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Research Article

Refining thermal processing parameters for retort pouch packaged fish paneer curry through textural and sensory analysis

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Abstract

Fish cubes were cut and developed into paneer from the mince of *Pangasianodon hypophthalmus* with the addition of binders and salt. Shallow-fried paneer was then incorporated into the curry medium and packed in four-layered laminated retort pouches. It was thermally processed in an over-pressure retort at 121.1ºC for three different F_0 values, i.e., 6-min, 7-min and 8-min. The F_0 values represented the integrated lethal value of heat received by the retort pouch in minutes. Data on time-temperature combinations were collected during heat processing using an Ellab Sterilisation Monitoring System. Texture profile analysis revealed that hardness, gumminess, adhesiveness and cutting strength declined with increased F_0 value. Instrumental analysis of colour showed a decreasing trend of a* (redness/greenness) and b* (yellowness/blueness) values and an increase in L* (lightness) \whiteness value with higher F_0. Sensory characteristics (appearance, colour, flavour, texture, taste and overall acceptability) were much higher in F_0 6 compared to F_0 7 and 8. Based on the tests, retort pouch packed fish paneer curry was standardised at F_0 value 6 min and cook value of 58.36 min, with a total process time of 27.67 min at 121.1°C.

Keywords: Fish paneer, Paneer curry, *Pangasianodon hypophthalmus*, Retort pouch, Thermal processing

Highlights

- Paneer-type products from fish mince give a new dimension to the value addition of fish
- Processing of the paneer in curry is a novel approach with a better scope of commercialisation
- The optimal F_O value for fish paneer curry in retort pouches was determined to be 6 min at 121.1°C
- Fish paneer in curry in retort pouches is a shelf-stable product and holds potential to create small entrepreneurship

INTRODUCTION

Fish provides important vitamins, minerals, lipids, and high-quality proteins, making it an essential part of the human diet. Omega-3 long-chain polyunsaturated fatty acids (LC-PUFAs), especially docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), are notably abundant in it. These fatty acids support the immune system, neurological, and cardiovascular processes, making them essential for human health. The human body is unable to produce EPA and DHA effectively; thus, they must be obtained through diet. Oily fish, such as salmon, mackerel, and sardines, are particularly high in these nutrients (Innes & Calder, 2020). People became aware of the value of fish in a regular diet as a result of all these health benefits. Consumers' interest, particularly in urban areas, is more in fish products of convenient forms, such as ready-to-eat or ready-to-cook products like fish fingers, cutlets, patties, burgers, nuggets, sausages, fish balls, etc. Recent trends in food marketing, which show a fast-growing demand for such processed, convenient foods, minimise the workload for the table. Such a changed situation is due to the increasing number of working women, reasonably increased income, education, awareness and consciousness towards quality, freshness, nutrition of food, hygiene, health benefits, etc. This has directed the development of several fishery products varied in taste, texture and appearance (Pagarkar et al., 2011). Thermal processing is a food processing method of heat processing for achieving long-term stability against microorganisms without the need for refrigeration or other preservation. The method involves application of prolonged heating in hermetically sealed containers (cans or retort pouches) that is sufficient to destroy spoilage or disease-causing microbes and render the food inside the container sterile. Thermal processing in all forms of application persists as the most widely used method for preserving and extending the useful shelf life of foods. High-quality, ready-to-eat (RTE) products that offer natural flavours, appealing taste, and fresh appearance continue to be highly valued by consumers.

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This preference has significantly contributed to the growth of the RTE food sector. The increasing demand for convenient, nutritious, and sensory-appealing foods has led to the development of innovative RTE products, such as millet-based snacks enriched with underutilised green leafy vegetables, which enhance both nutritional value and consumer appeal. Factors like convenience, taste, texture, and visual appeal are key drivers in the rising consumption of RTE foods (Soujanya et al., 2022).

