



Effect of vacuum tumbling assisted marination on textural and sensory properties of deep-fried Indian white shrimp

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ABSTRACT

Effect of vacuum tumbling assisted marination on nutritional composition, texture, colour and sensory acceptability parameters of deep-fried Indian white shrimp (*Penaeus indicus*) was evaluated in this study. Peeled and deveined shrimp meat was subjected to traditional marination for two hours at room temperature as control (TM) and vacuum tumbling with a revolution of 8 rpm and vacuum pressure of 15 Hg for 5 min (VT 5), 10 min (VT 10) and 15 min (VT 15) were attempted. After the marination procedure, all the portions were deep-fried in sunflower oil at a controlled temperature of 180°C for 2 min. Vacuum tumbling assisted marination, especially VT 10 exhibited similar textural, colour and sensory characteristics when compared to TM. The proximate composition analysis indicated superior moisture and protein content for VT 10 than TM. In addition, VT 10 recorded approximately 45% lower oil uptake after frying and around 90% reduction in marination time. The study successfully established that vacuum tumbling assisted marination could produce ready to eat (RTE) deep fried product from Indian white shrimp which is superior to traditional marination in terms of processing time and oil uptake while uncompromising sensory acceptability.

Keywords: Deep-fried shrimp, Marination, Sensory evaluation, Textural changes, Vacuum tumbling

Introduction

Marinated and deep fried shrimp is a popular ready to eat (RTE) product among tropical consumers but yet little subjected to scientific evaluation. Marination in combination with frying creates characteristic flavour, texture and colour highly appreciated by food enthusiasts. Standardisation of critical parameters such as marination time, method, frying temperature and duration, significantly influences the sensory acceptability of the final product (Bahram *et al.*, 2014). Marination is a commonly used process to improve the functional and sensory characteristics of foods especially meat, by soaking, injecting or tumbling with liquid solutions composed of different components (Latif, 2011). It also improves meat quality, water-holding capacity and cooking yield with organoleptic properties such as tenderness and flavour (He *et al.*, 2015). It has been observed by Bauermeister and Mckee (2005) that in comparison with traditional form of immersion marination, vacuum tumbling promotes swift and steady pickup at controlled temperatures, facilitates marination of large quantity and a wide variety of meat within a short period.

Vacuum tumbling is a physico-chemical treatment process, involving meat rotation and agitation while in contact with metal ramparts and paddling in a drum like container (Kim *et al.*, 2012). Tumbling is usually performed under vacuum to avoid protein and lipid oxidation (Suman *et al.*, 2017). It has been also observed that marination is extensively complemented with vacuum tumbling in the production of cooked meat products as it improved the product quality considerably (Martin, 2012). Deep frying which fundamentally is a heat and mass transfer process (Voong *et al.*, 2019), usually follows marination and is the final and most important critical control point (CCP) before consumption. It also provides a distinctive permutation of flavour and texture properties that improve the overall quality and acceptability of the food product (Nunak and Schleining, 2011).

Physical processes such as vacuum tumbling assisted marination and thermal processes such as frying generates characteristic changes in texture, colour, biochemical composition and sensory acceptability of meat products especially seafood like shrimps with a tender profile. Fish meat has been subjected to vacuum tumbling studies

with beneficial marinate penetration effects (Mathias *et al.*, 2003; Kin *et al.*, 2009; Lombard and Lanier, 2011). It has been observed by Daryl (2012) that there has been only limited studies undertaken to evaluate the impact of vacuum tumbling on seafood products, which is attributed to their delicate muscle structure compared to other meats such as beef, pork and poultry. Textural and other property studies in heat-processed RTE Indian white shrimp and related species products are largely concentrated on sterilised products such as retort pouch (Mallick *et al.*, 2010; Majumdar *et al.*, 2017), dehydrated products (Nwaoha and Itoje, 2016) and coated products (Haghshenas *et al.*, 2013; Ojagh *et al.*, 2016; Tai-Yuan *et al.*, 2016). Daryl (2012), studied the effect of vacuum tumbling on the incorporation of phosphates in Gulf shrimp and observed that the tumbling process positively affects the penetration of the additive. Chouljenko *et al.* (2015) evaluated the effect of vacuum tumbling and inferred that chitosan solution combined with vacuum tumbling was effective at reducing microbial counts and lipid oxidation in frozen white shrimp (*Litopenaeus setiferus*).

To the best of our knowledge, the effect of frying on shrimp meat in association with vacuum tumbling assisted marination has not been studied previously. Thus, the present study aims to evaluate the effect of vacuum tumbling assisted marination in comparison with the traditional marination method on the texture, colour, composition and sensory characteristics of deep-fried shrimp. The observations shall be utilised for adapting a machine-assisted marination technique for the production of RTE fried products from shrimp with maximum consumer acceptability.

