Control of matting temperature during pressing of *Paneer* and its effect on *Paneer* quality

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Abstract An attempt was made to design, fabricate and evaluate a heat exchanger for controlling the matting temperature of *Paneer* during pressing. Based on preliminary investigations, the range of process parameters to be evaluated during the pressing of *Paneer* was selected as: pressure (2, 3, and 4 kg/cm²), matting temperature (63, 66 and 69 °C) for pressing time of 8, 10 and 12 min. Experiments were designed in a central composite design for 20 runs and the *Paneer* was evaluated for its moisture content, hardness, springiness, chewiness, cohesiveness, bulk density, porosity and sensory attributes. It was observed that with increasing pressure and matting temperature, the hardness of the product increased; this corresponded with reduced moisture content and porosity of the product. The springiness of the samples correlated linearly with increasing matting temperature and pressing time. Increasing the pressure during pressing resulted in poorer

sensory scores. The process conditions for pressing of *Paneer* under controlled matting conditions were optimised using Response Surface Methodology for moisture content, overall acceptability, hardness and springiness of the pressed product. It was observed that the moisture content of *Paneer* pressed under controlled matting temperature was marginally lower than the control *Paneer*, the overall acceptability for the experimental samples was higher with superior body and texture scores.

Keywords *Paneer* · Matting temperature · Optimisation · Response Surface Methodology · Quality

Introduction

Paneer, a popular indigenous dairy product of India, is similar to an unripened variety of soft cheese. It is prepared by heat and acid coagulation of milk, entrapping almost all the fat, casein complexes with denatured whey proteins and a portion of salts and lactose, which is then pressed to expel whey to form a fused block. The product is characterized with a marble white appearance, firm, cohesive and spongy body with a close-knit texture and a sweetish–acidic–nutty flavour.

Pressing of the milk solid coagulum (curd) is an important unit operation of *Paneer* manufacture. Conventionally, the curd is transferred to metal or wooden hoops lined with muslin cloth and subjected to pressing (either manually by placing suitable weights or by simple hydraulic means using screw presses) to obtain a compact block of *Paneer*. It has been reported that process conditions during the pressing of *Paneer* i.e. the pressure, temperature and time, affect the yield, quality, acceptance and shelf life of *Paneer* (Khan and Pal 2011). Hence, a proper

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quantification of the process parameters and their precise control become important steps in ensuring uniform quality of *Paneer*.

Over the years different researchers (Bhattacharya et al. 1971; Sachdeva et al. 1991; De et al. 1971; Vishweshwaraiah and Anantakrishnan 1986; Kulshreshtha et al. 1987; Kumari and Singh 1992; Aneja et al. 2002) studied the effect of the pressing condition on the quality attributes of *Paneer*. Chitranayak et al. (2017) designed a microprocessor based automated *Paneer* press to facilitate automatic control of pressure and pressing time of *Paneer*. It was reported that during pressing of cheese, a single block of curd was formed when curd was pressed while hot, it was further recommended that care should be taken that pressing be done above 60 °C (Guinee 2003). It has also been suggested that to obtain acceptable product, the temperature of curd/coagulum, in the duration between the unit operations of coagulation and pressing, should be maintained above 63 °C (Khan and Pal 2011).

However, detailed information on matting temperature of *Paneer* and its influence on product characteristics is scarce. Conventional pressing hoops are not equipped with any provision to maintain the temperature of the curd at the desired level during pressing. Hence, the present study was conceived to develop a suitable heat exchanger assisted pressing hoop to control the matting temperature of *Paneer* at desired levels and to evaluate the physico-chemical, sensory and textural quality of *Paneer*.

