh B, Singh BP (2016) Development of low fat potato chips through microwave processing. J Food Sci Technol. https://doi.org/10.1007/s13197-016-2304-y

Konar N, Poyrazoglu ES, Artik N (2015) Influence of calcium fortification on physical and rheological properties of sucrosefree prebiotic milk chocolates containing inulin and maltitol. J Food Sci Technol 52(4):2033–2042

Kumar P, Pandey SK, Singh SV, Kumar D (2007) Irrigation requirements of chipping potato cultivars under West Central Indian plains. Potato J 34:193–198

Kumssa DB, Edward J, Joy M, Louise Ander E, Michael J, Watts Scott D, Young SW, Martin RB (2014) Dietary calcium and zinc deficiency risks are decreasing but remain prevalent. Sci Rep 5, Article number: 10974. https://doi.org/10.1038/srep10974

Larmond E (1977) Laboratory methods for sensory evaluation of foods. Canada Department of Agriculture Ottawa, Ottawa

Life Extension Update (2010) Insufficient calcium may link hypertension, osteoporosis. http://www.lifeextension.com/Newsletter/2010/6/Insufficient-Calcium-May-Link-Hypertension-Osteoporosis/Page-01

Luna-Guzman I, Barrett DM (2000) Comparison of calciumchloride and calcium lactate effectiveness in maintaining shelfstability and quality of fresh-cut cantaloupe. Postharvest Biol Technol 19:61–72

Marasca E, Greetham D, Herring SD, Fisk ID (2016) Impact of nitrogen flushing and oil choice on the progression of lipid oxidation in unwashed fried sliced potato crisps. Food Chem. https://doi.org/10.1016/j.foodchem.2015.11.136

Mujica-Paz H, Valdez-Fragoso A, Lopez-Malo A, Palou E, Welti-Chanes J (2003) Impregnation properties of some fruits at vacuum pressure. J Food Eng 56:307–314

Raghuramulu N, Nair KM, Kalyanasundaram S (2003) A manual of laboratory techniques, 2nd edn. National Institute of Nutrition, ICMR, Hyderabad

Raigond P, Singh B, Gupta VK, Singh BP (2014) Potato flavour: profiling of umami 5′-nucleotides from Indian potato cultivars. Ind J Plant Physiol 19(4):338–344

Raigond P, Singh B, Dhulia A, Chopra S, Dutt S (2015) Flavouring compounds in Indian potato snacks. J Food Sci Technol 52(12):8308–8314

Ranganna S (2007) Handbook of analysis and quality control for fruit and vegetable products, 2nd edn. Tata McGraw-Hill, New Delhi

Roach JA, Andrzejewskl D, Gay ML, Nortrup D, Musser SM (2003) Rugged LC-MS survey analysis for acrylamide in foods. J Agric Food Chem 51:7547–7554

Saftner RA, Bai J, Abbott JA, Lee YS (2003) Sanitary dips with calcium propionate, calcium chloride, or calcium amino acid chelates maintain quality and shelf stability of fresh-cut honeydew chunks. Postharvest Biol Technol 29:257–269

Salazara R, Arambula-Villaa G, Luna-Barcenasa G, Figueroa-Cardenasa JD, Azuarab E, Vazquez-Landaverdec PA (2014) Effect of added calcium hydroxide during corn nixtamalization on acrylamide content in tortilla chips. LWT Food Sci Technol 56:87–92

Singh B, Kaul HN, Ezekiel R (2004) Effect of Isopropyl-N (3-chlorophenyl) carbamate (CIPC) dusting on potatoes during nonrefrigerated storage: sprout suppression and residues. J Food Sci Technol 41:550–553

Singh BP, Rana RK, Govindakrishnan PM (2014) Vision 2050. Central Potato research Institute, Shimla, pp 16–17

Taniwaki M, Kohyama K (2012) Mechanical and acoustic evaluation of potato chip crispness using a versatile texture analyzer. J Food Eng 112:268–273

Tiwari P, Thakur M (2016) Vacuum impregnation: a novel nonthermal technique to improve food quality. Int J Curr Res Biosci Plant Biol 3(7):117–126

Van Loon WAM, Linssen JPH, Legger A, Posthumus MA, Voragen AGJ (2005) Process innovation and quality aspects of French fries. Food Chem 90(3):417–425

Verlinden BE, Yuksel D, Baheri M, De Baerdemaeker J, Van Dijk C (2000) Low temperature blanching effect on the changes in mechanical properties during subsequent cooking of three potato cultivars. Int J Food Sci Technol 35:331–340

www.lenntech.com/recommended-daily-intake.html (2015) Recommended daily intake of vitamins and minerals. Accessed 04 Mar 2015