Mysore J. Agric. Sci., 58 (2) : 285-295 (2024)

Effect of Moisture, Air Velocity and Temperature on Popping Characteristics of Quinoa Grain

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Received : December 2023
Accepted : January 2024

Abstract

The study on effect of moisture content, air velocity and temperature on quality attributes of quinoa undergoing hot air popping was investigated. Preliminary trials were conducted with different pre-treatments such as salt water conditioning, buttermilk conditioning and moisture conditioning of quinoa grains. Moisture conditioned quinoa found to give better results in sensory attributes and hence optimization of the experiments were conducted using response surface methodology (RSM) under different moisture levels (10, 14 and 18%), air velocity (6, 7 and 8 cfm) and temperature (260, 290 and 320ºC) combinations. The experimental results showed that the popping yield, popping effectiveness, volumetric expansion increased significantly ($P<0.05$) with an increase in moisture content, air velocity and temperature up to 14 per cent, 7 cfm and 290ºC, respectively. The popping yield was varied from 48.5-62 per cent and was significantly influenced by moisture levels, air velocity and temperature. The quinoa grains with 14 per cent moisture popped at 290ºC with air velocity of 7 cfm showed highest popping effectiveness (51.14%) volumetric expansion ratio (1.23) and lowest unpopped kernel percentage with lightness value, L* (79.37), redness, a* (2.87) and yellowness, b* (16.91) values. Hence, the study revealed that quinoa popped at 14 per cent moisture content, 7cfm air velocity and 290ºC temperatures were found to be optimum conditions for good popping quality attributes.

Keywords : Hot air popping, Popping yield, Popping effectiveness, Volumetric expansion ratio, Unpopped kernel

Quinoa is a pseudo cereal plant native to South America with 5000 to 7000 years of history. Botanical name of the quinoa is *Chenopodium quinoa*, belong to family *Chenopodium*. Plant was mainly cultivated in Andean region, Ecuador, Peru, Bolivia, Chile and it is substituted by foreign crops such as wheat and barley (Valencia-Chamorro, 2003). Quinoa grains are flat, round in shape with 1.5 to 40 mm diameter and colour of the grains varies based on variety from white to gray, black with tone of yellow, rose, red, purple and violet (Gordillo-Bastidas *et al.,* 2016). Quinoa is a nutritious grain and good source of protein with high biological value with carbohydrate of low glycemic index and contain essential amino acids particularly lysine, methionine with good amount of essential fatty acids (linoleic, oleic and palmitic acids). Quinoa grains even contain good amount of minerals, vitamins and dietary fiber (Kursat, 2014). Quinoa has been found to contain bioactive compounds like polyphenols, phytosterols, and flavonoids with possible nutraceutical benefits (isoflavons and lipids). Besides nutrient compounds, it also contain anti nutrients (phytic acid, saponin and tannin) which mainly concentrated in the outer layer of the grain (Antonio *et al.,* 2017). Saponin present in the outer layer of the grain is responsible for bitterness when we consume raw grains otherwise, quinoa has excellent functional properties such as solubility, galation, water holding capacity, emulsifying and foaming property (Mostafa, 2017).

Traditional foods which are healthy with good nutrient density and longer shelf life can be prepared through various conventional methods. Quality Protein Maize (QPM) based multipurpose mix was developed using conventional method along with the other ingredients (Shoba *et al.,* 2019). Literature cited indicated that researchers in different parts of the world conducted studies on development of various value added products from quinoa such as quinoa salad, porridges, soup and health drinks and has been recently used to develop breakfast cereals; granola bars (Garcia *et al.,* 2018). Owning to its nutritional benefits, it is used for the production of healthy snacks (Priyanka *et al.,* 2017); pasta (Mostafa, 2017); biscuits (Ibrahium, 2015); fried snacks (Kavali *et al.,* 2019) and cookies (Nisar *et al.,* 2018) and other processed products. In order to get rid of bitterness due to presence of saponins in the outer layer of quinoa grains processing techniques such as soaking, washing, germination, pearling, puffing or popping of grains can be done before value addition or product development.

The popping study of quinoa grains in different pre treatment conditions was not reported so far. Hence, the present study was undertaken with an objective to standardize the quinoa popping characteristics under different pre-treatments and popping of quinoa in hot air popping machine.

