Development of a process for the manufacture of shelf stable *dhal* and its physico-chemical properties

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Abstract Thermally processed, ready-to consume *dhal* with natural sensory attributes was developed. Product optimization was done using two variables, retort process time and ratio of water to *dhal*. *Dhal* were packed in retortable pouches and processed in a stationary air–steam retort. The product was characterized by a short lag period for the heating curve, j_h (0.52–0.64), small heating rate index, f_h (3.9–6.5 min) and a short lag factor for the cooling curve, j_c (0.53–0.73) implying essentially convective heating regime. The total process time (B') was 11.56–40.25 min for F_o value of 2.30–27.30 min. Process time of 25 min at 121 °C and ratio of water to *dhal* of 2.5 yielded a product that was microbiologically safe as well as sensorily acceptable. During storage, chemical parameters like thiobarbituric acid and free fatty acid increased, while pH decreased with concomitant decrease in sensory scores. Textural properties like, consistency, cohesiveness and index of viscosity underwent a significant ($P<0.05$) increase during the storage.

Keywords Thermal processing · Thiobarbituric acid value · Consistency · Index of viscosity

Introduction

India is the largest producer (81.49 %) and consumer of pigeon pea in the world (Ghadge et al. 2008) and almost all pigeon pea is milled to produce *dhal* (Faris and Singh 1990).

Out of 14.5 million tons of pulses, nearly 11 million tons are converted to *dhal* in India (Jain and Doharey 2009). *Dhal* is popular because dehulling pigeon pea greatly reduces its cooking time and improves the appearance, texture, palatability, digestibility and bioavailability of nutrients of the grain. The cooking process not only improves the palatability of pigeon pea but it destroys or minimizes some antinutritional factors (Singh 1993). With the increased urbanization and number of working-women, there is a need to develop products that need less preparation time in households. Greater emphasis is being given for marketing the new products of legumes such as quick cooking *dhal* or instant *dhal* of grain legumes which have good market potential.

The introduction of retort technology has made the sale of ready-to-eat food products commercially viable with great taste. Globalization of Indian food and its culture are the core factors for popularization of ready-to-eat food products. These foods meet the specific needs of convenience, nutritional adequacy, shelf stability, storage and distribution to the centres. The commercial retort processing ensures a reduction or inactivation of spore-forming microorganisms sufficient to guarantee commercial sterility (Awuah and Ramaswamy 2007). However, there are losses of food product quality during thermal processing and storage. Several studies have focused on the effect of retorting on food product quality properties such as colour, oxidation, nutrition loss, production of off-flavor, and textural changes (Durand and Collins 1991; Ramaswamy and Grabowski 1999).

Retortable pouches have been used for extending the shelf life of food products such as, mushroom curry (Chandrasekar et al. 2001), seer fish moilee (Manju et al. 2004), ready-to-eat rice (Byun et al. 2010), vegetable pulav (Kumar et al. 2011), prawn *kurma* (Mohan et al. 2006). Some of the traditional Indian foods that have been retort processed include *kheer* (Jha et al. 2011), *chapaties* (Khan et al. 2011), shelf stable

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dairy dessert *dalia* (Jha et al. 2012) and shelf stable dietetic *rabri* (Gautam et al. 2013).

In view of the immense possibilities that the retort processing using retortable pouches offers for newer and long-shelf life food products, present work was undertaken with the following objectives: to develop a commercial process for manufacture of *dhal* and to enhance the shelf life of the product.

Materials and methods

Food and packaging materials Pigeon pea (*Cajanus cajan* L.) was procured from the Agricultural Farm, Banaras Hindu University, Varanasi, India and green and dry spices were procured from local market of Varanasi, India. Commercially available refined soybean oil was used for sautéing of *dhal*. Indigenously manufactured retort pouches (Pradeep Laminators, Pune, India) of 20×15 cm size having 4 layer configuration (aluminium foil 9.0 µm, cast poly propylene 70.0 µm, polyester layer 12.0 µm and biaxially oriented nylon 15.0 µm) and thickness of 106.0 µm were used in this study.