Retort pouches have emerged as a modern alternative to metal cans for producing thermally processed, shelf-stable foods. These flexible laminated pouches can withstand high-temperature sterilisation processes, combining the advantages of metal cans and plastic packaging (Ramesh, 2020). Key benefits include a thin profile that allows for faster heat transfer, leading to reduced processing times by up to 60%, improved flavour retention, energy savings, and extended shelf life. Additionally, retort pouches are lightweight, cost-effective, and space-efficient, making them advantageous for storage and transportation. In recent years, the use of retort pouch technology has gained considerable attention in the seafood processing industry for its ability to produce shelf-stable, ready-to-eat fish products with extended shelf life and desirable sensory qualities (Kontominas et al., 2021). Thermal processing of products such as fish curry, fish soup, and fish burgers in retort pouches has proven effective in preserving flavour, texture, and microbial safety over long periods at ambient temperatures. Ditudompo et al. (2022) demonstrated that fish burgers developed from a blend of striped catfish and salmon, processed in retort pouches, maintained good sensory attributes and shelf stability for over 13 months, highlighting the potential of this technology in modern fish product development. This technique also helps to produce a variety of products such as fish cakes, fish balls, fish ham, fish sausages, fish nuggets, etc.Fish cracker is another such product prepared by thermal gelation and oven drying of low-value fish mince and is a very popular delicacy in Malaysia and other Asian countries (Yu & Low, 1992). A similar type of product was attempted to develop from the mince of low-cost fish after incorporation of different additives and thermal gelation of the mince. To make it shelf stable, it is incorporated in curry and thermally processed in a retort pouch. This study was aimed to evaluate the quality and safety of retort-pouch fish paneer curry at various F_O values in order to optimize the thermal processing conditions.

MATERIALS AND METHODS

Fish paneer: Fresh Thai pangas fish (*Pangasianodon hypophthalmus)* were procured from the local fish market and transported to the laboratory under iced conditions in plastic polystyrene insulated containers within 1h of collection and used for this study. Paneer from the mince of pangas was prepared following the method described by Chandravanshi et al. (2018).

Preparation of fish paneer curry: Standardised components that were adapted to the Indian palate were used to make fish paneer curry. This involved the preparation of spice and condiment pastes (comprising onion, garlic, green chilli and ginger, and spice paste comprising turmeric powder, coriander powder, cumin powder, chilli powder, salt and sugar), which were then cooked one after the other to create a thick gravy. 4-ply laminated retort pouches (300 g capacity, 150×200 mm) were filled with about 100±5 g of flash-fried fish paneer and 100±5 g of hot gravy, which were then sealed after steam injection to remove air. To obtain the required F_O value, thermal processing was performed at 121.1°C in a pilot-scale overpressure retort system (Sakara Equipments, Bangalore), followed by

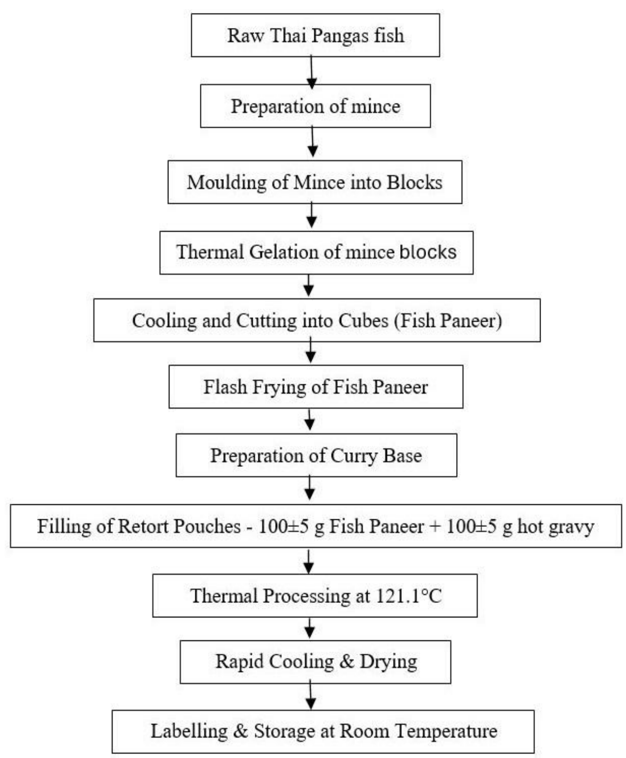

Fig. 1. Flowchart for preparation of fish paneer curry

rapid cooling, drying, labelling, and room temperature storage (Fig. 1).