METHODOLOGY

The details of the experimental material and methodologies adopted for the research are discussed as follows. Quinoa grains were procured from AICRP (Underutilized crops), UAS, GKVK, Bengaluru and stored under temperature and humidity controlled chamber at 6ºC till the experiments were conducted. Moisture content of quinoa samples were determined as per the AOAC (1980) method and the initial moisture content of the quinoa grains were found to be ranged between 10-10.5% (w.b). The whole quinoa grains contain outer cover rich in saponin and have to be removed by adopting a processing technique for further application of quinoa based food products development. The husk which is rich in saponin contributes to bitter taste and hence can be effectively removed by hot air puffing method where popping of grain breaks the husk and can be removed by winnowing technique.

Popping Methodology : The experiments on popping of quinoa were conducted using hot air puffing machine available at AICRP (PHET), GKVK, Bengaluru. Preliminary trials on popping of quinoa were conducted using different treatments. The treatments consisted of conditioning of quinoa with butter milk (5%), salt water (5%) and moisture conditioning (17%) at temperature range of 290ºC. The laboratory scale experimental trials were carried out to findout the optimal parameters of popping with maximum retention of quality.

Sensory Quality of the Popped Product : The sensory evaluation of popped grain with different treatments (salt conditioning, buttermilk conditioning and moisture conditioning of quinoa grains and control) was carried out using 9-point hedonic scale (Ranganna, 2005). The popped product were judged for the sensory quality attributes such as appearance, colour, crispiness, presence of bitterness, adhesive to teeth, texture and overall acceptability by a panel of 21 semi-trained judges. For each sample, the average score given by the judges for different quality characteristics were computed and mean scores were reported. Based on feeler trail result, further experiments were conducted using Response Surface Methodology (RSM).

Experimental Set up using Response Surface Methodology (RSM)

Popping technique : The hot air popping machine was operated in using single phase electricity. Later heat was given by gradually increasing the temperature up to 300°C.The air flow rate and puffing temperature were optimized for puffing of quinoa after feeler trials. The cleaned, preconditioned grains weighing 100 grams were fed from hopper to popping column where popping takes place. Later the popped product was collected through conveying chute. In the processing chamber, the grains were instantly heated by hot air at a temperature ranging from 260-320°C and air flow rate which is sufficient to fluidize the grains attained maximum convective heat transfer coefficient and the moisture in the grain was instantaneously converted into super heated vapour due to rapid heating which escapes through micro pores leading to simultaneous gelatinization and expansion of the grains. After popping, the density of the grains was reduced due to expansion and the popped product was carried away by the air stream from the processing chamber which was then collected through collector.

Quality Parameters of Popped Quinoa Grains

Different quality parameters which determine popped grain quality were analysed using the standard procedures described below.

Popping Yield : Popping yield indicates the quantity of grains that popped out of the raw grains taken for popping. After popping, the popped product was separated manually into fully popped, semi-popped and unpopped fractions by using different sized sieves. The grains were considered fully popped when they were reasonably expanded did not have any un popped part and they were separated using No.10 mesh sieve (ASTM E-11, 2 mm). Grains were considered semi popped when some part of the kernel was popped while the other part still remained un-expanded. The weight of both fully popped and semi-popped grains were recorded. The popping yield of grains was calculated by taking the ratio of weight of the popped grains to the initial weight of the grains before conditioning (Premavalli *et al.,* 2005) and it is expressed in percentage.

$$\text{Popping yield (\%)} = \frac{Wfp + Wsp}{W} \times 100 \qquad \text{Eq....2.1}$$

Where,

Wfp = Weight of fully popped grains (g)

Wsp = Weight of semi-popped grains (g)

W = Initial weight of the grains (g)

Popping Effectiveness : Popping effectiveness is of importance as it would indicate how many grains were actually popped fully. After popping, the fully popped, semi-popped and unpopped grains were separated by sieving and then weighed. Popping effectiveness was computed as a ratio of weight of fully popped grain to the sum of fully popped, semi-popped and unpopped grains.

$$\text{Popping effectiveness (\%)} = \frac{Wfp}{Wfp+Wsp + Wup} \times 100 \qquad \text{Eq....2.2}$$

Where,

Wfp = Weight of fully popped grain (g)

Wsp = Weight of semi-popped grain (g)

Wup = Weight of unpopped grain (g)

