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Effect of pre-treatment and oil popping conditions on quinoa popping quality

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ABSTRACT

Quinoa is a pseudocereal having outstanding nutritional profile and health-promoting biofunctional compounds. It is able to pop into an affordable, crispy, and flavourful ready-to-eat snack by conventional oil-popping method. Oil-popping is the process of frying grains in hot oil for a short time to induce vapour-driven expansion of grains. The effects of process variables on oil-popping quality of quinoa were evaluated. The conditions of processing were optimised using Response Surface Methodology. The grains (10 g) were hydrated by adding 0.1–0.3 mL of water containing a varying salt concentration of 0–1%, w/w and popped in coconut oil maintained at a popping temperature of 200–240 °C for a popping time of 10–30 s. The developed popped quinoa was analysed for popping quality indices. It was found that the increase in popping temperature, popping time, and salt concentration, and decrease in moisture level significantly decreased bulk density but increased popping yield (% popped grains), expansion ratio (degree of volume expansion), and flake size (average kernel size) of popped quinoa. Overall acceptability of popped quinoa in terms of sensory attributes was positively correlated with popping temperature and popping time. The optimised variables generated a popping yield of 75.56%, expansion ratio of 3.07, flake size of 11.58 mm^3, bulk density of 0.29 $\mathrm{g\,mL}^{-1}$, and overall acceptability score of 8.40. A threefold expansion and a fair popping yield obtained from oil-popped quinoa offer a significant potential to generate profit for manufacturers.

KEYWORDS

quinoa, popping, ready-to-eat snack, expansion, pseudocereals

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1. INTRODUCTION

The increased interest among consumers for foods having bioactive compounds and delivering additional health benefits has created a demand and opportunity to explore ancient grains. Quinoa (*Chenopodium quinoa*) is an ancient pseudocereal native to South America (Filho et al., 2017). It serves to be the best source of protein (16.5% (w/w)) relative to all cereals. It provides all the essential amino acids in a balanced amount, including lysine that is deficient in cereals (Valcárcel-Yamani and Lannes, 2012). Quinoa is the only plant-based protein source whose bioavailability, biological value, protein efficiency ratio, and net protein utilisation are equivalent to that of milk protein. As quinoa has low or no prolamin content, it can be used for developing gluten-free food products (Abdellatif, 2018). Quinoa is a fibre-rich food known to exhibit hypoglycaemic effect and lowering plasma free fatty acid levels. It could supply a sufficient quantity of essential fatty acids like linoleic and linolenic acids to the body (Filho et al., 2017). Quinoa has an exceptionally high calcium level compared to other cereals. It is also a valuable source of other minerals like iron, zinc, potassium, magnesium, and phosphorous (Jancurová et al., 2009). Quinoa has many bioactive compounds like phytosterols, sqaulene, glycine betaine, phytoecdysteroids, isoflavones that impart multiple health benefits not limited to cholesterol reduction, cardioprotection, immune modulation, anti-inflammation, and anti-hypertensive effects (Valcárcel-Yamani and Lannes, 2012). The shift in interest of consumers towards whole grain based snacks provides an opportunity to use puffing or popping technology to develop quinoa based ready-to-eat whole grain snack. Popping is the process of exposing the moisture-conditioned grains/seeds to a very high temperature for a short period so that the high vapour pressure building inside the grain explodes the pericarp and expands the cooked biopolymer (Mishra et al., 2014). Sand puffing and oil popping are the widely practiced traditional methods used to produce aerated, porous, and expanded snacks. Though sand puffing is cost-effective, the process involves the mixing of grains in a hot sand bed and it poses a serious health hazard due to contamination with silica of the puffed products (Nath and Chattopadhyay, 2007; Swarnakar et al., 2014). Oil popping is the process of shallow frying in which the grains are contacted with hot oil having temperature of around 200 °C for a few seconds. The convectional heat transfer from oil to surface of grain and subsequent conductional heat transfer from surface to the core part of grain induce the outflow of inherent moisture of grain. However, unlike other fried foods, here the hard outer shell of the grain not only hinders extrusion of moisture but also intrusion of oil into the grain. Once the outer shell reaches its yield point, the pressurised vapour bursts the outer shell and gushes out of the grain simultaneously expanding the endosperm starch matrix (Joshi et al., 2014; Oke et al., 2017). The fibrous and less permeable outer shell together with the high density and less moisture content in the grains could contribute to less oil absorption (Gazmuri and Bouchon, 2009; Phanitcharoen et al., 2010; Onipe et al., 2015). The study of Paucar-Menacho et al. (2018) reported better retention of many nutritional and bio-functional components in puffed pseudocereals as the grains were exposed to heat only for a short time. Interestingly, puffing improved the release of flavonoids from quinoa, which could ultimately enhance its bioavailability on consumption. There are no previous studies focusing on popping quality of quinoa or many other cereals during oil popping though the method is practiced globally. As the profitability from sales of popped snacks depends on the degree of expansion and other quality indices, manufacturers need to be well aware of the factors that provide the best popping quality (Quinn et al., 2005). Hence, this experimental study was carried out with an aim to evaluate the effects of pre-treatment and oil popping conditions on the popping quality of quinoa and suitably optimising these conditions using the Response Surface Methodology technique.