Thermal process evaluation: Filled and sealed pouches were thermally processed to achieve the required F_O values using an Ellab Eval Flex thermal validation system equipped with precision thermocouples and an F_O integrator. Temperature data were recorded at 60-second intervals, and heat penetration parameters such as lag factors for heating (J_h) and cooling (J_c), heating rate (F_h), and sterilisation time (U) were determined, and the process time was calculated (Stumbo, 1973). The total process time was the sum of Ball's process time (B) and 58% of the come-up time. Cook value (CV), indicating nutrient and texture degradation, was also determined using a reference temperature of 100°C and Z value of 33°C (Ranganna, 2002).

Biochemical and microbial analysis: The moisture content of raw fish and fish paneer was determined by heating the sample initially at 100ºC and later at a temperature of 170ºC using an automatic moisture analyser (Sartorius, Model MA 35, Bohemia, NY, USA). Moisture content corresponds to the weight loss of the sample. The crude protein content (total nitrogen×6.25) was determined by the Micro-Kjeldahl method (Association of Official Analytical Chemists [AOAC], 2023). Fat was determined following the method described by AOAC (2023) using a Soxhlet extraction system. Ash content was determined by ashing at 550±10 ºC for 6h in a mufûe furnace. Water holding capacity (WHC) of fish paneer was determined as expressible moisture content following the method of Suvanich et al. (2000). The total plate count (TPC) was estimated by the spread plate technique (Hitching et al., 1995). The average number of colonies was calculated and expressed as log $cfug^{-1}$ of the sample.

Analysis of texture profile: A TA-XT2 texturometer was used to assess the texture characteristics of fish paneer after samples had been allowed to acclimatise to room temperature for half an hour to avoid dehydration. A 50 mm cylindrical probe was used to perform texture profile analysis (TPA), compressing materials to 40% of their initial height using pre-test speed 1 mm s^{-1}, test speed 5 mm s^{-1} and post-test speed 5 mm s^{-1}, while a knife blade probe was used to evaluate cutting strength at a speed of 2 mm s^{-1}. Hardness, gumminess, cohesiveness, adhesiveness, and springiness were among the parameters that were noted. Each measurement was carried out in triplicate at 25–27°C.

Instrumental analysis of colour: A Colourflex EZ spectro-colourimeter (D65/10° illuminant) calibrated with black and white tiles was used to measure the colour of fish paneer in triplicate. The CIELAB scale was used to record the L* (lightness), a* (redness/ greenness), and b* (yellowness/blueness) values of a 5mm thick paneer slice and placed over the light source. The calculation of whiteness followed Lanier et al. (1991):

$$\text{Whiteness} = 100-[(100-L^*)^2 + a^{*2}+b^{*2}]^{1/2}$$

where, L*=lightness, a*=redness/greenness, b*=yellowness/blueness

Sensory analysis: Sensory evaluation of fish paneer processed at different F_O values was conducted by 10 trained panellists using a 10-point hedonic scale (Bureau of Indian Standards [BIS], 1971a; Vijayan, 1984). The panellists were asked to assign a score of 1 to 10 (1=dislike extremely, 2=dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like nor dislike, 6=light slightly, 7=like moderately, 8=like very much, 9=like extremely, 10=excellent) for appearance, colour, flavour, odour, taste, texture, and overall acceptability.

Commercial sterility test: Samples processed at different temperatures and F_O values were incubated for 15 days at 37°C and for at least 5 days at 55°C. Following incubation, 1-2 g of each sample was aseptically moved to sterile fluid thioglycolate broth, covered with sterile liquid paraffin to establish anaerobic conditions, subsequently cultured for an additional 48 hours at 37°C and four days at 55°C (Bureau of Indian Standards (BIS), 1971b).