Unpopped Kernel Percentage

Unpopped kernel percentage in the product was measured as a fraction of weight of unpopped kernel to the sum of weight of fully popped, semi-popped and unpopped grains. It is calculated using the following equation:

$$\text{Unpopped kernel (\%)} = \frac{Wup}{Wfp+Wsp + Wup} \times 100 \qquad \text{Eq....2.3}$$

Where,

Wfp = Weight of fully popped grain (g)

Wsp = Weight of semi-popped grain (g)

Wup = Weight of unpopped grain (g)

Volumetric Expansion Ratio : Volumetric expansion ratio determines the degree of expansion of grains during popping. It is the ratio of true volume of popped grain to true volume of raw grain (before conditioning). Volume of puffed product is measured by sand (silt) displacement method (Mohapatra *et al.,* 2012). Popped grain was poured into a graduated measuring cylinder and the inter granular void space was filled with fine, dry and clean sand (silt) with 10 gentle tapping. The total volume (Vt) was recorded. Sand and puffed grains were separated with a screen and the volume of the sand was measured (Vs). Thus, the difference between Vt and Vs was the volume of popped grain. The same procedure was followed for un puffed initial grain by taking the difference of total volume and sand volume (Vi). The volumetric expansion ratio was calculated using the equation given below:

$$\text{Volumetric expansion ratio} = \frac{Vt + Vs}{Vi} \times 100 \qquad \text{Eq.…2.4}$$

Where,

Vt = Total volume of popped product (ml)

Vs = Volume of sand (ml)

Vi = Difference between total volume and sand volume of raw grain (ml)

Product Bulk Density : Bulk density measures the degree of lightness of the popped product. Bulk density of popped product was determined by taking 100 g of fully popped product in a 1000 ml measuring cylinder. The volume of sample was noted after tapping the cylinder until no visible decrease in volume was noticed. The bulk density was calculated as the ratio of weight of the sample to the volume of the sample expressed in kg/m^3.

$$\text{Bulk density (kg/m}^3\text{)} = \frac{\textit{Weight of popped product (kg)}}{\textit{Volume of popped product (m}^2\textit{)}}$$

Eq.…2.5

Popped Product Colour : Tristimulus colour measurements of the popped product was calculated using a Spectrophotometer (Make: Konica Minolta Instrument, Osaka, Japan; Model-CM5). Before taking readings, the chromometer was calibrated with black and white standard plates. The colour of the sample was measured in L* a* b* coordinate system where L* indicated lightness of the sample; a* value indicated greenness (-) or redness (+) of the sample; and b* value indicated blueness (-) or yellowness (+) of the sample. Colour values of three replications were recorded and mean values were reported.

Experimental Design and Statistical Analysis : A box behnken method of RSM design was used to analyse the interaction of process variables on quality of popped quinoa in 17 experiments, out of which 4 experiments were for centre point and 13 were for non-centre point. The process variables were maintained in different combinations (Table 1). The response parameters were popping yield, popping effectiveness, unpopped kernel percent, volumetric expansion ratio, bulk density, color values in terms of L*, a*, b*. The analysis of variance (ANOVA) tables

TABLE 1

RSM design of the experiments for dependent and independent variables

Independent variables	Moisture content (10, 14 and 18%) Temperature (260,290 and 320ºC) Air flow rate (6, 7 and 8 cfm)
Dependent variables	Popping yield Popping effectiveness Unpopped kernel per cent Volumetric expansion ratio Bulk density Product color

TABLE 2

Effect of pre-treatment's on sensory quality of Popped quinoa grains

Sensory characteristics	A	B	C	D	F-value	SEm±	CD @ 5%
Appearance/ colour	8.5	7.1	6.8	6.6	*	0.20	0.55
Taste	8.4	6.8	6.8	6.5	*	0.21	0.59
Crispiness	8.4	7.0	6.9	6.6	*	0.15	0.42
Adhesive to teeth	8.6	7.3	6.6	6.7	*	0.15	0.42
Presence of bitterness	8.5	7.1	6.5	6.6	*	0.20	0.56
Over all acceptability (OAA)	8.6	7.1	6.7	6.6	*	0.15	0.42

A : Moisture conditioned, B : Buttermilk conditioned, C : Salt solution conditioned, D : Control were generated and the effect of individual linear, quadratic and the interaction term was studied using design expert program (V 6.0.8) of the state ease software (Design expert, 2002). The significance of all the polynomial was judged statistically by computing the F value; the significance of the F value was judged at a probability level (P) of 0.01 and 0.05.