Product formulation Detailed flow chart with mass balance and process details for production of shelf stable *dhal* is presented in Fig. 1. Pigeon pea was soaked in water (pulse:water-1:3) for 1 h. Soaked pulses were drained and then sautéed in refined oil (10 g oil/100 g *dhal*) with measured quantity of green and dry spices. For product optimisation, varying quantity of sautéed pulses and water were filled into retort pouches, the range of ratio of water to 1 part of pulse being 1.5 to 3.5, followed by cooking-cum-sterilization in a retort.

Thermal processing of dhal Retort pouches containing 200 g of *dhal* and water were sealed immediately using a semiautomatic paddle operated sealing machine (Sun Ray Industries Pvt. Ltd., Mysore, India). Filled pouches were loaded in the pilot-scale horizontal still retorting system (Lakshmi Engineering, Chennai, India). For every production trial, two pouches transferred to the retort were fitted with Cu/CuNi thermocouples (Lakshmi Engineering, Chennai, India) for measurement of the product temperature every minute during the process. Thermocouple was linked to a precision data logging device (Factory Talk® View Site Edition Client software, Rockwell Automation, USA) which was capable of converting the temperature input data into corresponding process lethality values. These process lethality values were expressed as F_o values. The retort temperature was set at 121.1 °C, with a steam pressure of 105 kPa. An overpressure of 210 kPa was maintained during each process cycle. Retort pouches containing varying quantity of *dhal* and water were processed for different process time according to the combination generated through RSM experimental design (Design

Fig. 1 Flow diagram of production of shelf stable *Dhal* along with mass balance

Expert, version 8.0.3.1). After processing, they were cooled rapidly till the core temperature reached 75 °C by pumping water into the retort and circulating it. The pouches were wiped dry and stored at ambient temperature (25–27 °C) for further studies.

Generation of heat penetration data The data generated were analysed and heat penetration curve was plotted on a semi-log graph paper with temperature deficit against time. F_o value was obtained from the software used along with the data logger. The lag factor of heating (J_h), lag factor of cooling (J_c) and slope of heating curve (f_h) were calculated by the Ball's formula method (Ball 1923).

$$j_h = \frac{RT - ThIT}{RT - IT} \quad (1)$$

$$j_c = \frac{CWT - ThITc}{CWT - ITc} \quad (2)$$

Where, RT = retort temperature (121 °C), ThIT = theoretical initial temperature during heating (obtained from the heating curve), IT = initial temperature during start of heating, CWT = coolant water temperature (27 °C), IT_c = initial temperature during start of cooling, ThIT_c = theoretical initial temperature during cooling (obtained from the cooling curve).

The total process time (B') was calculated by adding 58 % of the come up time to the process time (B).

Analysis of dhal Moisture, protein, fat and total ash content of the shelf stable dhal were determined on dry basis by adopting the methods of AOAC (1990). The pH of the dhal sample was measured using a digital pH meter (Orion 2 Star, Thermo Scientific, Singapore). The extent of lipolysis was measured by the level of free fatty acids (FFA) (Cox and Pearson 1962). The extent of oxidation of fat in dhal was measured in terms of thiobarbituric acid (TBA) value by the method used by Jha et al. (2013). Spore formers were determined after killing the vegetative cells by keeping the sample in boiling water bath for 10–20 min and subsequently incubated at 37 and 55 °C for 48 h after inoculation.

Sensory evaluation Descriptive rating was used for sensory evaluation of shelf stable dhal by a panel of 50 judges from the Banaras Hindu University, Varanasi, India. Dhal samples were served hot (45–50 °C) after reheating in a 600 W microwave oven (Sanyo Electric Company, Ltd., Japan). Evaluation was done on a 15 cm descriptive scale for the following parameters: colour (1-pale, 7.5-optimum, 15-too dark), visual consistency (1-too thin, 7.5-optimum, 15-too thick), grain integrity (1-all grains deformed, 7.5-many deformed, 15-all grains intact), relative amount of grains (1-too low, 7.5-optimum, 15-too high), hardness of grains (1-too soft, 7.5-optimum, 15-too tough), saltiness (1-too low, 7.5-optimum, 15-extreme), overcooked or stale flavour (1-nil, 7.5-moderate, 15-extreme).