Materials and methods

Standardized cow milk (Fat 3.5% and SNF 8.5%) was collected from the Experimental Dairy, SRS of ICAR-NDRI, Bengaluru. *Paneer* was prepared in the laboratory using the method described by Aneja et al. (2002). Initially, preliminary trials were undertaken to determine the range of matting temperature that could be applied during the pressing of *Paneer*. The pressing of coagulum for the preliminary studies was carried out by immersing the slotted hoop filled with coagulum into a hot water bath maintained at the selected temperature. The pressing of the milk coagulum was carried out in a microprocessor controlled automated pneumatic *Paneer* press designed and fabricated in our laboratory by Chitranayak et al. (2017). The pressure during the preliminary studies for the pressing of the coagulum was maintained at 2 kg/cm² and a constant pressing time of 10 min was considered (Aneja et al. 2002). Post-pressing of the coagulum, the *Paneer* block was removed from water bath and immersed in potable water chilled to 4 °C for 90 ± 10 min. Based on sensory and physico-chemical quality of the *Paneer*

obtained during the preliminary analysis, three temperatures were chosen for evaluation, i.e. 63, 66 and 69 °C.

Fabrication of heat exchanger

A flooded jacket type heat exchanger was selected for maintaining the matting temperature during the pressing of *Paneer* and the dimensions of the unit and rating of the electric heating element was computed based on heat load calculations (for pressing 3 kg of coagulum) using water in the jacketed space to be heated to a maximum of 69 °C within 30 min. The inner and outer vessels of dimensions 18 × 18 × 9 and 28 × 28 × 15 cm ($\ell \times b \times h$), respectively, was fabricated using SS 304; this material was chosen as it is a sanitary material and has good machinability (Kaladhar et al. 2012). A pressing plate (3 mm thickness) made of SS 304 was also fabricated with 3 in-built holes to facilitate insertion of thermocouples to measure the temperature of the coagulum during pressing, a handle was provided on the top surface of the plate for ease of handling of the plate. The heat exchanger was fabricated by using Tungsten Inert Gas (TIG) welding process with bended corner having 6 mm radius of curvature. The quality of the weld joints in the unit was tested using dye penetration test. The assembled heat exchanger was subjected to hydraulic test (4 bar) to ascertain that the fabricated unit was leak proof. The heat exchanger was finished to Roughness Average (RA) value of 0.8, so that the assembled heat exchanger was in conformity with FDA standards.

For the drainage of whey that would be expelled during the pressing of *Paneer*, 5 holes (1.4 mm dia.) were drilled to the bottom plate of the inner vessel and MS tubes (3 mm thickness) were inserted through the jacket (Fig. 1) to facilitate the drainage of whey. These bottom tubes were extended by 1 cm beyond the outer vessel to act as support legs for the heat exchanger unit. Two additional tubes (0.5 mm dia.) were also inserted through the side walls of the inner and outer vessel to aid in better drainage of the whey. Tubular inlet (0.05 m length and dia.) and outlet (ball valve) for filling and draining of water into/out of the jacket space, respectively, were provided in the unit. The heat exchanger was supported with a PID—based thermostatic control to maintain the set temperature of the water in the jacket at ± 0.1 °C. The PID based temperature controller was programmed to monitor the temperature of hoop jacket without overshoot and undershoot through electromagnetic contactor housed inside the control panel through DIN rail. Also the short circuiting of system was prevented using Miniature Circuit Breaker (MCB) installed inside the panel. The fabricated and assembled pressing hoop was placed in the microprocessor based pneumatically controlled press, that could press the *Paneer*

Fig. 1 Heat Exchanger for controlling matting temperature of *Paneer*. **a** Schematic sketch, **b** assembled unit

coagulum for the set duration of time at a predetermined pressure.