2. MATERIALS AND METHODS

2.1. Procedure for product preparation

The cleaned, sorted, and dried white quinoa (*C. quinoa*) of commercial type was procured from Organic India Private Limited, Bangalore. The average initial moisture content of the quinoa was 11.9%. Sample size of about 10 g was used for each experiment trial. The grains were pre-treated by spraying with either distilled water or salt solution (based on treatment levels). A tray containing pre-treated grains was kept undisturbed open at room temperature (27 ± 2 °C) for 6 h to equilibrate. About 5 mL of refined coconut oil was used for the chosen sample size. The temperature of oil in a cast iron pan (length × breadth × height = $32 \times 26.5 \times 9$ cm) was monitored continuously using a high-precision infrared thermometer and the heat feed was controlled by adjusting the LPG burner knob. At the appropriate temperature, the prepared grain sample was added into the pan and stirred for a fixed time. As popping of quinoa occurs within a few seconds, no significant heat fluctuations in the meantime were observed. The popped quinoa was immediately taken out of the pan, cooled to room temperature, packed in aluminium laminate, and sealed.

2.2. Design of experiment

Design Expert 12 (Stat-Ease) software package was used in designing the experiment, analysis, and optimisation. Box-Behnken design with 4 independent variables, each having 3 levels and 5 dependent variables was selected for study. Each of the total 29 trials was replicated three times and each replication was analysed once. The average of replications for a trial was used for the statistical analysis of variance. The independent variables coded as A, B, C, and D were moisture level (0.1–0.3 mL/10 g sample), salt concentration (0–1%, w/w), popping temperature (200–240 °C), and popping time (10–30 s), respectively. The dependent variables measured were popping yield (%), expansion ratio, flake size (mm^3), bulk density ($g\ mL^{-1}$), and overall acceptability. The model and its terminologies were considered significant under 5% level of significance ($P < 0.05$). A validation trial was conducted at optimised condition and analysed using Minitab 20 statistical software.

2.3. Method of analysis

Popping yield (%) was calculated by measuring the percentage of grains fully popped out of the total grain mixture in terms of weight (Mishra et al., 2015). Expansion ratio states the degree of expansion upon popping. It was estimated by the ratio of the volume of popped grains to the volume of raw grains (Joshi et al., 2014). Flake size or puff size (mm^3) was determined by the ratio of the volume of popped grains to the number of popped grains (Quinn et al., 2005). Bulk density ($g\ mL^{-1}$) was measured by tapping method involving finding the ratio of the mass of popped grains to the volume of popped grains (Swarnakar et al., 2020). Sensory analysis was conducted based on 9 point hedonic scale. The organoleptic quality of the coded and randomly arranged popped products was evaluated by 17 semi-trained panellists based on parameters like colour, texture, taste, odour, flavour, and overall acceptability (Joshi et al., 2014).