Experimental design and statistical analysis A two-factor response surface methodology (RSM) experimental design (Design Expert, version 8.0.3.1) was followed. The overall acceptability of any product is judged by its sensory quality and safety, so the two variables used were retort processing time and ratio of water to dhal. Retort processing time range was chosen from 15 to 25 min to ensure adequate cooking-cum-sterilisation of the product. Adequate quantity of water is required during cooking of dhal as it affects its sensory and textural properties; the ratio of water to dhal used in this study was 1.5 to 3.5. The two variables were integrated into the matrix design as illustrated in Table 1. For the storage analysis of the optimized product, all the experiments were done in triplicate. Data was subjected to one way analysis of variance (ANOVA) taking into account the storage time. Mean

Table 1 Thermal process parameters of shelf stable dhal

Trial no.	Process time (min)	Ratio of water to 1 part dhal	F_o	f_h	j_h	j_c	B'
1	35.0	3.5	23.00	4.2	0.52	0.69	36.30
2	25.0	2.5	13.39	4.0	0.61	0.53	25.90
3	25.0	3.9	18.41	3.9	0.56	0.69	25.05
4	25.0	2.5	12.00	4.8	0.58	0.55	26.13
5	15.0	1.5	4.36	5.5	0.62	0.59	15.77
6	25.0	2.5	12.70	4.3	0.64	0.59	25.97
7	10.8	2.5	2.30	4.7	0.54	0.58	11.56
8	25.0	2.5	12.02	4.5	0.60	0.55	25.95
9	39.1	2.5	27.30	4.6	0.63	0.65	40.25
10	25.0	1.0	13.20	6.5	0.63	0.64	26.49
11	35.0	1.5	19.29	6.0	0.59	0.58	36.01
12	15.0	3.5	8.10	4.1	0.62	0.73	16.41
13	25.0	2.5	12.10	4.7	0.59	0.65	26.24

F_o : Process lethality value; f_h : Heating rate index; j_h : Lag factor of heating; j_c : Lag factor of cooling; B' : Total process time

separations were performed using Duncan's test. Differences at ($P < 0.05$) were considered significant.

Storage analysis of shelf stable dhal Hundred lots of shelf stable dhal pouches were stored at 37 °C and monitored for changes in pH, TBA, FFA, microbial count, sensory and textural properties for a period of 90 days.

The shelf stable dhal was analysed for their microbiological stability. The pouches were incubated at 37 and 55 °C for 7 days. Total plate count and coliform count were determined using plate count agar and violet red bile agar, respectively, after incubation for 48 h at 37 °C. Pathogens viz., *E. coli*, *Salmonella* and *Staphylococci* were also determined by inoculating the sample on Mac Conkey agar, Bismuth sulphite agar and Mannitol salt agar, respectively followed by incubation for 48 h at 37 °C. Yeast and molds were estimated with the help of potato dextrose agar, after incubation at 25 °C for 72 h. The various medium used for microbial study were procured from Hi media, Mumbai, India. Spore formers were determined after killing the vegetative cells by keeping the sample in boiling water bath for 10–20 min and subsequently incubated at 37 and 55 °C for 48 h after inoculation.

Dhal was analyzed for different textural characteristics like consistency, cohesiveness and index of viscosity using a texture profile analyzer (Stable Micro System Model TA-XT Plus, Surrey, UK), using a backward extrusion rig (A/BE 35 mm disc). Tests were performed on uniform size samples and were compressed to a depth of 30 mm. The test parameters were set as: pre-test and test speed 1 mm/s, post-test speed 10 mm/s and force 0.1 N. Textural parameters were analyzed at 25 °C.

Results and discussion

Heat penetration characteristics of shelf stable *dhal*

Lag period for heating curve (j_h) Thermal process parameters of shelf stable *dhal* are presented in Table 1. The j_h value given as pseudo-initial temperature deficit (PID) divided by the actual initial temperature deficit (ID) ranged from 0.52 to 0.64. For purely convective packs, there is little or no lag period (i.e., the come-up time is very short); hence, PID and ID coincide, so that j_h is equal to 1.0. However, in actual practice, there is always some gap in time period before a product could reach the retort temperature, leading to differences in come up time depending on the composition, size etc. and hence to variations in j_h values. Pigeon pea *dhal* could be considered as a particulate food which after thermal processing was converted into a semi-liquid product and the mode of heating could be said to be convective. The j_h value for convective heated shelf stable dairy dessert *dalia*, was found in the range of 0.40 to 0.85 (Jha et al. 2012).