Results and Discussion

Sensory Quality of Popped Quinoa under different Pre-treatment Conditions

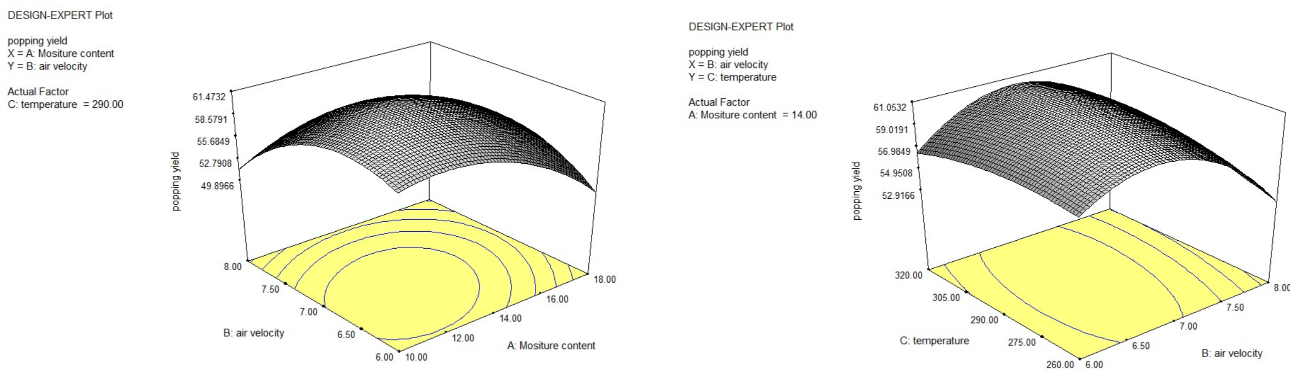
The perusal of Table 2 revealed that, among different pre-treatment's (moisture treated, buttermilk treated, salt solution treated and control- without any pre treatment) of quinoa grains revealed that, moisture pre-treatment (moisture treated sample 17 %) received significantly higher scores for appearance (8.5) taste (8.4), crispiness (8.4) with a overall acceptability score of 8.6 on a 9 point hedonic scale. The lower sensory scores for salt treated and buttermilk treated samples were due to presence of bitterness imparted by residual husk attached to the grain. The popped quinoa grain with moisture treatment is depicted in Plate 1.

Effect of Moisture Content, Air Flow Rate and Temperature on Popping Yield

Popping yield of quinoa with different moisture contents, air flow rate and temperature combinations is presented in Fig.1. The maximum and minimum popping yield of 48.5 and 62 per cent were observed at 10 and 14 per cent moisture levels, 8 and 7 cfm air velocity and 260°C and 290°C temperature, respectively. Statistical analysis of RSM showed that there was a significant ($P<0.05$) difference in popping yield with initial grain moisture levels, air velocity and temperature combinations. It was observed that first order and second order interaction effects of the popping treatments namely, moisture level, air velocity and puffing temperature were significant.

The yield was observed to be maximum at 290 °C. The popping yield increased with increase in moisture content up to 14 per cent and decreased thereafter with further increase in moisture content. Similar findings were reported by Malleshi and Desikachar (1985), wherein the yield decreased with increase in grain moisture content beyond 19 per cent for ragi. The results of the study indicated that with increase in moisture content of the grain, puffing yield was reduced, as high moisture content might have softened

Plate1. The popped quinoa grain using hot air popping machine .



a) b)

Fig. 1 : Effect of a) moisture content, air velocity b) temperature and air velocity on popping yield

the peri carp or hull portion making the grain unable to withstand the internal pressure for puffing (Rahman *et al.,* 2019). On the other hand, at lower moisture, there was an inadequate amount of water required for generation of super heated vapour which is the driving force for better puffing of grains.