Statistical analysis: The data were collected in triplicate and analysed using single-factor analysis of variance (ANOVA). The significant difference was determined using the Duncan test ($p<0.05$).

RESULTS

Biochemical and microbial analysis: Fresh pangas fish had proximate compositions of 74.25% moisture, 15.18% protein, 6.20% fat, and 1.05% ash, respectively. In comparison, fish paneer had 1.79% ash, 4.89% fat, 15.66% protein, and 75.47% moisture.Compared to raw fish, which had a WHC of 71.19%, paneer had a greater WHC of 77.34%. For raw fish and fish paneer, the total plate count (TPC) was 5.19 log CFU/g and 4.83 log CFU/g, respectively, and both values were within the International Commission on Microbiological Specifications for Foods [ICMSF] permissible limits (1986).

Standardisation of thermal process for fish paneer curry in retort pouch: Three different F_O values of 6, 7 and 8 were used to thermally process fish paneer curry that was packaged in retort pouches at 121.1°C (Fig. 2A, 2B and 2C). Commercial sterility was attained by all treatments. The sample that was processed at F_O 6 min, with a cook value of 58.36 min and a total process duration of 27.67 min, retained the best instrumental colour values, texture, and sensory qualities.

Thermal processing: The total process times to achieve F_O values of 6, 7, and 8 min for fish paneer curry were 27.67, 30.75, and 36.79 min, respectively (Table 1), all sufficient for achieving commercial sterility. Corresponding cook values were recorded as 58.36, 64.67, and 68.64 min at F_O values of 6, 7, and 8 min, respectively (Table 1). Similarly, heating rate index (f_h) values rose with increasing F_O, measured at 15.00, 17.00, and 19.00 min for F_O 6, 7, and 8, respectively (Table 1).

Sensory analysis: The sensory evaluation of fish paneer curry processed at 121.1ºC for F_O values of 6, 7, and 8 minutes revealed variations across sensory parameters (Table 2). Scores recorded for appearance were 8.1±0.74, 7.3±1.16, and 7.5±0.97, while those for colour were 8.3±0.67, 7.5±0.85, and 7.8±1.03 at F_O 6, 7, and 8, respectively. Flavour scores followed a similar trend, highest score at F_O 6 (8.4±0.70). Texture, taste, and overall acceptability also represented the highest

Table 1. Heat penetration characteristics of thermally processed fish paneer curry in retort pouch at 121.1°C with F_0 values 6, 7 and 8

Parameters	F_0 6	F_0 7	F_0 8
F_0 value	5.84	6.86	7.88
J_h	1.08	1.13	1.12
J_c	1.11	1.40	1.24
f_h	15.00	17.00	19.00
f_h/u	2.57	2.43	2.41
g	1.45	1.64	1.52
B	25.35	27.85	32.15
CUT	4.00	5.00	8.00
TPT	27.67	30.75	36.79
Cook value	58.36	64.67	68.64

#Jh=lag factor of heating, Jc=lag factor of cooling, fh=slope of heating curve, U=time in minutes for sterilization at retort temperature, g=final temperature deficit, B=Ball's process time, CUT=Retort come up time, TPT=total process time

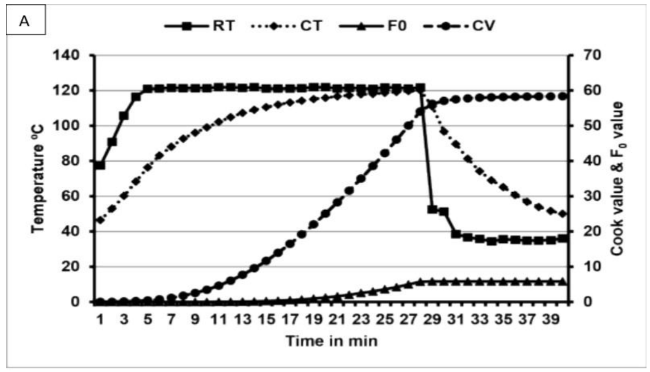

Fig. 2A. Heat penetration characteristics of thermally processed fish paneer curry at 121.1ºC and F_0 6