3. RESULTS AND DISCUSSION

The resulting data for analysed dependent variables corresponding to the different combinations of independent variables of the oil popping experiment is given in Table 1. The second-order

Table 1. Effect of independent variables of oil popping on quality indices of popped quinoa

Trial	Independent variables				Dependent variables				
	A	B	C	D	Popping yield (%)	Expansion ratio	Flake size (mm^3)	Bulk density (g mL^{-1})	Overall acceptability
1	0.1	0.5	200	20	9.50 ± 0.56	2.27 ± 0.05	7.4 ± 0.18	0.45 ± 0.02	6.14 ± 0.20
2	0.3	0.5	220	30	60.00 ± 1.18	2.59 ± 0.11	9.0 ± 0.23	0.48 ± 0.01	7.70 ± 0.20
3	0.2	0	220	10	10.02 ± 0.39	2.60 ± 0.03	8.5 ± 0.10	0.42 ± 0.01	7.00 ± 0.12
4	0.2	1	240	20	63.42 ± 2.17	2.65 ± 0.05	10.0 ± 0.25	0.35 ± 0.03	8.00 ± 0.10
5	0.1	0	220	20	54.49 ± 1.56	2.97 ± 0.11	10.5 ± 0.25	0.38 ± 0.03	8.55 ± 0.32
6	0.2	0.5	240	10	42.93 ± 0.52	2.27 ± 0.02	10.5 ± 0.38	0.40 ± 0.02	8.00 ± 0.25
7	0.1	1	220	20	70.75 ± 4.01	3.00 ± 0.05	11.0 ± 0.18	0.28 ± 0.01	8.77 ± 0.10
8	0.2	0.5	220	20	58.82 ± 2.94	2.81 ± 0.12	9.5 ± 0.10	0.44 ± 0.04	8.10 ± 0.10
9	0.2	0.5	220	20	56.04 ± 0.89	2.70 ± 0.10	10.5 ± 0.32	0.35 ± 0.03	8.30 ± 0.32
10	0.1	0.5	220	10	34.42 ± 0.64	2.70 ± 0.05	9.0 ± 0.28	0.38 ± 0.03	7.14 ± 0.26
11	0.2	1	220	30	67.85 ± 2.56	2.92 ± 0.09	10.0 ± 0.48	0.34 ± 0.01	8.35 ± 0.18
12	0.3	0	220	20	45.69 ± 0.32	2.50 ± 0.05	8.0 ± 0.36	0.49 ± 0.02	7.55 ± 0.10
13	0.2	0	240	20	53.62 ± 2.18	2.49 ± 0.08	8.5 ± 0.20	0.45 ± 0.02	7.70 ± 0.22
14	0.2	0.5	220	20	49.00 ± 2.56	2.75 ± 0.06	10.0 ± 0.53	0.33 ± 0.03	8.10 ± 0.28
15	0.2	0.5	240	30	58.83 ± 1.54	2.43 ± 0.12	8.0 ± 0.25	0.40 ± 0.01	7.40 ± 0.20
16	0.2	0	220	30	66.91 ± 0.56	2.70 ± 0.05	9.5 ± 0.20	0.37 ± 0.01	8.23 ± 0.32
17	0.3	0.5	240	20	59.23 ± 1.33	2.10 ± 0.10	7.5 ± 0.37	0.50 ± 0.03	7.90 ± 0.10
18	0.3	0.5	200	20	1.12 ± 0.10	2.11 ± 0.04	6.0 ± 0.10	0.59 ± 0.02	4.30 ± 0.10
19	0.1	0.5	240	20	69.76 ± 3.50	2.75 ± 0.02	12.0 ± 0.36	0.36 ± 0.01	8.03 ± 0.25
20	0.1	0.5	220	30	68.01 ± 1.52	3.14 ± 0.05	13.0 ± 0.18	0.34 ± 0.02	8.60 ± 0.18
21	0.2	0	200	20	7.87 ± 0.24	2.16 ± 0.09	7.0 ± 0.10	0.49 ± 0.01	5.70 ± 0.10
22	0.3	1	220	20	46.32 ± 1.72	2.70 ± 0.05	9.0 ± 0.28	0.40 ± 0.03	7.60 ± 0.16
23	0.2	0.5	200	30	27.94 ± 0.78	2.60 ± 0.10	9.0 ± 0.25	0.45 ± 0.01	7.00 ± 0.20
24	0.2	0.5	200	10	5.69 ± 0.10	1.73 ± 0.01	4.5 ± 0.08	0.59 ± 0.01	4.50 ± 0.10
25	0.2	1	200	20	23.78 ± 1.01	2.65 ± 0.08	8.5 ± 0.40	0.46 ± 0.01	6.55 ± 0.30
26	0.2	1	220	10	45.86 ± 1.25	2.76 ± 0.05	9.0 ± 0.28	0.40 ± 0.03	7.44 ± 0.10
27	0.3	0.5	220	10	30.97 ± 1.09	2.50 ± 0.05	7.4 ± 0.10	0.51 ± 0.02	7.20 ± 0.10
28	0.2	0.5	220	20	53.15 ± 3.26	2.80 ± 0.11	11.0 ± 0.28	0.3 ± 0.02	7.80 ± 0.28
29	0.2	0.5	220	20	50.04 ± 3.13	2.54 ± 0.10	10.0 ± 0.50	0.44 ± 0.03	8.30 ± 0.30

