Development of ready to eat (RTE) tiger prawn-rice based extruded snacks using twin screw extruder

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Abstract

Extrusion of rice flour and fish mince of tiger prawns (*Penaeus monodon*) was carried out to study the effect of various extrusion operating parameters (barrel temperature, screw speed, moisture content of feeding material, feeder speed, prawn mince percentage) on the properties (product density, expansion ratio, crispness and hardness) of extruded snack using twin screw extruder. Multiple regression analysis was carried out for different properties of the finished product using Rotatable Central Composite Design (RCCD) of response surface methodology. Temperature was found to be most influencing parameter followed by moisture content. Screw speed and feed rate were found to be having least influence on extrudate properties. Optimum condition with desirability of minimum product density and maximum expansion ratio was found at 119.49^{0}C barrel temperature, 260 rpm screw speed, 10 % M.C., 13.95 % prawn muscle flour percentage and 29 rpm feeder speed, which gave the output as 339.24 Kg/m^3 of product density and 8.51of expansion ratio. Increasing fish muscle percentage increased the protein and fat percentage of final extruded product while slight decline was observed with increasing temperature for both.

Key words: Twin Screw extruder, extrudates, Bombay duck, Response Surface Methodology, ANN model

Fish is a rich source of proteins, minerals and vitamins which are essential for human nutrition. A low value fish can be termed as, "Fish that have a low commercial value by virtue of their low quality, small size or low consumer preference – they are either used for human consumption (often processed or preserved) or used for livestock/fish, either directly or through reduction to fish meal/ oil" (FAO, 2005). According to Venugopal (1995) underutilized fishery resources can be defined in number of ways viz. (i) species that are variable but difficult to catch, process or market (ii) species caught in large quantities or as by-catch and used for low value industrial products that can be upgraded for human consumption (iii) waste of edible flesh generated as a result of inefficient handling, processing or distribution of the products and simple loss of quality and value in the handling and sale of fishery products.

Utilization of low value or trash fish is important for several reasons including recognition of depletion of the commercially important fish stocks throughout the world, nutritional importance of fish as a human food and environmental significance.

The term 'Twin-screw' applies to extruders with two screws of equal length placed inside the same barrel either co-rotating or counter rotating. Twin-screw extruder has certain advantages over single-screw viz., flexibility, easy to handle, better control, variability, cheaper production cost/metric ton, almost nil survival of microbial count (Riaz, 2000). Response surface methodology, first introduced by Box and Wilson (1951), can be effectively used for regression analysis of quantitative data obtained from appropriate experimental designs to construct and simultaneously solve multivariate equations describing the relationship of the dependent variables to product quality characteristics and to process and design parameters for a complex process like extrusion (Olkku and Vainionpaa, 1983).

The purpose of this study was to investigate the effect of fish mince incorporation along with various extrusion process parameters as one of the raw materials on properties of the extrudates prepared from twin-screw extruder.

Materials and methods

Raw Material: Tiger prawn (*Penaeus monodon*) was selected for the experimental purpose after that washed with fresh water. Shell and veins was removed from the prawn body and muscle of prawn was blanched at 100±2^{0}C for 5 min. After that dried in hot oven dryer at 80 ± 2^0 C for 24 hr and grinding was done in grinder after that the flour was sieved through 44 mesh BS sieve (353 m).

Rice Flour: Rice flour was selected for its better expansion property, easy availability, high mineral and fiber content.

Extruder: The extruder used for this experimental purpose was BTPL make laboratory co-rotating twin-screw extruder (EB-10 model) with L/D ratio of 14.4:1. The main drive was provided with the 10 HP motor (400 Volts, 3Ph, 50Hz). The barrel of extruder received feed from a co-rotating feeder fitted with variable speed controller. The extruder barrel was provided with three electric band-heaters (just before die section, kneading section and feeding section and also surrounded with three water jackets. The cutting knife driven by a variable speed DC motor was fixed on a rotating shaft of knife drive assembly. The extruder was provided with stand-alone type control panel which indicated and controlled the extruder screw speed, barrel temperatures, feed rate and cutter rpm.

Experimental Procedure: The independent variables considered to vary during experiment were, barrel temperature (90 to 120 ^{0}C), Screw speed (150 to 300 rpm), Moisture content of feeding material (10 to 30 %), Feeder speed (10 to 30 rpm), Prawn muscle percentage (0 to 20 %) in order to study their effect on expansion ratio (ER), product density (P.D.), hardness (H) and crispiness (Cr) of the extruded product. The die size of 2.5 mm diameter opening was used throughout the experiment.