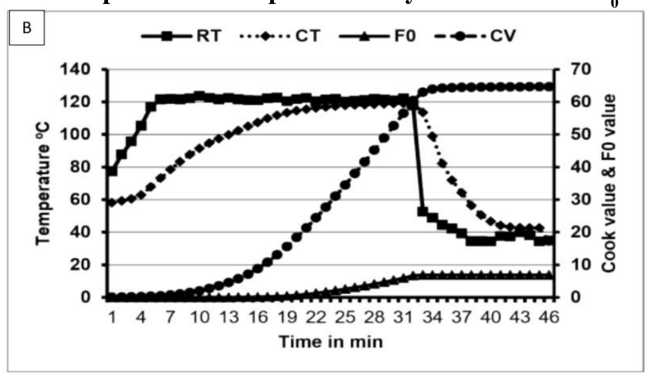

Fig. 2B. Heat penetration characteristics of thermally processed fish paneer curry at 121.1ºC and F_0 7

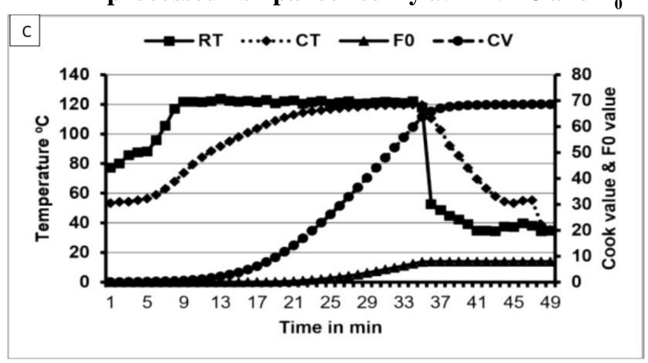

Fig. 2C. Heat penetration characteristics of thermally processed fish paneer curry at 121.1ºC and F_0 8

Table 2. Sensory score of thermally processed fish paneer curry in retort pouch at 121.1ºC with three different F_0 values

Parameters	$F_0$6	$F_0$7	$F_0$8
Appearance	8.1±0.74	7.3±1.16	7.5±0.97
Colour	8.3±0.67	7.5±0.85	7.8±1.03
Flavour	8.4±0.70	7.7±0.95	7.9±0.57
Odour	8.2±0.79	7.8±0.79	7.8±0.92
Taste	8.2±0.63	8.0±0.82	8.0±0.82
Texture	8.2±0.79	8.1±0.74	7.9±0.74
Overall acceptability	8.3±0.48	7.9±0.99	7.9±0.99

Data presented in the table are mean±SD, n=10.

Table 3. Instrumental colour score of thermally processed fish paneer curry in retort pouch at 121.1°C with F_0 values 6, 7 and 8

Parameters	F_0 6	F_0 7	F_0 8
L*	46.46±0.53	53.55±1.26	52.87±2.14
a*	7.81±0.61	7.25±0.39	3.94±0.59
b*	27.00±2.62	20.11±1.24	14.37±1.99
Whiteness	39.51±1.73	48.87±1.69	50.56±2.65

Data presented in the table are mean±SD, n=3.

scores at F_O 6.

Colour analysis: The colour parameters of fish paneer curry processed at F_O values of 6, 7, and 8 min are presented in Table 3. The L* (lightness) values were 46.46±0.53, 53.55±1.26, and 52.87±2.14, respectively, at F_O values of 6, 7, and 8. The a* (redness) values decreased from 7.81±0.61 (F_O 6) to 7.25±0.39 (F_O 7) and further to 3.94±0.59 (F_O 8). The b* (yellowness) values also decreased with increased F_O, 27.00±2.62 (F_O 6), 20.11±1.24 (F_O 7), and 14.37±1.99 (F_O 8). Whiteness values were 39.51±1.73, 48.87±1.69, and 50.56±2.65 for F_O 6, 7, and 8 min, respectively.