Physico-chemical parameters of *Paneer*

The moisture content of the *Paneer* samples was determined according to the procedure specified for *Paneer* under IS: 10484 (BIS 1983). The fat content of the *Paneer* samples was determined using the Mojonnier-gravimetric method described in AOAC (2005). The protein content of the *Paneer* samples was estimated using standard micro-Kjeldahl method as described in AOAC (2005). Porosity in percentage was evaluated following the methodology proposed in Chitranayak et al. (2017). *Paneer* cubes were cut to the size of dimensions $1.5 \times 1.5 \times 1.5$ cm, their initial mass recorded and then soaked in distilled water (1:20 ratio by volume) for 12 h in a refrigerator. The soaked samples were then taken out of the distilled water bath and their surface was gently wiped to remove surface moisture. The mass of the soaked samples was recorded and the % porosity was expressed as the volume of water absorbed (computed as the ratio of the difference of mass of the sample during soaking and the density of water) and volume of the sample. The textural profile of the sample expressed in terms of textural parameters, such as hardness, cohesiveness, springiness, and chewiness, was evaluated using a Texture Analyser (Stable Micro Systems, U.K.). Sensory evaluation for the *Paneer* samples was carried out using 9-point hedonic scale. The *Paneer* cubes for SEM analysis were subjected to primary and secondary chemical fixation based on the methodology suggested by Hallab et al. (2007), freeze fractured to approximately 1 mm pieces and dried to critical point using CO_2 as a carrier. The sample was then mounted and sputter-coated with gold before acquisition of the SEM images using the microscope (Zeiss EVO LS15, Zeiss GmbH., Germany) operated at 15 kV.

Statistical analysis and optimization

Based on preliminary investigations, three process factors (independent variables) were identified for the study, namely, the pressure, duration or time and matting temperature during the pressing of *Paneer* using the automatic press. The range of the process parameters selected for the study were as follows: Pressure (2, 3 and 4 kg/cm^2) Temperature (63, 66 and 69°C) and pressing time (8, 10 and 12 min). Face-centered central composite design (CCF) with three replicates at the centre point was used to develop predictive models for studying effects of the independent variables on the physico-chemical, textural and sensory qualities of *Paneer*. This design was selected as it is a cubic design, with axial points that are situated at a distance α (value of ± 1) from the centre of the design (Cam and Aaby 2010). Replications of experiments in the centre of design are applied to estimate the pure error that could occur due to systematic errors during experimentation (Qiu et al. 2010). The combination of process variables, for the 20 runs of experiments as per the selected design, in terms of actual values of the independent variables are tabulated in Table 1.

The experimental design as per Table 1 was conducted and the responses for each run were recorded in terms of the moisture, fat and protein content, sensory score (for the quality attributes of colour and appearance, flavour, body and texture and overall acceptability), textural profile (in terms of the hardness, springiness, cohesiveness and chewiness of the *Paneer* samples), colour profile in terms of L^* , a^* and b^* and bulk density and porosity of the *Paneer* samples. The main and interaction effects of independent variables on the different responses were assessed using Response Surface Methodology (RSM) of Design-Expert v.10.0 software (Stat Ease Inc., Minneapolis). Based, on statistical analysis, the number of responses for optimisation were reduced to four (by eliminating the responses that were not significantly influenced

Table 1 Face-centered central composite design with experimental values of response variables

Run	Independent variables			Dependent variables			
	X ₁ : pressure (kg/cm ²)	X ₂ : time (min)	X ₃ : temp (°C)	Moisture (%)	Overall acceptability	Hardness (N)	Springiness
1	2	8	63	52.14	8.20	23.25	0.85
2	4	8	63	50.17	7.80	29.08	0.815
3	2	12	63	51.73	8.00	26.8	0.83
4	4	12	63	49.09	7.60	33.32	0.81
5	2	8	69	50.69	8.00	32.47	0.86
6	4	8	69	47.99	7.85	35.87	0.85
7	2	12	69	50.35	8.35	33.53	0.86
8	4	12	69	46.62	7.80	34.84	0.8
9	2	10	66	51.64	8.15	26.37	0.84
10	4	10	66	47.41	7.80	32.11	0.81
11	3	8	66	51.08	8.20	28.3	0.84
12	3	12	66	49.24	8.00	30.79	0.84
13	3	10	63	51.28	8.00	29.34	0.82
14	3	10	69	49.24	8.20	32.35	0.86
15	3	10	66	50.21	8.10	30.81	0.83
16	3	10	66	50.13	8.20	31.25	0.84
17	3	10	66	50.18	8.20	30.95	0.82
18	3	10	66	50.20	8.20	30.23	0.84
19	3	10	66	50.15	8.30	30.81	0.83
20	3	10	66	50.20	8.10	30.81	0.83

by the process parameters in the experimental design). The responses selected for the optimisation proves were moisture content, overall acceptability, hardness and springiness. The experimental data obtained for each of these selected responses were fitted with second order polynomial equation as presented in Eq. 3.19.