Extrusion: Calculated amount of rice flour (90 % of the total flour), prawn mince flour (10 % of the total flour) were mixed well. Then required amount of water was added to the above mixture. After mixing it thoroughly, the sample was sieved through 44 mesh BS sieve in order to get uniform sample. The BTPL lab model co-rotating twin-screw extruder was used for extrusion of the material. The extruded strands were dried at 80^{0}C for 1-1.5 hr. the dry extrudates with moisture content of 4-12 % were kept in polyethylene pouches and remove the air from polyethylene pouch after that sealed with the help paddle sealer and stored in air tight containers.

Dependent Variables

Expansion ratio: Expansion ratio is the ratio of area of cross section of extruded product to area of die.

$$ER = \frac{D^2}{d^2}$$

Where, D is cross diameter of the extrudate product and d is the die diameter.

Product density: The product density is the ratio of weight of product divided by its volume.

$$PD = \frac{4m}{\pi d^2 L}$$

Where, m is mass (g) of a length *L* (cm) of extrudate with diameter d(cm).

TPA analysis: Texture analysis of RTE prawn-rice snack were analyzed using a stable micro system TA-XT2 texture analyzer (Texture Technology corp., UK) fitted with a 25 mm cylinder probs.The sample was placed on a flat platform and was subjected to double compression by a cylindrical probe with a 50-mm diameter. The test was conducted at a speed of 12 mm/s using a 50-N load cell. The sample was allowed for a double compression of 40% with a trigger force of 0.5 kg during which Hardness and crispiness were determined. Five samples from each stage were analyzed and the mean value was taken.

Proximate composition: Moisture content, Protein content, fat and ash content were determined by standard AOAC (2000) methods.

Sensory attributes: The sensory evaluation was carried on nine-point Hedonic scale with ‘1’ being lowest possible value and ‘9’ being highest possible value. It included evaluating product quality based on texture, taste, colour, flavour, appearance and overall acceptability of the product

Results and Discussion

Table 1 shows the different physical properties of extrudates under different operating conditions. The value of product density varied between 175.58 to 956.78 kg/ m^3, expansion ratio varied between 5.74 to 18.16, final moisture content varied between 5.4% to 18.5%, Hardness varied between 4352.74 g to 16789.49 g and crispiness varied between 1 to 7. The data obtained was analyzed using second order polynomial model, multiple regression equations were generated relating barrel temperature (Temp), screw speed of extruder (S.S.), moisture content of feed material (M.C.), prawn muscle percentage (F.C.) and feeder speed (F.S.) to coded levels of the output variables.

Table1 Experimental data based on rotatable experimental design for Product density (PD),Expansion ratio (ER), Final moisture content (FMC), Hardness (H) and Crispiness (Cr)

Run	Temp., 0C	S.S., rpm	M. C., (% wb)	F.C., %	F.S., rpm	P.D., kg/m3	ER	FMC., (% wb)	H., (g)	Cr
1	105	225	20.00	10	20	301.9	12.78	12.4	6888.74	2
2	105	150	20.00	10	20	310.88	10.27	14.7	8874.41	1
3	105	225	30.00	10	20	365.11	10.83	15.7	7855.47	2
4	111	256	24.20	5	15	396.54	9.32	14.8	11385.2	2
5	111	256	15.80	5	24	261.83	12.17	10.5	12877.43	6
6	105	225	20.00	10	20	284.78	10.98	7.1	6487.22	3
7	98	193	15.80	5	24	440.42	9.29	7.4	14566.75	1
8	105	225	20.00	10	20	367.44	8.56	7	8742.65	4
9	98	193	24.20	5	15	450.77	9.74	9.3	10413.55	1
10	105	225	20.00	10	20	324.45	9.74	12.7	6742.89	4
11	105	225	20.00	10	30	314.79	10.65	7.9	12456.26	2
12	98	193	15.80	14	24	450.74	7.77	15.6	9874.44	4
13	105	225	20.00	10	20	361.75	10.41	8.2	7542.35	3
14	111	193	15.80	5	24	371.08	12.29	9.2	4978.458	3
15	111	256	24.20	14	15	341.78	11.74	18.5	8713.98	4
16	111	193	24.20	5	15	387.34	10.78	8.6	15911.7	1
17	111	256	15.80	14	15	313.67	11.23	8.5	9745.85	5
18	111	256	24.20	14	24	321.42	12.74	10.3	8465.25	4
19	98	256	24.20	14	15	378.12	8.74	13.4	7474.44	2
20	98	193	15.80	14	15	327.24	10.55	12.1	15789.47	3
21	98	256	24.20	14	24	410.32	11.41	12.3	14214.21	3
22	98	256	24.20	5	24	657.06	6.45	12.5	10789.42	1
23	111	193	24	5	24	701.46	6.28	12.9	12784.73	1
24	111	256	15	14	24	324.95	13.56	11.8	10567.74	5
25	111	193	24	14	24	297.65	12.91	6.8	8456.12	3
26	105	225	20	10	10	374.84	15.45	6.2	6484.45	5
27	105	300	20	10	20	268.09	5.89	6.6	6534.9	6
28	111	193	15	5	15	175.58	12.66	7.8	7952.48	4
29	105	225	20	20	20	390.82	10.86	7.5	16789.49	3
30	90	225	20	10	20	400.78	5.74	6.2	15642.02	1