Texture profile analysis (TPA): The instrumental TPA of fish paneer curry processed at 121.1ºC for different F_O values is shown in Table 4. Hardness decreased with increasing F_O 6, 7 and 8 with values of 33.14±4.90 N, 26.62±2.37 N, and 17.93±1.99 N, respectively. Gumminess values were 22.80±3.59 N, 22.28±2.72 N, and 17.54±0.64 N for F_O 6, 7, and 8, respectively. Cutting strength also declined from 11.20±0.14 N (F_O 6) to 9.84±0.78 N (F_O 8). Springiness remained nearly constant across treatments, with values of 0.95±0.04 mm, 0.98±0.04 mm, and 0.98±0.04 mm. Minimal variations were observed in adhesiveness and cohesiveness across all F_O values.

DISCUSSION

Hossain et al. (2004) reported similar results of 78.6% moisture, 16.5% protein, 6.8% lipid and 0.78% ash for *P. hypophthalmus*. The slightly higher moisture content in fish paneer (75.47%) compared to fresh pangas fish (74.25%) can be attributed to water incorporation during paneer preparation. The observed increase in protein content (from 15.18% in raw fish to 15.66% in fish paneer) could be due to concentration during processing, similar to findings by Kanawjia et al. (1990) in soya-fortified milk paneer. The reduction in fat content in paneer(4.89%) relative to raw fish (6.20%) likely resulted from thermal processing losses, including fat leaching and heat-induced breakdown, as supported by Larsen et al. (2010) and Aberoumand et al. (2024). The higher ash content in fish paneer (1.79%) may be due to the addition of functional ingredients, aligning with observations by Jindal and Bawa (1988) in cooked sausages. The partial unfolding of myofibrillar proteins and the creation of a three-dimensional network after thermal gelation, which improves water entrapment, may be the cause of the greater WHC seen in paneer (77.34%) as compared to raw fish (71.19%) (Lan et al., 1995; Tolano-Villaverde et al., 2016). By encouraging protein-protein interactions and fortifying the gel matrix, salt addition during processing probably considerably enhanced WHC (Lefèvre et al., 2001). In line with research by Park and Yongsawatdigul (1998), the lower microbial burden in fish paneer (4.83 log CFU/g) compared to raw fish (5.19 log CFU/g) illustrates how well heat treatment works to inactivate microorganisms, improving the microbiological safety and shelf life of the product.

The F_O 6 min treatment was determined to be the most effective in maintaining the quality features of fish paneer curry, even though all F_O values guaranteed commercial sterility. Better sensory and textural qualities were preserved due to the reduced processing time, which also reduced heat degradation. These results are consistent with other research that optimised thermal processing parameters for fish-based ready-to-eat products, including Rohu fish stew (Mallick et al., 2006), Tilapia fish curry (Dhanapal et al., 2010), Mahseer stew (Bindu et al., 2011), and Rohu fish balls (Majumdar et al., 2016). However, those studies reported slightly higher F_O and cook values. The reduced F_O value of this study provides an effective thermal processing environment without sacrificing the quality of the final product.

Increase in cook value, f_h (heating rate index), and total process time were

Table 4. Texture profile of thermally processed fish paneer curry in retort pouch at 121.1°C with F_0 values 6, 7 and 8

Parameters	F_0 6	F_0 7	F_0 8
Hardness(N)	33.14±4.90	26.62±2.37	17.93±1.99
Adhesiveness(gs)	-0.81±0.03	-1.64±0.92	-1.59±0.37
Springiness(mm)	0.95±0.04	0.98±0.04	0.98±0.04
Cohesiveness	0.84±0.02	0.84±0.00	0.82±0.03
Gumminess(N)	22.80±3.59	22.28±2.72	17.54±0.64
Cutting strength (N)	11.20±0.14	10.91±0.07	9.84±0.78