The quadratic equation (3.1) confirms, the positive influence of A and B and C on popping yield.

$$\text{Popping yield} = -148.73437 + 2.25152*A + 41.72420*B + 0.37738*C - 0.23636*A^2 - 4.33182*B^2 - 1.03535E-003*C^2 + 0.55312*A*B - 1.04167E-004*A*C \quad \text{Eq... 3.1}$$

Where,

A - moisture content

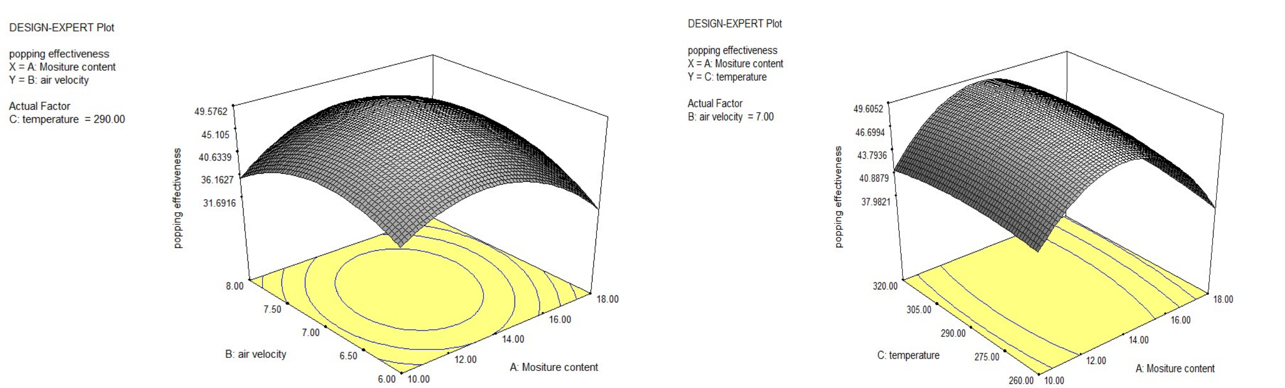
B - air velocity and

C - temperature

Effect of Moisture Content, Air Velocity and Temperature on Popping Effectiveness

Popping of quinoa at different process parameters is presented in Fig.2. The popping effectiveness of popped quinoa was maximum (51.14 %) at 14 per cent moisture content, 7 cfm at 290ºC and minimum (31.18 %) at 18 per cent moisture, 6 cfm and 320ºC temperature. Statistical analysis of RSM showed that there was a significant difference in popping effectiveness when quinoa grains were popped under different popping temperature, moisture levels and air velocity.

Interaction effect of moisture content and air velocity were found to be significant (Fig.1a) and the interaction effect of moisture content and temperature were found to be non significant with respect to



a) b)

Fig. 2 : Effect of a) moisture content and air velocity b) Moisture content and temperature on popping effectiveness

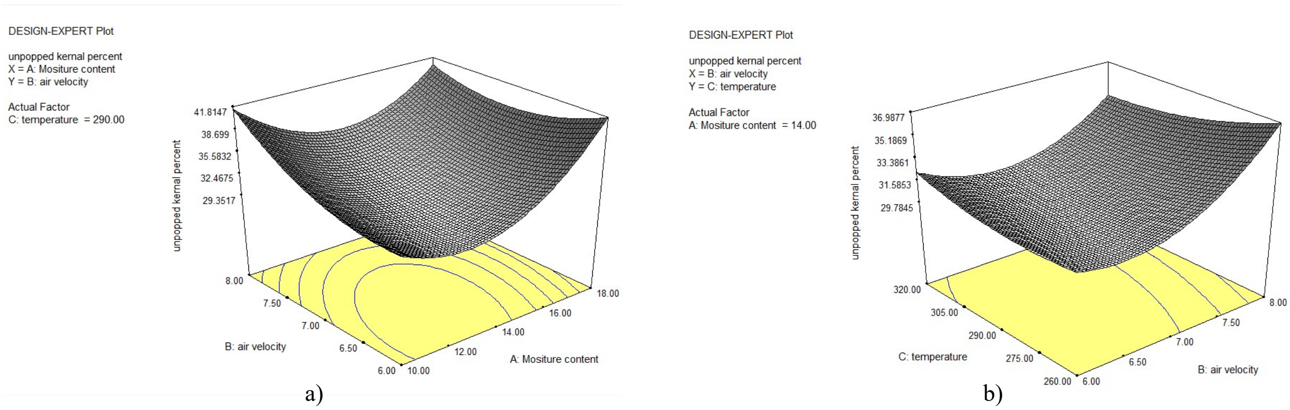


Fig. 3 : Effect of a) moisture content and air velocity b) temperature and air velocity on unpopped kernel percentage