$$Y_K = \beta_{ko} + \sum_{i=1}^n \beta_{ki}x_i + \sum_{i=1}^n \beta_{kii}x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n \beta_{kij}x_ix_j \quad (1)$$

where Y_k = response variable [Y_1 = moisture content (% w.b.), Y_2 = overall acceptability, Y_3 = Hardness (N) and Y_4 = Springiness], x_i = independent variable [x_1 = pressing pressure (kg/cm²), x_2 = pressing time (min) and x_3 = matting temperature (°C)], β_{ko} = value of the fitted response at the centre point of the design (intercept), β_{ki} , β_{kii} and β_{kij} = coefficients of the linear, quadratic and cross-product regression, respectively.

Depending on the statistical significance of the higher order term and interactive effect process variables, the respective terms were retained or eliminated from the quadratic model represented in Eq. 1. The effects of the process variables on the selected responses were elucidated in the form of 3-D surface plots generated for any two independent variables, while holding the value of the third variable as constant (at the central value). The goodness of fit of the model was evaluated by considering both the

statistical significance of lack of fit (non-significant) of the model as well as the adjusted and predicted coefficient of determination (R^2) of the fit (required to be as close to unity as possible). The optimal combination of process parameters (pressure, time and matting temperature) was determined using the numerical optimization option of the software, by setting suitable constraints to the model.

Validation of the optimised process parameters

The *Paneer* sample pressed under the optimal combination of process parameters (pressure, time and matting temperature) was evaluated for its moisture content, hardness, springiness and overall acceptability for the validation of the prediction model. The quality of the sample prepared using the optimal process parameters was also compared for the above indices against a control *Paneer* sample prepared without the control of the matting temperature.

Results and discussion

The heat exchanger equipped pressing hoop was fabricated and assembled as indicated in Fig. 1 and pressing of *Paneer* coagulum was carried out under controlled matting temperature and pressure for the pressing time as per the

experimental design presented in Table 1. The pressed *Paneer* samples were immediately immersed in chilled water (4 °C) for about 2 h and then cut in to cubes ($2 \times 2 \times 2$ cm), the fresh *Paneer* samples were subjected to the physico-chemical analysis.

Effect of the process parameters on moisture content of the *Paneer*

The moisture content of the *Paneer* recorded in the study is presented in Table 1 and the effect of process parameters on this variable is depicted in Fig. 2a. It was observed that the moisture content of the sample for all combinations of the process parameters (pressure, temperature and time) evaluated was in compliance with the requirement of FSSAI (2017), (i.e. the moisture content of *Paneer* should not be more than 60% on dry matter basis) and corresponded to the average values reported for market *Paneer* (Desale et al. 2009).

It can be seen from Fig. 2a that the interactive effect of the process parameters at the lower range evaluated resulted in higher moisture content in the product. This result was anticipated since lower pressure and duration of pressing is expected to result in more retention of moisture due to lesser expulsion of whey from the *Paneer* matrix. It was further observed that pressing at lower matting temperatures increased moisture retention in the pressed product. Further, it was observed that the interactive effect of time and temperature on the moisture content of the product was linear while, the interactive effect of Pressure—time and Pressure—temperature on the moisture content of *Paneer* was quadratic.