Heating rate index (f_h) The time taken for a heat penetration curve to traverse one log cycle is called the f_h value. In the present study, f_h values were found to be in the range of 3.9 to 6.5 min (Table 1). These values are reported for convective heat transfer in food products, in contrast, the f_h value in conductive heat transfer are higher i.e. 30–40 min (Horner 1992). In this study, f_h values were found to decrease with increase in water ratio, this could be due to higher rate of heat penetration in the product. The f_h value for shrimp *kurma* was found to be 19.00 min (Mohan et al. 2006).

Lag factor for cooling curve (j_c) Lag factor in cooling curve is because of the fact that the product temperature does not fall as rapidly as the retort temperature falls. The j_c values for convective heating products are reported to be close to 1.0, whereas for conducting heating packs the values could be much higher as the cooling process is much slower for these products. As shown in Table 1, j_c values for the shelf stable *dhal* ranged from 0.53 to 0.73, which were in conformity with the values reported for convective heating liquid products (Horner 1992). j_c values increases with increase in processing temperature but in this study, retort temperature was set constant at 121 °C so not much variation in these values was observed. j_c values for ready-to-eat shrimp curry was 0.95 (Mohan et al. 2006), for rice based dairy dessert (*kheer*) was in the range of 1.09–2.31 (Jha et al. 2011) and for shelf stable dairy dessert *dalia* was 0.91–1.10 (Jha et al. 2012).

Total process time (B') In a convective heating regime, come up time, is very short so B' is very close to B . The B' value for *dhal* ranged from 11.56 to 40.25 min (Table 1) depending on F_o value (2.30–27.30 min). Process time for

products heated in conduction-heating regime are generally very long as compared to the ones observed in this study. B' for ready-to-eat squid *masala* in tin-free steel cans ranged from 41 to 48 min corresponding to a F_o range of 6.0 to 8.0 min indicating a conduction heating regime (Gopinath et al. 2007) as compared to *dalia* dessert which exhibited a convection heating regime, B ranged from 10.20 to 15.78 min (Jha et al. 2012).

Proximate composition of optimized *dhal* The protein, fat, carbohydrate, moisture and ash contents of the optimised product were found to be 11.4, 8.3, 26.7, 50.63 and 2.97 %, respectively.

Sensory attributes of shelf stable *dhal* as influenced by process time and ratio of water to *dhal* Using a CCRD, levels of variables viz., retort process time and ratio of water to *dhal* were selected through 13 experiments. The sensory scores as influenced by different combination of time and ratio of water to *dhal* are presented in Table 2. Good quality pigeon pea *dhal* should have bright yellow colour, optimum consistency and saltiness and grains should be sufficiently cooked. The average sensory scores for different attributes of shelf stable *dhal* are given in Table 2 and the results of regression analysis are presented in Table 3. The output result showed that model had an efficiency of 95.4 % which is more than the minimum required level of 50 %.

It is evident from the Table 3 that the colour score was inversely related to the ratio of water used in *dhal*, the relationship being significant ($P<0.01$). Further, the effect of process time was positive and significant at 5 % level. As indicated by model summary statistics (Table 3) the model could be considered reliable. It can also be seen from Table 3, the linear function was highly significant ($P<0.01$). The ratio of water to *dhal* had a significant ($P<0.01$) negative effect (Fig. 2a), while the process time had a significant ($P<0.05$) positive effect on the visual consistency score (Table 3). The coefficient of determination was high enough for the model to be reliable. The coefficient of estimates of *dhal* (Table 3) showed that the process time had negative and significant ($P<0.01$) effect on the grain hardness score and grain integrity, while ratio of water to *dhal* has a positive effect on grain hardness and negative effect on grain integrity, however the effect was non-significant.