interaction effects of air velocity and temperature (Fig.1b). The temperature of 290°C showed maximum effectiveness, whereas with further increase in temperature to 320°C, there was a negative impact on puffing effectiveness. At lower grain moisture content (10 %), some of the grains remained semi-popped due to lack of development of adequate water vapour pressure required for popping. The present results are in line with the research findings of Murugesan and Bhattacharya (1986), who reported that at very low moisture content, most of the popped grains remained cylindrical in shape without opening up or popping, probably due to lack of adequate steam pressure or water vapour pressure needed for bursting. Further, by increasing the grain moisture content, the popping effectiveness was significantly increased but further increase in grain moisture content was found to be having negative impact on the popping effectiveness. Conditioning of quinoa with optimum moisture level (14%) was observed to have positive impact on popping effectiveness of the grains was due to development of sufficient vapour pressure inside the grain so that maximum number of grains could pop. However, further increase in moisture content beyond 14 per cent has led to softening of the grain which negatively impacted on the popping effectiveness.

The best fit second order quadratic equation (R^2 = 0.9205) for popping effectiveness of quinoa is as follows:

$$\text{Popping effectiveness} = +49.52 - 1.21 * A + 0.67 * B + 0.44 * C - 8.27 * A^2 - 5.53 * B^2 - 0.97 * C^2 + 2.15 * A * B + 0.64 * A * C + 1.50 * B * C$$

Effect of Moisture Content, Air Velocity and Temperature on Unpopped Kernel Percentage

The perusal of Fig. 3, depicts the unpopped kernel percentage of quinoa after popping at different combinations of the process parameters. The unpopped kernel percentage of quinoa was maximum (43.93%) at 10 per cent moisture level with 8 cfm air velocity and 260^{0}C and the same was minimum (29.55 %) at 14 per cent moisture 7 cfm air velocity at 290^{0}C temperature. Statistically significant difference was observed in unpopped kernel per cent in the product popped at different popping temperature, different grain moisture level and pretreatments. Unpopped kernel percentage decreased significantly ($P<0.05$) with increase in moisture content, air velocity and temperature up to 14 per cent moisture, 7 cfm air velocity and 290ºC temperature which increased with further increase of all the three variables.

The quadratic equation confirms the negative influence of moisture, air velocity and temperature on unpopped kernel percentage. At lower moisture content, due to inadequate amount of water required for generation of vapour pressure and at higher moisture levels due to softening of the grain pericarp contributed for more unpopped kernels. This was in consistent with the results of Chaturvedi and Srivastava (2008) who reported an unpopped kernel percentage ranging from 16 to 45.4 per cent among the six finger millet varieties which popped at 19 per cent moisture level.

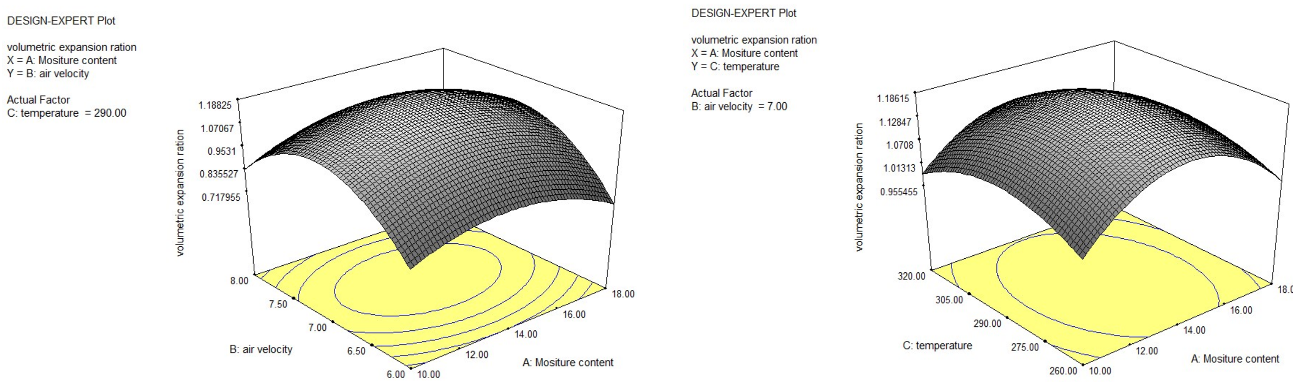


Fig. 4 : Effect of a)moisture content and air velocity b) Temperature and moisture content on volumetric expansion ratio

The best fit second order quadratic equation (R^2 = 0.9205) for unpopped kernel percentage of popped grain is as follows.