A: Moisture level (mL/10 g sample), B: Salt concentration (%, w/w), C: Popping temperature (ºC), D: Popping time (sec).

The data for dependent variables are expressed as mean ± standard deviation of three replications of a trial.

polynomial models establishing the effect of independent variables of oil-popping on quinoa popping yield, expansion ratio, flake size, bulk density, and overall acceptability were all found to be significant ($P < 0.05$). A higher "F value" of all generated models and their non-significant "lack of fit" implied that the models were consistent and compatible with the data (Table 2).

3.1. Popping yield

Popping yield of oil-popped quinoa varied widely from 1.12% to 70.75% (Table 1). The second-order polynomial equation (1) fitted for popping yield in coded form after eliminating non-significant terms is expressed as

$$\begin{aligned}\text{Popping yield}(\%) = {} & 53.41 - 5.3\times \mathrm{A} + 6.61\times \mathrm{B} + 22.66\times \mathrm{C} + 14.97\times \mathrm{D} - 8.73\times \mathrm{BD} \\ & - 16.45\times \mathrm{C}^2 \end{aligned} \tag{1}$$

The higher F value (115.72) of popping temperature (C) reveals its dominating effect on popping yield followed by popping time (D) and salt concentration (B) (Table 2). The variation in moisture level (A) has the least effect on popping yield. The increase in salt concentration and

Table 2. One-way analysis of variance and fit statistics for different models

Parameter	*F* value and fit statistics				
	Popping yield (%)	Expansion ratio	Flake size (mm^3)	Bulk density (g mL^{-1})	Overall acceptability
Model	16.09*	12.84*	13.72*	6.75*	21.74*
A: Moisture level	6.33*	33.65*	50.33*	33.06*	21.15*
B: Salt concentration	9.86*	9.84*	5.95*	7.44*	3.01
C: Popping temperature	115.72*	8.49*	39.09*	17.65*	131.87*
D: Popping time	50.52*	20.53*	18.12*	5.56*	27.62*
AB	1.15	0.5374	0.1475	0.0163	0.0665
AC	0.0217	4.46	5.67*	0.0000	4.77*
AD	0.0977	2.28	3.40	0.0163	2.12
BC	0.1753	2.03	0.0001	0.7987	0.6963
BD	5.72*	0.0669	0.0001	0.0163	0.2357
CD	0.1894	9.37*	28.90*	3.19	22.12*
A^2	0.0484	0.0030	0.8937	3.98	1.51
B^2	0.0031	4.71*	1.19	0.4737	0.1646
C^2	32.98*	72.45*	39.38*	21.87*	84.75*
D^2	2.45	1.03	4.49	1.81	5.65*
Lack of fit	4.05	1.16	1.43	0.1149	3.22
R^2	0.9415	0.9277	0.9321	0.8709	0.9560
Adjusted R^2	0.8830	0.8555	0.8641	0.7418	0.9120
Predicted R^2	0.6850	0.6615	0.6721	0.6774	0.7671
Standard deviation	7.30	0.1159	0.6511	0.0392	0.3296
C.V %	16.38	4.49	7.16	9.36	4.42

The model parameters having *F* value with '*' in superscript are significant ($P < 0.05$).