Ratio of water to *dhal* was found to have a negative and more significant ($P<0.01$) effect than the process time on the descriptive score for relative amount of grains. It is also evident from the Table 3 that the score for saltiness was inversely related to the ratio of water used in *dhal*, the relationship being significant ($P<0.01$). Descriptive score for overcooked/stale flavour for retort processed *dhal* was positively affected by the process time and the effect was significant ($P<0.01$). It thus appeared that increase in process time

Table 2 Effect of retort process time and ratio of water to *dhal* on the sensory properties* of shelf stable *dhal*

Trial No.	Retort processing time (min)	Ratio of water to 1 part <i>dhal</i>	Colour	Visual consistency	Grain hardness	Grain integrity	Relative amount of grains	Saltiness	Overcooked Flavour	OA score
1	35.0	3.5	6.0	6.0	6.0	4.5	5.0	6.5	2.0	9
2	25.0	2.5	7.5	7.0	7.0	7.5	7.5	7.5	0.5	12
3	25.0	3.9	5.0	7.5	5.0	4.0	7.0	6.0	0	8
4	25.0	2.5	8.0	7.0	7.0	7.5	7.0	8.0	0	13
5	15.0	1.5	9.0	9.0	10.0	10.0	9.5	11.0	0	7
6	25.0	2.5	7.0	7.0	7.0	7.0	8.0	8.0	0	12
7	10.8	2.5	6.5	11.0	6.0	8.0	12.0	8.0	0.5	8
8	25.0	2.5	8.0	7.5	7.5	7.5	8.0	8.0	0.5	12
9	39.1	2.5	9.0	5.0	8.5	8.5	4.0	7.5	3.5	10
10	25.0	1.0	10	7.0	11.0	11.0	8.0	12.0	0	7
11	35.0	1.5	9.5	6.0	12.0	12.0	5.0	11.0	2.5	8
12	15.0	3.5	6.0	9.5	6.0	5.5	9.0	6.0	0	10
13	25.0	2.5	7.0	7.0	8.0	7.5	7.0	7.0	1.0	12

OA overall acceptability

*Means of ratings by 50 panellists using a descriptive sensory scale ($n=50$)

resulted in increase in score for overcooked/stale flavour (Fig. 2b).

The regression coefficient of estimates for OA score (Table 3) showed the linear terms of water to dhal ratio was significant ($P<0.01$) and positively related to OA score. However, process time had positive but not significant ($P>0.01$). The OA score was initially found to increase with increase in both process time and ratio of water to *dhal* and after reaching an optimum level it was found to decrease with increase in both the variables (Fig. 2c).

Optimization Optimization of retort process time and ratio of water to *dhal* for manufacture of *dhal* was based on

sensory score using RSM and microbiological safety, determined through spore count. Out of 5 suggested formulations, the formulation no.1 had better OA score of 12.2 than all other formulations and also the desirability was 0.95, highest amongst all other formulations. This formulation also showed zero spore count. The recommended F_o value for vegetarian food products ranges from 3.0 to 6.0 (Khan et al. 2011) and F_o for *dhal* processed at 121 °C for 25 min was found in the range of 12–13.39. *Dhal* processed for longer time though microbiologically stable, had a degraded texture and colour quality which in turn lowered its sensory acceptance. Hence, the formulation with processing time and ratio of water to *dhal* of 25 min and 2.5,

Table 3 Coefficient of full second order polynomial model for sensory responses to process time and ratio of water in *dhal*

Factor	Colour ^a	Grain hardness	Consistency ^a	Amount of grains	Grain integrity ^a	Saltiness	Overcooked/ stale flavour	OA Score
Intercept	7.58	7.10	7.77	7.40	7.46	7.76	0.40	12.20
A-Ratio of water	-1.70**	0.15	-2.31**	-2.74**	-0.24	-2.25**	-0.063	0.68*
B- Process time	0.50*	-1.87**	0.69*	0.21	-2.48**	—	1.09**	0.35
AB	—	-0.12	—	-0.75**	—	—	-0.13	-0.50
A ²	—	0.075	—	0.081	—	0.70**	-0.17	-2.29**
B ²	—	0.45**	—	0.46**	—	—	0.83**	-1.54**
R ²	0.9137	0.9771	0.8814	0.9878	0.9393	0.9700	0.9511	0.9504
Adequate precision	20.53	24.69	17.18	34.74	25.77	35.93	16.41	12.96
PRESS value	4.16	3.85	11.86	4.53	6.02	2.46	1.60	15.19
Model F value	52.96	59.62	37.15	112.94	77.40	161.80	27.24	26.84

OA overall acceptability

*Significant at 5 %, ** Significant at 1 % level

^a Linear model

Fig. 2 Effect of process time and ratio of water to dhal on sensory responses of dhal in retort pouches **a** visual consistency **b** overcooked/stale flavour and **c** overall acceptability score

respectively was considered to be the most appropriate for retorting the *dhal*.