31	90	225	20	0	20	281.61	13.52	9.4	8297.9	3
32	98	193	24	5	5	956.78	8.65	7.4	11560.2	1
33	98	256	15	5	15	213.73	14.14	12	11981.2	2
34	98	256	15	5	24	309.53	10.57	9.9	13789.42	1
35	111	193	15	14	24	282.04	18.16	5.4	14586.2	3
36	111	193	15	14	15	194.74	12.65	10.6	6136.74	5
37	105	225	20	10	20	354.74	10.75	12.3	9635.74	3
38	98	193	15	5	15	412.44	9.28	14.6	13564.47	1
39	111	256	24	5	24	397.42	13.99	6.2	13315	3
40	98	193	24	14	24	450.87	6.74	6.3	13879.44	1
41	111	193	24	14	15	332.53	11.25	6.2	9987.41	3
42	105	225	20	10	20	290.17	11.08	16.1	5421.44	4
43	105	225	20	10	20	362.47	12.78	6.9	7458.44	3
44	111	256	15	5	15	315.74	13.78	6.6	6241.77	4
45	98	256	15	14	24	429.42	11.93	10.1	8875.74	6
46	120	225	20	10	20	337.48	10.87	7.7	4352.74	3
47	98	256	24	5	15	446.22	10.79	12.2	15464.45	1
48	105	225	10	10	20	324.74	13.78	6.1	6555.47	7
49	98	256	15	14	15	354.08	9.5	13.7	11543.44	4
50	98	193	24	14	15	365.44	9.76	8.6	15472.44	2

Product density,

$$P.D. = +369 - 41.28A - 19.09B + 34.96C + 51.03D - 24.45E + 18.35AB - 20.54AC - 7.55AD + 3.83AE - 29.78BC - 14.46BD + 33.45BE + 16.61CD - 29.29CE - 52.25E \quad (R^2 = 0.644,\ C.V.\ \% = 23.63)$$

Expansion ratio,

$$E.\ R. = +10.91 + 1.21A + 0.067 B - 0.29C - 0.81D + 0.095E - 0.57AB + 0.57AC - 0.21 AD + 0.48 AE + 0.25BC + 0{,}15BD - 0.35BE - 0.15CD + 0.64 CE - 0.25DE - 0.44 A^2 - 0.48B^2 + 0.40C^2 + 0.27D^2 + 0.25E^2 \quad (R^2 = 0.6244,\ C.V.\ \% = 18.07)$$