Materials and methods

Raw materials

Fresh specimens of Indian white shrimp *Penaeus indicus* (135±0.46 mm; 32.5±0.52 g) were procured from Cochin Fisheries Harbour and transported to the laboratory in iced condition, maintaining the temperature <4°C. The raw material was properly washed in chilled potable water to remove the adhering filth and then pre-processed into peeled and deveined (PD) form. The meat was then immediately taken for the study without any delay. Good quality ingredients for marination experiments were procured from a local hypermarket in Kochi, Kerala, India. Other reagents and chemicals used for the analysis were of analytical grade (Merck, Mumbai, India).

Preparation and application of marinades

A basic marinade was prepared by adding ingredients in percentage w/v of shrimp meat. To standardise the traditional marination time (TM), a preliminary study

with five-time periods was conducted *viz.*, 15 min (A), 30 min (B), 1 h (C), 1.5 h (D) and 2 h (E) of marination at room temperature. Room temperature was selected as the popular practice in Indian conditions especially for the preparation of RTE fried seafood products. For performing the tumbling process, a F-15 Flavour Maker 15 Lb. Vacuum Tumbler (Doug Care, USA) with a capacity of 12-15 lbs, a drum speed of 8 rpm and an internal vacuum pressure of 21 inches Hg was used. The shrimp meat was first divided into equal portions after the addition of marinade and subjected to traditional marination (2 h) and vacuum tumbling for 5 min (VT5), 10 min (VT10) and 15 min (VT15). The marinated shrimp was later deep-fried at 180°C for 2 min and subjected to sensory evaluation as per the 10 points hedonic scale method, IS: 6273 [II] (ISI, 1971).

Deep frying process

The vacuum tumbled and control marinated portions were subjected to deep fat frying in sunflower oil at 180°C for 2 min using an AMI-DFP-30LDx-3 Liter Electric Deep Fryer (American Micronic, India), with timer and variable temperature control.

Proximate composition

The proximate composition of the raw and fried shrimp samples was determined as per AOAC (2005) and expressed as gram per 100 g meat.

Frying loss

Frying loss was calculated according to the method prescribed by Xavier *et al.* (2017), using the following formula:

$$\text{Frying loss} = \frac{(\text{Weight of the deep-fried shrimp} - \text{Weight of raw shrimp})}{\text{Weight of raw shrimp}} \times 100$$

Texture profile analysis (TPA)

The TPA method proposed by Bourne *et al.* (1978) was used to objectively estimate textural differences between the treatments. Fried shrimp samples of uniform size were used for the analysis. A flat-ended cylindrical probe of 50 mm diameter with a 500 N load cell was used for the evaluation. The samples were subjected to double compressions of 40% of their original height with a crosshead speed of 0.1 mm s⁻¹ and a trigger force of 2N. Force by time data from each test was used to calculate average values for the parameters of TPA evaluation. The values for Hardness (N) 1 and 2 which is the maximum resistance at compression in the 1st and 2nd phase, Cohesiveness conceived as a fraction of the positive force area in the 2nd compression to that in the 1st compression of Area 2/Area 1, Springiness (mm) which is

the fraction of the time period of force input during the 2nd compression to that in the 1st compression of length 2/length 1, Gumminess (kgf) which is the product of hardness and cohesiveness, the force required to break down a semi-solid food for swallowing, Chewiness (kgf/mm) which is the product of Hardness, Cohesiveness and Springiness, the work required to chew a solid food into a state of readiness for swallowing, Stiffness (kgf/mm) which is described as the stress-to-strain ratio or modulus of deformation were determined as described by Bourne (1978). All texture measurements were done at 18±2°C and a minimum of five shrimp samples were used for each analysis. The TPA result was tabulated using the Nexygen software (AMETEK, Inc., Largo, Florida).

Measurement of colour parameters

Colour measurement of the fried shrimp samples was evaluated using Hunter lab MiniScan XE Plus spectrophotometer (Model No D/8-S, Hunter Associates Laboratory Inc., Reston, Virginia) with 8°C of geometry of diffuse and an illuminant of D65/10 degree. The calibration of the apparatus was conducted with black and white reference tiles before examination. The sample enclosed in a glass cell was positioned above the light sources and L^* , a^* , b^* values were recorded. The average values were calculated out of 5 readings. The CIELAB (L^* , a^* , b^*) colour scale was used for the study in which the L^* value is a measurement of the lightness of a sample and ranges from 0 (black) to 100 (white). The chromaticity dimensions, a and b give a comprehensible account of colour. The parameter a^* indicates redness with a positive value, grayness when zero and greenness with a negative value and b^* indicates yellowness with a positive value, grayness when zero and blueness with a negative value. Elevated values of a^* and b^* specify more saturation in colour.