Storage analysis of shelf stable *dhal*

Changes in physico-chemical attributes The variation in pH of canned/retorted food is associated with growth of microorganisms and consequent production of organic acids. Variation in pH, even as small as 0.15 to 0.2, may often be significant. The pH value of shelf stable *dhal* decreased from initial value of 5.89 to 5.81 (Fig. 3a) during 90 days of storage however, the decrement was insignificant ($P>0.05$). Jha et al. (2011) reported a significant decrease in pH of long life *kheer* from the initial values in the range of 6.05–6.09 to 5.83–5.86 at the end of 150 days of storage.

Fig. 3 Effect of storage on physico-chemical properties of shelf stable *dhal* **a** pH **b** free fatty acids and **c** thiobarbituric acid value. Each point represent mean of triplicate values. Vertical bar represent standard deviation (SD)

The relevance of FFA in monitoring degradation cannot be ignored as the formation of organic acids and free fatty acids is an initial step in fat deterioration, development of rancidity and off flavours in foods. The FFA content of *dhal* increased significantly ($P<0.05$) from initial value of 2.42 to 3.97 mg KOH/g after storage period of 90 days, thereby leading to 39 % increment in the FFA (Fig. 3b). This may be due to the breakage of long fatty acid chains into individual fatty acid moieties and also increased lipid hydrolysis at elevated temperatures. Khan et al. (2011) have reported a 4 times increment in FFA values of ready-to-eat black clam and ambient stable *chapattis*, respectively after 12 months of storage. TBA value is an index of secondary lipid oxidation. TBA was expressed as absorbance at 532 nm as shown in Fig. 3(c). TBA value increased significantly ($P<0.05$) with the increase in storage period from initial value of 0.054 to 0.061 at the end of storage. However, Downey (1968) stated TBA did not exceed taste detection thresholds i.e. 0.080 in the case of the TBA index. Jha et al. (2011) and Khan et al. (2011) have also reported significant increase in TBA values with increase in storage time for long life *kheer* and ambient stable *chapattis*, respectively. However, the result was contradictory to the findings of Manju et al. (2004) who reported a decrease in TBA for seer fish moilee packed in retort pouch and canned mackerel, respectively along with storage period.

Microbiological properties The microbiological data showed that no TPC, coliform and yeast and mold were found in the stored *dhal* samples upto 90 days of storage. The pathogens viz. *E. coli*, *S. aureus* and *Salmonella* were also absent in all the samples. When the product is subjected to retort processing by packaging in 3-layered retortable pouches with target heat treatment, the microbial growth is not expected to take place; hence product is microbiologically stable. This validates the role of retort processing in maintaining the microbiological quality of shelf stable *dhal*. Similar results have also been reported by Khan et al. (2011) for shelf stable *chapattis*. Kumar et al. (2011) have reported a TPC of 2×10^1 for RTE vegetable *pulav* processed to a F_o of 2.0 min.

Changes in textural properties Texture is an important attribute of any product which also decides its ultimate acceptance by the consumers. The changes in the textural attributes (consistency, cohesiveness and index of viscosity) of *dhal* during storage are presented in Fig. 4a–c. Consistency values of shelf stable *dhal* ranged in between 5.15 and 11.33 N s, during the storage period of 90 days at 37 °C (Fig. 4a). The consistency values at the end of storage were significantly higher ($P<0.05$) as compared to the initial values. This could be attributed to the water absorption by the starch granules. Cohesiveness and index of viscosity also underwent a significant ($P<0.05$) increase from 0.05 to 0.46 N and 0.010–0.074 N s, respectively. These textural changes might be due

Fig. 4 Effect of storage on textural properties of shelf stable dhal **a** consistency **b** cohesiveness and **c** index of viscosity. Each point represent mean of triplicate values. Vertical bar represent standard deviation (SD)

to retrogradation of the starch particles of the *dhal* upon storage.