Effect of the process parameters on overall acceptability of the *Paneer*

The overall acceptability scores obtained for the combination of process parameters evaluated in the study ranged from 7.60 to 8.35 (Table 1). The surface plots depicting the influence of the process parameters on the overall acceptability of the *Paneer* is presented in Fig. 2b. All the three factors during pressing, i.e. pressure, temperature and time, influenced the overall acceptability of the product. It was observed that the overall acceptability scores for the *Paneer* decreased with increasing pressure and time, while elevated matting temperature had a positive effect on the sensory score.

Effect of the process parameters on textural quality of the *Paneer*

The textural characteristics of the *Paneer* were analysed in terms of its hardness and springiness and the 3-D surface

plots of the effect of the process parameters on these parameters are depicted in Fig. 2. The quantity and rate of whey expulsion during pressing, is influenced by the temperature, applied pressure and time; this in turn affected the textural quality of *Paneer*.

From Fig. 2c, it can be clearly seen that the hardness value of the pressed *Paneer* increased at the higher levels of all the three process parameters considered for evaluation. The maximum hardness for *Paneer* recorded in this study was 35.87 N while, the minimum value was 22.45 N. The pressing time had a linear influence on hardness of the samples, while the interaction of pressure and temperature was quadratic.

The springiness values recorded ranged from 0.80 to 0.86 and were observed to vary linearly with the process variables. Springiness of the samples were found to vary inversely with pressure and directly with increasing matting temperature; the pressing time had the least influence on this parameter (Fig. 2d).

Regression analysis and model fitting

The selected responses, i.e. moisture content, overall acceptability, hardness and springiness in terms of the process parameters during pressing was modelled using reduced quadratic models. The regression coefficients, p values and model fit statistics of the fitted quadratic models (Eq. 1) for the four responses are presented in Table 2. It can be seen that the R^2 value for the responses, moisture content, overall acceptability and Hardness were > 0.80 indicating a good fit to the model (Adepoju 2014).

Optimisation of process parameters for pressing of *Paneer*

The in-built numerical optimisation option of Design-Expert v10.0 software was applied to obtain the optimal combination of process parameters, namely pressure, time and matting temperature during the pressing of *Paneer*. Constraints were set to maximise the moisture content and overall acceptability score of the pressed *Paneer*; while the target value for Hardness and Springiness was set as 30 N and 0.85, respectively. These values were chosen as they corresponded to the values that recorded maximum acceptance scores during sensory evaluation. The software suggested 31 solutions for the optimal combination of process parameters, the combination of 2.5 kg/cm² pressure at 67.0 °C for 9 min with a desirability of 0.925 was selected as the most optimal combination of parameters for pressing of *Paneer* under controlled matting temperature.

Fig. 2 3-D plots for effect of process parameters during pressing on quality of the *Paneer*. **a** Moisture, **b** overall acceptability, **c** hardness, **d** springiness

Validation of the optimised process conditions

The moisture content, overall acceptability, hardness and springiness of the sample prepared using the optimised process parameters for pressing of the *Paneer* coagulum along with the values predicted by the developed models are presented in Table 3.

Statistical analysis of the values indicate that the predicted and actual values of the responses did not differ significantly ($p > 0.05$), further confirming the adequacy of the developed quadratic models. The values were also

comparatively evaluated with those obtained for the control sample (pressed at 2 kg/cm² pressure for 10 min), without the control of matting temperature (Aneja et al. 2002) and the data is presented in Table 3. It can be seen that even though the pressing time with the control of matting temperature was 10% less than that of the control samples (9 min for experimental samples vs. 10 min for control samples), the overall acceptability and hardness of the experimental samples were significantly superior to that of the control sample. This could be attributed to the better

Table 2 Regression coefficients, *p* values and model fit statistics of the fitted quadratic models for the four responses