Sensory analysis

Sensory analysis of deep-fried vacuum tumbled and control marinated shrimp portions were carried out by 10 panellists using a 10-point hedonic scale as prescribed in Indian Standard, IS 6273 [II] (ISI, 1971). The panellists were asked to score for colour, flavour, texture, overall appearance and overall acceptability of samples. A score of above 4.0 was considered as the margin for acceptance.

Statistical analysis

The results were expressed as mean±standard deviation of three replicates per sample and one-way analysis of variance using SPSS (Statistical Package for Social Sciences), version 20.0 for windows, was used for the statistical analysis of all the experimental parameters under the investigation. Differences between the treatment

means were determined by Duncan's multiple range tests. Results were considered statistically significant at $p \leq 0.05$.

Results and discussion

Optimisation of marination time

From the evaluation (Table 1), it was clear that the marination time of 2 h had scored the maximum overall acceptability score based on colour, flavour and textural property analysis. Accordingly, the traditional marination time of 2 h at room temperature was selected as control (TM).

Proximate composition of vacuum tumbled and marinated shrimp

The proximate composition indicates the basic nutritional status of the commodity. It also gives a basic idea regarding the effect of the processing method on the biochemical quality of the food. The proximate composition of raw *P. indicus* has been studied by Parisa *et al.* (2013) and the average moisture, lipid, protein and ash contents were 72.1, 4.32, 21.5 and 1.31 g per 100 g, respectively. The proximate composition analysis of vacuum tumbled shrimp portions (VT 5, VT 10 and VT 15) in comparison with traditionally marinated control (TM) indicated (Table 2) that all the parameters such as moisture, protein, lipid and ash content were significantly different ($p \leq 0.05$) between the treatments. VT 5 and VT 10 reported higher moisture content than TM while VT 15 was marginally lower than control. Regarding the protein content, all the vacuum tumbled portions reported higher values than the control (TM). Considering the lipid composition, VT 5 and VT 10 reported lower levels compared to VT 15 and TM. The ash content on the other hand was analogous between the treatments.

Parisa *et al.* (2013) observed that all cooking methods including frying decreased moisture content and increased protein content in *P. indicus*. Bordin *et al.* (2013) also reported that as frying is a dehydration process, the content of protein is increased due to the effect of concentration. Vacuum tumbling has been

Table 1. Optimisation of traditional marination time (TM) based on the sensory score of deep fried shrimp

No.	Colour	Flavour	Texture	Overall acceptability
A	3.50±0.52 ^a	6.60±0.51 ^a	3.50±0.56 ^a	3.80±0.53 ^a
B	6.40±0.51 ^b	6.90±0.51 ^b	6.40±0.50 ^b	6.30±0.53 ^b
C	7.50±0.52 ^c	8.40±0.51 ^d	7.00±0.50 ^c	6.88±0.52 ^c
D	8.60±0.50 ^d	8.20±0.50 ^c	8.50±0.50 ^d	8.33±0.50 ^d
E	8.40±0.51 ^d	8.20±0.52 ^c	8.80±0.44 ^c	8.66±0.50 ^c

Values are presented as mean±SD (n=10). Values bearing different superscripts in the same column are significantly different ($p < 0.001$). (A: Traditional marination for 15 min; B: Traditional marination for 30 min; C: Traditional marination for 1h; D: Traditional marination for 1.5 h and E: Traditional marination for 2 h).

Table 2. Proximate composition and frying loss of deep fried shrimps marinated by vacuum tumbling process and traditional marination

Treatment	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Frying loss (%)
TM	45.53±0.17 ^c	7.83±0.03 ^b	18.53±0.14 ^d	28.11±1.03 ^b	59.86±0.02 ^b
VT 5	49.46±0.48 ^a	7.92±0.03 ^a	10.28±0.09 ^a	32.34±0.54 ^a	60.20±0.37 ^{bc}
VT 10	47.71±0.10 ^b	7.35±0.04 ^c	10.86±0.07 ^b	34.08±0.16 ^c	60.24±0.08 ^c
VT 15	44.54±0.27 ^d	7.12±0.01 ^d	14.79±0.09 ^c	33.55±0.25 ^{bc}	57.40±0.04 ^a