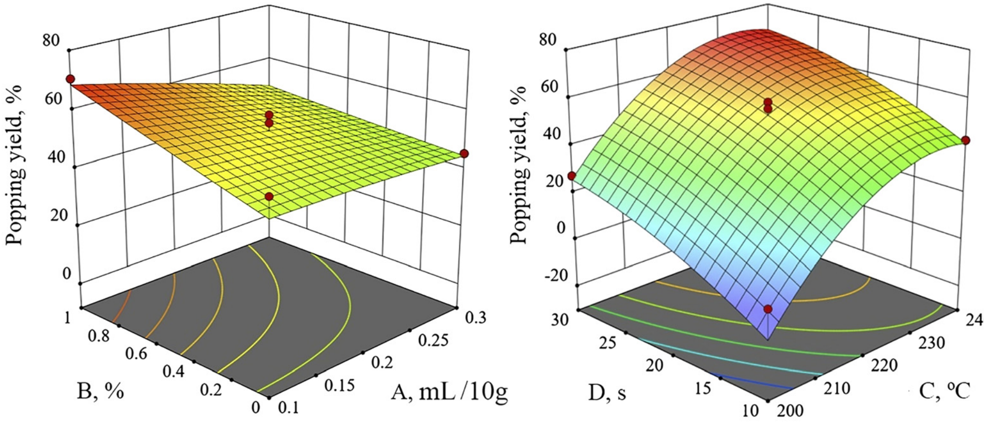

Fig. 1. Effect of moisture level (A), salt concentration (B), popping temperature (C), and popping time (D) on popping yield of popped quinoa

a decrease in moisture level during pretreatment of grains increase popping yield (Fig. 1). As per Mir et al. (2016), salt concentration increases the popping yield of brown rice due to the ability of salt to conduct more heat inward. The decrease in melting point of the pericarp of grain and collapse in starch structure at high moisture levels would result in lower popping yield (Farahnaky et al., 2013). The rise in popping temperature and popping time enhances popping yield (Fig. 1) due to increased steam generation on greater exposure to heat (Vorwald and Nienhuis, 2009). The negative coefficient of interaction term “BD” in regression equation (1) reflects that when the grains were treated with a high salt concentration and exposed to a long popping time, they result in very low popping yield due to case-hardening effect of salt and subsequent charring (Maisont and Narkrugsa, 2009).

3.2. Expansion ratio

The expansion ratio should be high enough for a popped product to derive significant profit after its commercial sales transaction. The expansion ratio of popped quinoa ranged between 1.73 and 3.14 (Table 1). The regression equation (2) stating the effect of independent variables on the expansion ratio without insignificant terms is expressed as

$$\begin{aligned}\text{Expansion ratio} = {} & 2.72 - 0.1942\times A + 0.1050\times B + 0.0975\times C + 0.1517\times D - 0.1775\times CD \\ & + 0.0988\times B^2 - 0.3875\times C^2\end{aligned} \tag{2}$$

On comparing the F values (Table 2), it is observed that expansion ratio of popped quinoa is highly influenced by moisture level (A) followed by popping time (D), salt concentration (B), and popping temperature (C). When popping temperature and popping time increases, expansion ratio increases (Fig. 2) due to increased rate of steam generation. In such a situation, significantly high pressure differential between quinoa grain and its surrounding favours sudden greater expansion (Mishra et al., 2014). The negative interaction term “CD” and quadratic term “C^2” means that at a very high temperature (240 °C) and higher residence time (30 s), expansion