Changes in sensory attributes of dhal during storage The results of the sensory evaluation of *dhal* during storage at 37 °C are given in Table 4. The descriptive colour score for shelf stable *dhal* samples showed significant ($P<0.05$) decrease, from initial value of 7.5 ± 0.7 to 7.0 ± 0.3 , indicating slight decrease in yellowness of the sample. This may be due to degradation of colour components upon storage. Pre-cooked and dried pulses have been reported to undergo rapid auto-oxidation during storage (Patki and Arya 1994) leading to disappearance of yellow colour and formation of off flavour. Scores for consistency of *dhal* showed an increasing trend during the storage period and ranged from 7.5 ± 0.1 at first day to 8.2 ± 0.1 on day 90. This increase in consistency might be due to the absorption of water by the starch granules. This result was consistent with the textural data that also exhibited an increasing trend in consistency value. Hardness score of *dhal* decreased up to 90 days from 7.5 ± 0.5 to 6.7 ± 0.4 , this was also supported by a significant ($P<0.05$) decrease in grain integrity score. The main textural defect in cooked *dhal* is due to retrogradation of starch leading to starch separation. However, no visible starch separation was observed in shelf stable *dhal* till the end of storage. Shelf stable *dhal* did not undergo staling upon 90 days of storage as depicted by score for staleness (Table 4). The OA scores of *dhal*, decreased with progressive period of storage from 13.5 ± 0.4 to 12.0 ± 0.2 , indicating a shift from like extremely to like moderately. Although there was a decrease in OA score of the product along with the storage period but it was always above the threshold level of acceptability. Earlier researchers (Jha et al. 2011, 2012; Khan et al. 2011; Gautam et al. 2013) have also reported good retention of sensory attributes of retort processed food till the end of long storage periods.

Table 4 Changes in sensory attributes of shelf stable *dhal* upon 90 days storage at 37 °C

Sensory parameters	Storage days						
	0	15	30	45	60	75	90
Colour	7.5 ± 0.7^a	7.5 ± 0.4^a	7.3 ± 0.6^a	7.3 ± 0.2^a	7.2 ± 0.6^{ab}	7.2 ± 0.2^{ab}	7.0 ± 0.3^b
Consistency	7.5 ± 0.1^a	7.5 ± 0.3^a	7.7 ± 0.2^{ab}	7.8 ± 0.1^{ab}	8.0 ± 0.4^b	8.1 ± 0.2^b	8.2 ± 0.1^b
Grain hardness	7.5 ± 0.5^a	7.5 ± 0.3^a	7.0 ± 0.7^b	7.0 ± 0.2^b	6.8 ± 0.3^b	6.8 ± 0.5^b	6.7 ± 0.4^b
Grain integrity	11.3 ± 0.4^a	11.2 ± 0.2^a	11.0 ± 0.3^a	11.0 ± 0.4^a	10.9 ± 0.6^{ab}	10.5 ± 0.5^b	10.4 ± 0.4^b
Staleness	0.0 ± 0.0^a	0.0 ± 0.0^a	0.0 ± 0.0^a	0.5 ± 0.1^{ab}	0.5 ± 0.1^{ab}	0.8 ± 0.1^b	0.8 ± 0.1^b
OA score	13.5 ± 0.4^a	13.5 ± 0.2^a	13.5 ± 0.1^a	13.2 ± 0.3^{ab}	13.0 ± 0.2^b	12.5 ± 0.5^c	12.0 ± 0.2^c

Values represent mean of triplicate values ($n=3$)

Values within the same row with different superscripts differ significantly ($P<0.05$)

OA Overall acceptability

Conclusions

Heat penetration characteristics of *dhal* represented a convective heating regime. The process time and ratio of water to *dhal* used in the product formulation had a pronounced effect on its sensory attributes. The product was characterized by a short lag period for the heating curve, j_h (0.52–0.64), small heating rate index, f_h (3.9–6.5 min) and a short lag factor for the cooling curve, j_c (0.53–0.73), implying essentially convective heating regime. The total process time (B') was 11.56 to 40.25 min for F_o value of 2.30 to 27.30 min. Based on optimization, retort processing of the *dhal* at 121 °C for 25 min with ratio of water to *dhal* being 2.5 was found to be the most optimum. In view of the acceptability of the product both in terms of sensory properties and its stability to physico-chemical and microbiological changes it could be established that by using retort technology traditional food products like *dhal* can be preserved for long term storage, increasing their commercial scope and viability.

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