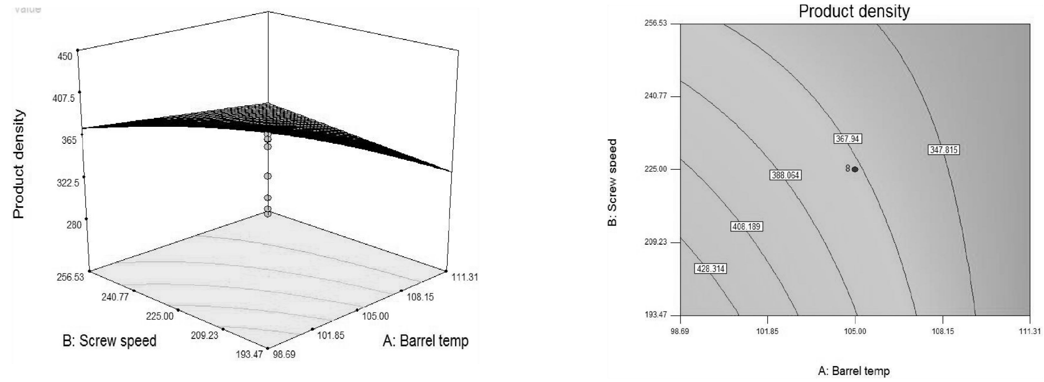
Crispiness,

$$Cr = +2.98 + 0.62A + 0.64 B - 0.12C - 0.83D + 0.55E \quad (R^2 = 0.635,\ C.V.\ \% = 33.88)$$

The higher value of R^2 indicated that the models were significant. The comparative effect of each output factor on input parameters can be observed by the magnitudes of coefficients of variables.

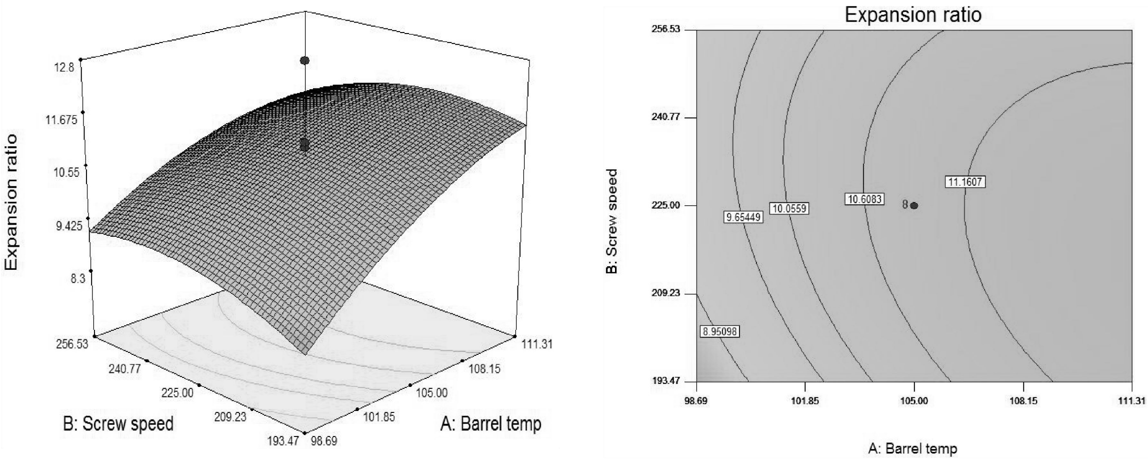
Product Density: Temperature and moisture content were the major parameters affecting product density of extruded snack at linear and quadratic level. The product density decreased with increase of these variables. The product density increased with increase moisture content and fish muscle percentage. Lower product density resulted at low moisture and high temperature (Fig. 1A & 1B). Fish muscle increased product density slightly. Decrease in product density with increasing temperature was found which was due to formation of air cells and foamed structures. Besides temperature dough moisture and fish content were the most important factor affecting bulk density (Shankar, 2002).

Expansion Ratio: Expansion ratio increased with increase of temperature, screw speed and feed rate while excessive increase of these variables resulted in decrease of expansion ratio. The expansion ratio decreased with increase of moisture content (Fig 2). Expansion ratio of extruded snacks was mostly influenced by barrel temperature followed by feed moisture. With increasing temperature and low feed moisture, gelatinization process might have produced more expansion (Giri and Bandyopadhyay, 2000). Increase in moisture and fish content resulted in lower expansion. Expansion increased with increasing screw speed. Maximum expansion (6.8) was observed around 250 rpm (Fig. 2A & 2B). As the screw speed was increased the shear inside extruder barrel would increase giving rise to a more developed and uniform dough with better expansion properties at the die exit (Ozer *et al.*, 2004).