$$\text{Unpopped kernal percent} = +161.56810 - 6.26230 * A - 16.64194 * B - 0.26420 * C + 0.39068 * A^2 + 2.68091 * B^2 + 8.17677E{-}004 * C^2 - 0.64031 * A * B + 1.19792E - 003 * A * C - 0.034208 * B * C$$

Effect of Moisture Content, Air Velocity and Temperature on Volumetric Expansion Ratio

Volumetric expansion ratio of quinoa after popping at different combinations of the process parameters is presented in Fig. 4. Volumetric expansion ratio increased significantly with increase in moisture content and temperature while air velocity did not have significant effect on popping quality. The reason for higher expansion ratio with increase in moisture content might be due to higher vapour pressure build up inside the grains. Further, increase in grain moisture content might have softened the grains to make it rubbery which resulted into decreased expansion ratio (Mishra *et al.,* 2014). The positive coefficients of the second order terms of moisture, air velocity and temperature (A, B and C) confirmed that the expansion ratio increased with increase in these terms up to certain level and then decreased.

The best fit second order quadratic equation (R^2 = 0.9205) for volumetric expansion ratio of popped quinoa is as follows.

$$\text{Volumetric expansion ratio} = -18.90284 + 0.22695 * A + 3.49719 * B + 0.042375 * C - 8.38068E - 003 * A^2 - 0.25909 * B^2 - 7.67677E - 005 * C^2 + 4.37500E - 003 * A * B - 8.33333E{-}005 * A * C + 4.16667E - 004 * B * C$$

Effect of Moisture Content, Air Velocity and Temperature on Bulk Density

The bulk density of popped quinoa under different combinations of popping temperatures, grain moisture levels are presented in Fig. 5. Statistical analysis showed that there was a significant difference in bulk density of popped product for each of three popping temperatures and grain moisture levels. The interaction effect of popping temperature and moisture levels were found to be significant. The bulk density of quinoa was found to be maximum at 14 per cent moisture level, 7 cfm air velocity and 290ºC and minimum at 18 per cent moisture level, 6 cfm air velocity and 320 ºC temperature. Generally, bulk density of popped product will decrease with increase in volumetric expansion. Study conducted by Swarnakar *et al.* (2018) reported that bulk density of product decreased with increase in expansion ratio. Better volumetric expansion decreased the product bulk density due to loss of integrity between starch–starch; starch-protein matrix; or due to the formation of spaces in the starchy endosperm during puffing (Chandrasekhar and Chattopadhyay, 1991).

The best fit second order quadratic equation (R^2 = 0.9205) for bulk density of popped quinoa is as follows.

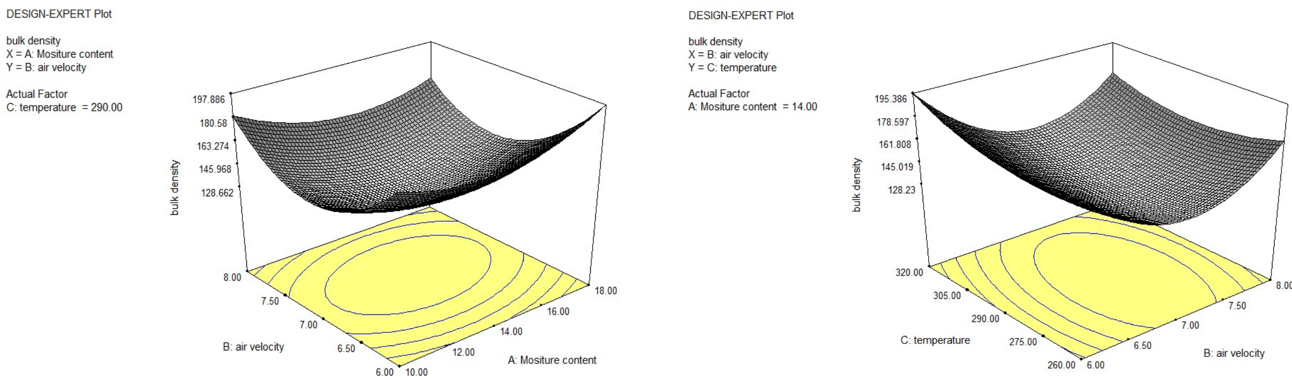


Fig. 5 : Effect of a)moisture content and air velocity b) Temperature and moisture content on Bulk density

$$\text{Bulk Density} = +2872.36364 - 16.26894*A - 471.69318*B - 6.72159*C + 1.07955*A^2 + 37.27273*B^2 + 0.013636*C^2 - 1.56250*A*B - 0.010417*A*C - 0.12500*B*C$$