Factor	Moisture content		Overall acceptability		Hardness		Springiness	
	Coeff.	<i>p</i> value	Coeff.	<i>p</i> value	Coeff.	<i>p</i> value	Coeff.	<i>p</i> value
Intercept	50.30*		8.15*		30.71*		0.83*	
X ₁	− 1.53*	< 0.0001	− 0.19*	< 0.0001	2.57*	< 0.0001*	− 0.016*	0.003*
X ₂	− 0.50*	0.0031	− 0.030*	0.2890 ^{NS}	1.30*	0.0010*	− 7.5E−003*	0.0388*
X ₃	− 0.95*	< 0.0001	0.06*	0.0448	2.90*	< 0.0001*	0.010*	0.0062 ^{NS}
X ₁ X ₂	NS		NS		− 0.92*	NS	NS	
X ₁ X ₃	NS		0.080*	0.0122	NS		NS	
X ₁ X ₃	NS		NS		NS	0.0198*	NS	
X ₁ ²	− 0.51*	0.0230	− 0.19*	0.0002	NS		NS	
X ₂ ²	NS		NS		NS		NS	
X ₃ ²	NS		NS		NS		NS	
Adj R ²	0.90*		0.81*		0.91*		0.64*	
Model F-value	44.14*		17.24*		36.03*		12.21*	
Lack of fit	NS		NS		NS		NS	

X₁ pressure (kg/cm²), X₂ pressing time (min), X₃ matting temp (°C)

*Terms were significant at *p* < 0.05. NS: terms were not significant at *p* < 0.05

Table 3 Comparative evaluation of quality of *Paneer* prepared using optimised process parameters with the control sample

Parameter	Predicted value	<i>Paneer</i> prepared using optimised combination of parameters ^a	Control sample
Moisture content % w.b.	50.90	51.64	52.75
Fat content (%)	–	23.69	22.50
Protein content (%)	–	20.08	19.50
Overall acceptability (out of 9)	8.21	8.15	7.13
Hardness (N)	30.0	29.84	25.00
Springiness	0.85	0.84	0.82
Bulk density (g/cc)	–	1.13	0.96
Porosity (%)	–	14.00	16.00

^aPressing of the coagulum at a pressure of 2.5 kg/cm² for 9 min at a matting temperature of 67 °C

fusing of the curd due to the controlled matting temperature which also resulted in marginally improved bulk density and lower porosity of the experimental sample (Table 3).

Micro-structure of the *Paneer* samples

The microstructural features of *Paneer* samples prepared using optimal combination of process parameters and control sample prepared without controlling matting temperature are illustrated in Fig. 3. Two distinct regions i.e. protein aggregates and voids could be delineated from the micrographs. This in agreement with the observations reported by Hallab et al. (2007) and Hussein and Shalaby

(2014) for cheese. Further, it was observed that the experimental sample prepared with the control of matting temperature depicted more densely packed aggregate structure when compared to the control sample. The difference in microstructure of the two samples assumes significance since it has been reported that a compact protein matrix is directly correlated to the elastic behaviour or springiness of the product (Madadlou et al. 2006).

Conclusion

The study demonstrated the effect of pressing of *Paneer* under controlled matting temperature on its physico-chemical, textural and sensory quality. The matting temperature of *Paneer* during pressing was controlled using a thermostatically controlled electrically heated jacketed heat exchanger around the *Paneer* hoop. Interactive effect of matting temperature, pressure and pressing time positively influenced the quality attributes of the pressed *paneer*. Optimal process conditions for pressing of *Paneer* under controlled matting temperature in an automatic press were identified using Response Surface Methodology as pressing at 2.5 kg/cm² pressure for 9 min at a matting temperature of 67 °C. The values of the responses in terms of its moisture content, overall acceptability, hardness and springiness determined at this optimal combination of process parameters agreed well with the predicted values, confirming the adequacy of the developed quadratic models. *Paneer* pressed with control of matting temperature under the optimal process parameters reported marginally lower moisture

Fig. 3 Scanning Electron Micrographs of *Paneer* sample. **a** Control sample and **b** optimised sample

content, but recorded higher hardness, springiness and overall acceptance when compared to samples pressed without controlling the matting temperature.

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