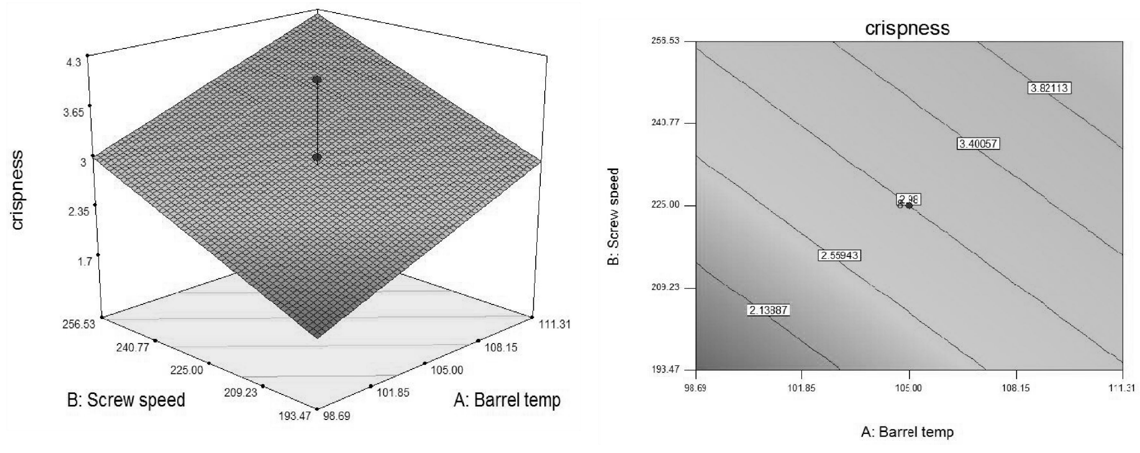
(A) (B)

Fig. 1 Response surface (A) and contour plot (B) for the effect of screw speed and barrel temperature on product density of extruded snack



(A) (B)

Fig. 2 Response surface (A) and contour plot (B) for the effect of moisture content and barrel temperature on expansion ratio of extruded snack.



(A) **(B)**

Fig. 3 Response surface (A) and contour plot (B) for the effect of moisture content and barrel temperature on crispness of extruded snack.

Crispiness: Observations of crispiness with different combinations of the process parameters are given in (Table 1). The experimental minimum (1) was obtained at the process condition of 98^{o}C temperature, 256 rpm screw speed, 24% moisture, 14 % prawn muscle and 24 rpm feeder speed and maximum (7) was obtained at105^{o}C temperature, 225 rpm screw speed, 10 % moisture, 10 % prawn muscle and 20 rpm feeder speed.

The ANOVA of product density was obtained and is presented in (Table 2). The Model F-value of 15.33 implies the model is significant. There is only a 0.01 % chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.05 indicate model terms are significant. In this case temperature, moisture content, screw speed, prawn content are significant model terms. That means these two variable have maximum influence on product density. Values greater than 0.1 indicate the model terms are not significant.

The second order polynomial model was fitted with experimental data and tested for adequacy through analysis of variance. The response surface method gave an empirical equation showing product density as a function of five independent process variables temperature, screw speed, moisture content, prawn muscle percentage and feed rate. Following are the equations obtained from Design Expert 7.1.6

The higher value of R-Squared = 0.635 indicates that the model is significant. The comparative effect of each factor on crispness could be observed by the F- values in ANOVA. (Table 4.6) and also by the magnitudes of coefficients of variables (Cr.). Barrel temperature, Feed rate and Moisture content are significant model terms at 1% level of significance. Thus ANOVA revealed that temperature and moisture content were the major parameters responsible for crispness of extruded snack at linear and quadratic level.The negative coefficients of first order terms feed rate, moisture content indicated that crispness decreases with increase of these variables. The positive coefficients of first order terms of temperature, screw speed and prawn content indicated that crispness increases with increase of these variables.

Surface plot as shown in Fig.3 gives the clear idea about changes in crispness with variation of different input process variables. Contour plot gives the clear idea of prediction point at different combinations of input process variables. It is clear from graph that lower crispness resulted at high moisture and low temperature. Screw speed has no much affect on crispness. Increase in crispness was found with increase in temperature and low moisture content. Further increase of these variables resulted in lowering of crispness.

Optimization of Process Conditions for Extruded Product: Optimization of extrudate properties viz., product density and expansion ratio was carried out. To perform this operation 'Design Expert 7.1.6' program of STAT-EASE software was utilized and used for simultaneous optimization of multiple responses. The desired goals for each factor and response were chosen and different weights were assigned to each goal to adjust the shape of its particular desirability function.The optimization was done for minimizing the product density and maximizing expansion ratio. The optimum condition was selected at maximum desirability by software itself which gave the common optimum condition for all product properties (Table 3).