Effect of Moisture Content, Air Velocity and Temperature on Colour (L*A*B*) Values

Colour value of popped quinoa indicated by L* a* b* values are presented in Fig. 6.1, 6.2 and 6.3, respectively. The L* a* and b* values of the popped quinoa at different treatments varied from 71.12 to 79.37 (L*), 2.87 to 5.91 (a*) and 16.91 to 22.64 (b*), respectively indicating the influence of treatment combinations on colour parameters of popped quinoa grains. The lightness (L*) showed significant difference with the variation in moisture and temperature, while air velocity affected non-significantly with all the parameters. The a* and b* values did not affect significantly when the moisture, air velocity and temperature varies. The statistical analysis showed no significant difference between "colour" of puffed product with respect to different popping temperatures and moisture levels employed during popping.

The best fit second order quadratic equation ($R^2 = 0.9875$) for L*a*b* values of popped quinoa are as follows.

$$L^* = -231.13252 + 2.21090*A + 1.89455*B + 2.00317*C - 0.086136*A^2 - 0.84318*B^2 - 3.90354E\text{-}003*C^2 - 0.027500*A*B + 1.20833E\text{-}003*A*C + 0.034000*B*C$$

$$a^* = +3.04 - 0.065*A + 0.095*B + 0.099*C + 0.88*A^2 + 0.53*B^2 + 1.06*C^2 + 0.059*A*B - 0.036*A*C - 0.33*B*C$$

$$b^* = +17.43 - 0.28*A - 0.074*B - 0.20*C + 1.26*A^2 + 0.89*B^2 + 2.27*C^2 - 0.040*A*B - 0.37*A*C - 0.40*B*$$

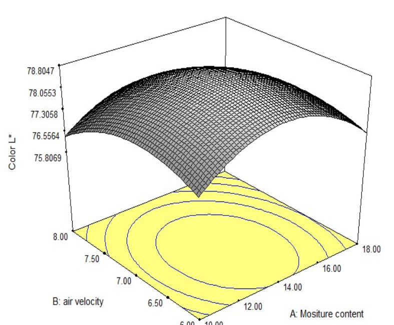


Fig. 6.1 : Effect of moisture content, air velocity and temperature on L* value

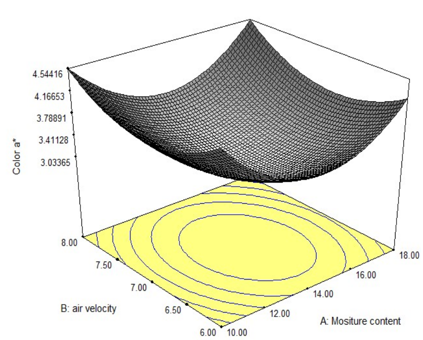


Fig. 6.2 : Effect of moisture content, air velocity and temperature on a*value

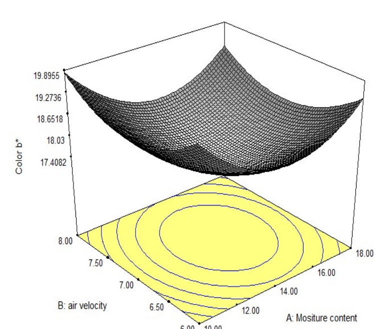


Fig. 6.3 : Effect of moisture content, air velocity and temperature on b*value

Quinoa grains were popped in a hot air puffing machine and analysed for its quality characteristics. Among the different pre treatments tested (moisture conditioning, buttermilk conditioning, salt solution conditioning and control; without any pre treatment) of quinoa grains revealed that, moisture conditioning (moisture 17%) received significantly higher overall acceptability score of 8.6 on a 9 point hedonic scale. The RSM experimental results showed that quinoa popped at a moisture content, temperature and air velocity of 14 per cent, 290 ºC and 7 cfm showed best popping yield. The best L* (79.37), a* (2.87) and b* (16.91) values were received at 14 per cent moisture, 7 cfm air velocity and 290 ºC temperature. Thus, study indicated that the moisture, air velocity and temperature had significant dependent parameters which influence the popping quality and popped grain yield.

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