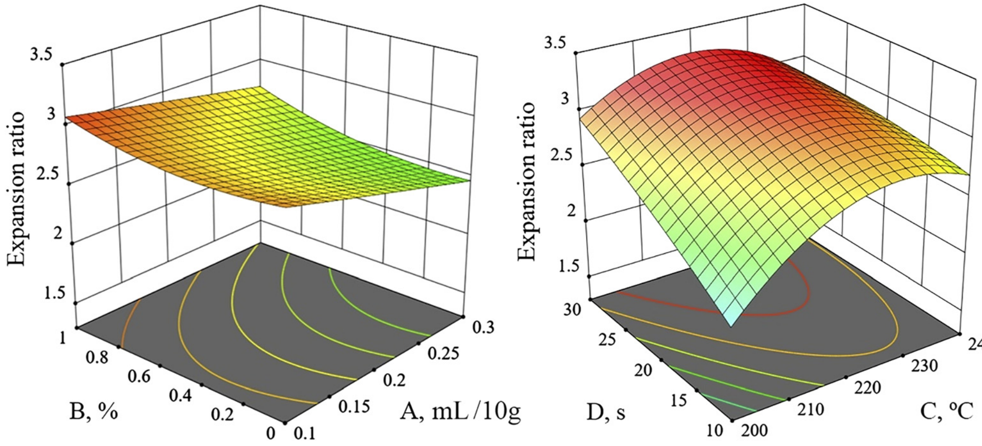

Fig. 2. Effect of moisture level (A), salt concentration (B), popping temperature (C), and popping time (D) on expansion ratio of popped quinoa

ratio decreases due to shrinkage of grain on carbonisation (Mir et al., 2016). Similarly, higher expansion ratio of puffed rice was obtained at 240–260 °C, while a further increment in temperature resulted in charring of rice (Nakade et al., 2020). In case of an increment in moisture level, negative effect was observed in expansion ratio probably due to softening of grain pericarp, reducing its pressure-holding capacity (Joshi et al., 2014). Ertas et al. (2009) found a sharp reduction in expansion volume of popcorn at a very high moisture level of 14%. As salt increases the conduction of heat and assists in building pressure by blocking pores in grain, expansion ratio of popped quinoa increases (Mir et al., 2016).

3.3. Flake size

Flake size of popped quinoa is within 4.5–13 mm^3 (Table 1). The quadratic equation expressing the effect of significant process parameters on flake size of popped quinoa is given as

$$\begin{aligned}\text{Flake size}\left(\text{mm}^3\right) = {} & 10.20 - 1.33\times \text{A} + 0.4583\times \text{B} + 1.18\times \text{C} + 0.80\times \text{D} - 0.7750\times \text{AC} \\ & - 1.75\times \text{CD} - 1.60\times \text{C}^2 \end{aligned} \tag{3}$$

The moisture level (A) is the most effective process parameter affecting the flake size of popped quinoa followed by popping temperature (C) and popping time (D) (Table 2). Salt concentration (B) has the least effect on flake size. Similar to expansion ratio, the average flake size of individual popped quinoa also increased with a decrease in moisture level and an increase in rest of the independent variables (Fig. 3). Ertas et al. (2009) reported that flake size of popcorn cultivars such as Ant Cin-98 and Con Cin-98 are comparatively higher at a moisture content of 12% than at 14%. Quinn et al. (2005) stated that flake size of popcorn can be increased by increasing the pressure gradient between grain and atmosphere. As heating at high popping temperature and popping time increase pressure gradient, flake size of popped quinoa increases due to a higher degree of expansion resulted. However, as inferred from the negative coefficient of interaction term “AC”, the pressure gradient would not be sufficient even at a high

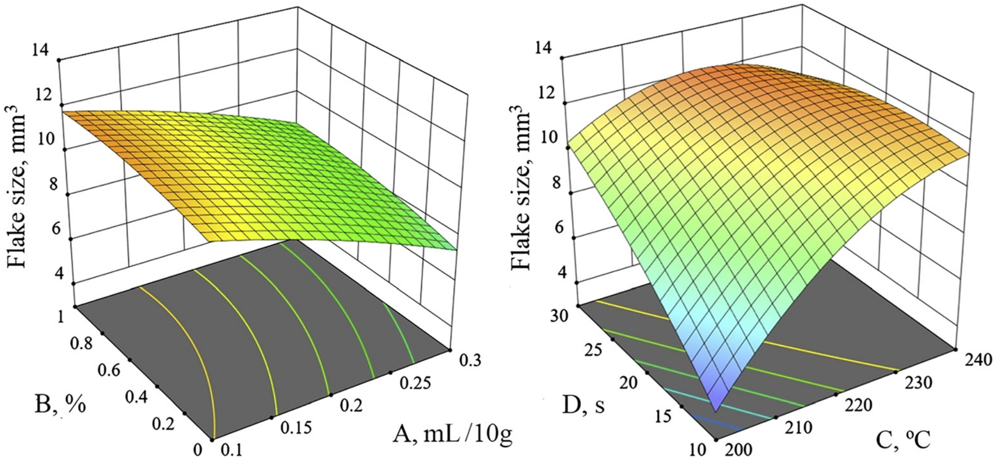

Fig. 3. Effect of moisture level (A), salt concentration (B), popping temperature (C), and popping time (D) on flake size of popped quinoa