Data presented in the table are mean±SD, n=3

all directly correlated with rising F_O values, suggesting increased thermal exposure. These findings align with earlier research done by Mallick et al. (2006), Dhanapal et al. (2010), Majumdar et al. (2016), Dinakaran et al. (2017), and Tameshwar et al. (2024), who documented comparable patterns in a variety of fish-based retort products. The observed f_h values also signify that the heat penetration was by both convection and conduction heating. Since the U value is the number of minutes for sterilisation at the retort temperature, f_h/U decreased with increasing F_0 value, which is probably caused by slower heat penetration. Heat penetration pattern of fish paneer curry in retort pouch thermally processed at F_0 6 is shown in Fig. 2 A.

Fish paneer curry processed at F_O 6 min consistently received higher sensory scores throughout most of the parameters, indicating shorter thermal exposure better preserved desirable qualities such as appearance, colour, and flavour. The decline in texture score with increasing F_O values suggests thermal degradation of muscle structure during prolonged heating (Majumdar et al., 2016; Zhang, 2016). The superior taste and overall acceptability at F_O 6 suggest its suitability in balancing the product quality. However, careful optimisation of the thermal process is required to ensure food safety (Chandravanshi et al., 2018; Chaudhari et al., 2022).

The results make it clear that both a* and b* values dropped during thermal processing, suggesting a decrease in red and yellow tones, whereas higher F_O values resulted in higher L* and whiteness values, showing greater lightness. These alterations imply a less colourful, duller appearance with extended processing. Maillard browning and pigment degradation brought in by higher temperatures and longer processing times are probably the cause of the colour intensity decrease (Bhattacharya et al., 1994; Majumdar et al., 2016; Dhanapal et al., 2016). Increased whiteness may be a sign of improved uniformity and sterility, but the loss of distinctive colour might reduce consumer acceptability, highlighting the need to strike a balance between heat intensity and visual quality.

The declining trend in hardness, gumminess, and cutting strength with increasing F_O values indicates significant softening of the fish paneer due to prolonged heat exposure. This can be attributed to the denaturation of myofibrillar and connective tissue proteins, leading to a weakened muscle structure (Rao & Patil, 2006; Gopinath et al., 2007). These findings are consistent with previous studies on thermally processed fish products, such as rohu in curry medium (Majumdar et al., 2014; Majumdar et al., 2015). While springiness showed a slight increase, suggesting internal matrix reorganisation, the stability of cohesiveness and adhesiveness across treatments implies some structural integrity despite thermal stress (Mallick et al., 2010). Overall, although thermal processing at higher F_O values ensures microbial safety, it adversely affects texture, especially hardness and gumminess, which are critical to consumer acceptance. Thus, optimising processing conditions is essential to balance food safety with desirable textural attributes.

The fish paneer curry in retort pouch demonstrated no microbial growth post-processing, confirming that the applied thermal treatment was effective in achieving commercial sterility. This outcome aligns with established standards for retort processing, which necessitates precise time-temperature control to eliminate pathogenic and spoilage microorganisms. Final process temperature of 121.1°C at F_0 6 was optimised for fish paneer curry processed in retort pouch based on the commercial sterility test, sensory evaluation, colour analysis and texture profile analysis of the finished product. Since the product passed the commercial sterility test, it can be said that the thermal process adopted was sufficient to attain commercial sterility and shelf stability of the product. This processing condition can serve as a basis which may be recommended for other value-added fish products.

Conflict of interest: No conflict of interest among the authors regarding this manuscript.

Author's contribution: SKC: Involved in analysis, investigation, data generation, manuscript draft preparation; BD: Conceptualization of the research, supervision, final draft editing; S: Manuscript draft preparation, data analysis and manuscript correction; PK: Result analysis, manuscript editing and correction; AS: Involved in research analysis and supporting throughout the research; SSN: Manuscript correction and graph preparation.

Data availability statement: Data set generated during the research will be available from the corresponding author upon reasonable request.

Use of artificial intelligence tools: During the preparation of this work, the author(s) used "QUILLBOT AI" to "reduce plagiarism and grammer check of the manuscript". After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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