Table 2 Analysis of variance for crispness

ANOVA for Response Surface Quadratic Model						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	78	5	15.63	15.33	<0.0001	significant
A-Barrel Temp.	16.53	1	16.53	16.22	0.0002	
B-S.S	17.74	1	17.96	17.62	0.0001	
C-Feeder speed	0.61	1	0.61	0.60	0.4437	
D-MC	29.74	1	29.74	29.18	<0.0001	
E- Prawn content	13.30	1	13.30		0.0008	

Table 3 Comparison of experimental and predicted values

Responses	**Predicted value ± SD**	**Actual Value**	**% Variation**
ER	20.43 ± 2.06	21.79	0.062
PD, kg/m^3	7.03 ± 0.24	6.89	-0.0199
FMC, % w b	6.59 ± 12.33	7.12	0.0744
Cr	7.2418 ± .22	7.987	0.092
H (g)	100.87 ± 0.0	101.78	0.008

Extrudate Quality Evaluations

Proximate analysis: Increasing fish muscle percentage resulted in increase of protein content of final extruded product. The maximum protein content of 16.98% was observed at prawn muscle percentage of 25 %. The same trend was also observed in case of fat. The maximum amount of fat (1.095%) in extrudate was observed at 15% fish muscle and 15% moisture content. Percentage of ash was increased with prawn muscle and moisture content. Maximum ash content was observed at 15% prawn muscle and 40% moisture content.

Sensory evaluation of extrudate: Sensory evaluation was carried out for the product based on different quality characteristics like taste, flavor, colour, texture and overall acceptability. The extrudates were analyzed for their quality attributes. Nine point hedonic scale was used for product quality evaluation on the basis of texture, taste, colour, flavour and overall acceptability. The samples were analyzed by group of 10 untrained peoples including staff and students from Agricultural and Food Engineering department. Fig 4 show comparison of mean attributes for original snack and snack added with masala and optimized RTE prawn-rice snack product respectively.

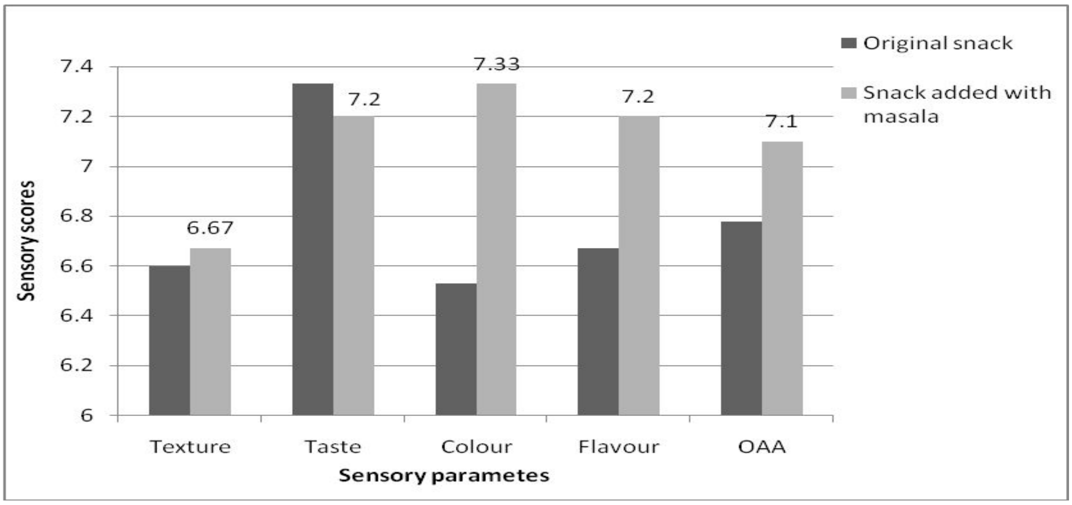


Fig 4 Comparison of mean attributes for original snack and snack added with masala.

Conclusions

Barrel temperature was found to be the most influencing parameter affecting all four extrudate properties strongly. Moisture content was the second most influencing parameter. Prawn muscle percentage had influence on product density and expansion ratio. Increase in moisture and prawn content resulted in lower expansion and higher bulk density. Screw speed and feed rate were found to be having least influence on extrudate properties product density, crispness and expansion ratio considered for this experimental purpose. Decrease in product density with increasing temperature and decreasing moisture content was found. Combination of high temperature and high screw speed yielded a product with low density.

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