temperature if the initial moisture level of the grain is high. It is because the available time is not enough to vaporise inherent moisture and weakened swollen cell walls release the pressure gradually rather than as a sudden outburst that gives desired expansion (Joshi et al., 2014).

3.4. Bulk density

Bulk density of popped quinoa obtained from different treatments varied in the range of 0.28–0.59 g mL^{-1} (Table 1). The model reflecting the effect of puffing conditions on bulk density of popped quinoa after neglecting the non-significant terminologies is expressed as

$$\text{Bulk density}\left(\text{g mL}^{-1}\right) = 0.3720 + 0.0650\times A - 0.0308\times B - 0.0475\times C - 0.0267\times D + 0.0719\times C^2 \tag{4}$$

It can be observed from Table 2 that moisture level (A) having a high F value of 33.06 is identified as a major contributor to bulk density, whereas popping time (D) is the least affecting parameter. The higher the popping temperature and popping time, the lower is the bulk density (Fig. 4) due to the transformation of hard raw grain into an aerated and light-weighed popped quinoa. An intensified water evaporation, polymer expansion, and dehydration at this rapid heating condition create more non-homogenously distributed air vacuoles with a larger diameter thereby reducing bulk density of product (Ngadi et al., 2008). Similar results have been obtained by Nath and Chattopadhyay (2007), where bulk density of puffed potato snack decreased with an increase in puffing temperature and puffing time. The ability of salt to conduct heat and promote expansion volume ultimately reduced bulk density. With an increase in moisture level, bulk density value increased to an unacceptable greater extent. The expansion process involves a gelatinisation-induced transition of starch to a rubbery state. As the high moisture level reduces the viscosity of starch matrix and affects the expansion of air cells, the structure shrinks and collapses leading to less porosity and a high density of popped grain (Gui et al., 2012). It is in accordance with the findings of Swarnakar et al. (2020), where puffed

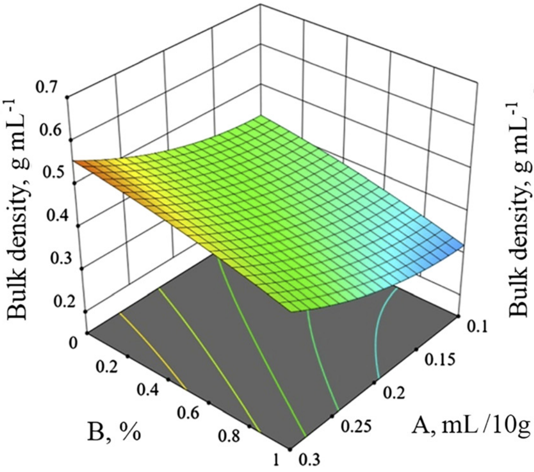

Fig. 4. Effect of moisture level (A), salt concentration (B), popping temperature (C), and popping time (D) on bulk density of popped quinoa

brown rice exhibited a higher bulk density when the grains were conditioned to a higher moisture level.

3.5. Overall acceptability

Based on sensory evaluation, the mean value of overall acceptability of trial products varied between 4.3 and 8.77 (Table 1). The model was reduced by neglecting the non-significant terms and expressed as

$$\text{Overall acceptability} = 8.12 - 0.4375\times A + 1.09\times C + 0.5\times D + 0.36\times AC - 0.775\times CD - 1.19\times C^2 - 0.3075\times D^2 \quad (5)$$

Overall acceptability of popped quinoa is greatly affected by popping temperature (F value = 131.87) followed by popping time (*F* value = 27.62) and moisture level (*F* value = 21.15). However, the overall acceptability of popped quinoa was not significantly influenced by salt concentration (Table 2). The negative relationship of moisture with overall acceptability was attributed to high hardness, oiliness, and incomplete expansion of quinoa, which was less accepted by sensory panellists (Mishra et al., 2015). Kantrong et al. (2018) reported an increment in hardness and a decrement in crispiness of extrusion puffed snack with an increase in moisture level. As popping temperature and popping time increased (Fig. 5), overall acceptability also increased due to better expansion. The larger the size of the expanded grain the greater is its aesthetic appeal to the consumer. The higher temperature and time greatly reduce the moisture content of frying product thereby increasing crispiness. The product is less oily, because the intense and pressurised outflow of vapour from grain inhibits the intrusion of oil (Ngadi et al., 2008; Oke et al., 2017). However, as inferred from the negative coefficient of interaction term "CD" and quadratic terms "C^2" and "D^2", extreme levels of heating caused charring of popped quinoa grains, appearing darker, unattractive in colour, with burnt flavour

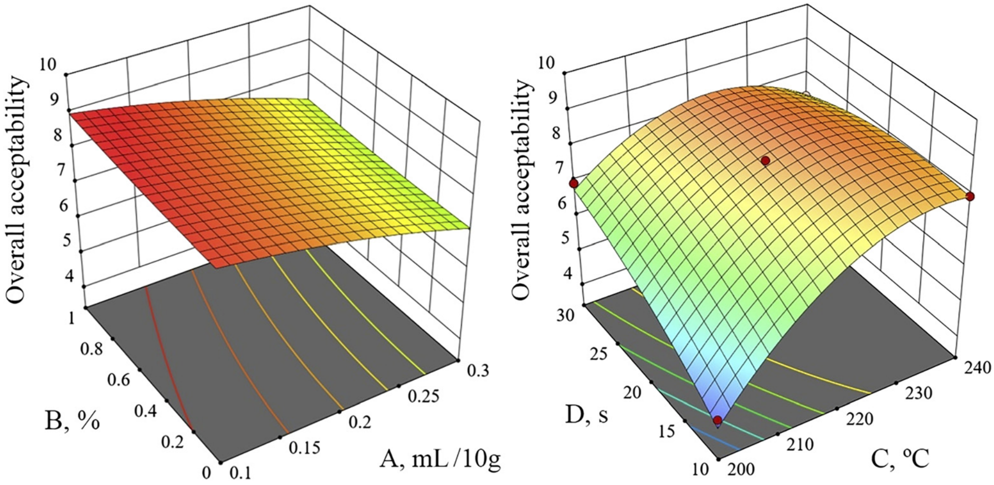

Fig. 5. Effect of moisture level (A), salt concentration (B), popping temperature (C), and popping time (D) on overall acceptability of popped quinoa

note. Similar results were observed by Joshi et al. (2014), where the overall acceptability of puffed rice increased with an increase in oven preheating temperature, but its negative quadratic term infers the reduction in acceptability if exposed to an elevated temperature zone for a long time.

3.6. Optimisation and validation of model

The model predicted to get quinoa popping yield of 77.54%, expansion ratio of 3.16, flake size of 12.08 mm^3, bulk density of 0.28 g mL^{-1}, and overall acceptability of 8.77 at an optimised level of 0.1 mL moisture level/10 g sample, 1% (w/w) salt concentration, 228.8 °C popping temperature, and 26 s popping time. In the verification trial under optimised conditions, a popping yield of 75.56%, expansion ratio of 3.07, flake size of 11.58 mm^3, bulk density of 0.29 g mL^{-1}, and overall acceptability of 8.40 were obtained. As the actual and predicted response were in a close range without significant difference ($P < 0.05$), the developed models can be interpreted as reliable.

4. CONCLUSIONS

The study established the empirical relationship between factors influencing oil popping of quinoa and popping quality indices. The best popping quality of quinoa could be obtained at the optimised condition of 0.1 mL water/10 g sample, 1% (w/w) salt concentration, 228.8 °C popping temperature, and 26 s popping time. The developed ready-to-eat popped quinoa could be an affordable, nutritious, and flavourful snack. It could generate significant profit to manufacturers as three-fold expansion is achievable. A further study focusing on oil-popping of quinoa under vacuum is possible and it creates scope to reduce oil absorption and improve popping quality of the product.

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