Data presented as mean±SD (n=3). Values bearing different superscripts in the same column are significantly different ($p \leq 0.05$). (TM: Traditionally marinated; VT 5: Vacuum tumbling 5 min; VT 10: Vacuum tumbling 10 min and VT 15: Vacuum tumbling 15 min).

evaluated to have beneficial effects as it results in the formation of protein exudates which act as a protective layer during thermal processing minimising the loss of moisture (Suman *et al.*, 2017). The deep-frying process is observed to induce significant absorption of oil and a further increase in lipid content in fried food products which is considered as a negative aspect for human health (Primo-Martín *et al.*, 2010; Haghshenas *et al.*, 2014). In this regard, it is desirable to minimise the loss of moisture of the fried food products. The physical blending action of tumbling is observed to disrupt the microstructure of meat tissue which in turn causes swelling and thus enhances the ability of the meat to retain moisture (Offer and Trinick, 1983). The deep fried shrimp meat which was traditionally marinated (TM) reported a crude fat content of 18.53±0.14% while that of VT 5, VT 10 and VT 15 were 10.28±0.09, 10.86±0.07 and 14.79±0.09%, respectively. All the vacuum tumbled portions registered a lower crude fat content than the traditionally marinated control. The lowest was registered by VT 10, which was 45% lesser than TM ($p \leq 0.05$). This considerable reduction in oil absorption among vacuum tumbled portions may be due to the elevated protein exudates formation as reported by Suman *et al.* (2017) which protects the crust from loss of moisture as well as oil penetration. All the test portions including the control reported higher ash content compared to the ash content reported in raw white shrimp meat (Parisa *et al.*, 2013; Fernandez *et al.*, 2018). This may be probably due to the elevated salt penetration during marination with and without tumbling (Lamkey *et al.*, 1986; Dzudie and Okubanjo, 1999).

Frying loss of deep-fried vacuum tumbled marinated shrimps

Frying loss is represented as the weight decrease or weight increase during the frying process (Xavier *et al.*, 2017). All the treatments in the study showed a significant difference ($p \leq 0.05$). The loss is mainly due to dehydration and eventual moisture reduction caused by the heat from frying. The study indicated that irrespective of the tumbling process all the fried shrimp showed considerable frying loss (Table 2). A study conducted by Xavier *et al.* (2017) on coated fish products also observed considerable frying loss unless any water retention enhancing hydrocolloid

is applied with the marinade. Bauermeister and Mckee (2005) also in their experiment on chicken meat observed that irrespective of the tumbling process, the marinated and fried meat demonstrated identical loss after frying.

Texture profile analysis of deep-fried and vacuum tumbled marinated shrimp

Texture and colour of meat products are the most important quality parameters that impact consumer acceptance (Bishnoy *et al.*, 2017). Both vacuum tumbling and deep-fat frying are understood to generate significant changes in texture. The study conducted on firm meat such as chicken meat has demonstrated that vacuum tumbling for a shorter time (2 h) in comparison to traditional marination (6 h) resulted in superior tenderness scores and comparable flavour, texture, juiciness and overall acceptability scores (Singh *et al.*, 2018). This indicates the possibility of similar effects on tender meat such as shrimp for shorter durations of tumbling time. Vacuum tumbling also has been observed to increase marinade penetration and improve texture in smoked trout fillets (Mathias *et al.*, 2003) and halibut (Lombard and Lanier, 2011). Chouljenko *et al.* (2017) observed that vacuum tumbling assisted in increasing the penetration of nano-chitosan particles and improved the texture of cryogenically frozen shrimp. Cael (2012) also inferred that vacuum tumbling helped elevated absorption of phosphates in Gulf shrimp.

Deep fat frying is a thermal processing procedure ensuing denaturing of structural proteins resulting in changes in their water holding capacity and further alteration in textural properties. Gao *et al.* (2016) have observed that thermal denaturation results in significant denaturation of shrimp muscle proteins and modified its textural properties significantly. Mizuta *et al.* (1999) observed histological changes in collagen by thermal processing which induced noticeable changes in the muscle texture of prawn meat. The temperature responsible for denaturation of sarcoplasmic proteins, collagen and actin are estimated to be 54 to 58°C, 65 to 67°C and 80 to 83°C as observed by Tornberg (2005). Bordin *et al.* (2013) observed that deep-frying resulted in the creation of pores within the food surface. The intense heat results in rapid evaporation of water from

the surface creating pores and shrinkage leading to significant textural changes.

The TPA evaluation (Table 3) of vacuum tumbled (VT5, VT10 and VT15) and traditionally marinated control (TM) which were deep-fried in controlled temperature and duration revealed that there were significant differences ($p \leq 0.05$) among the treatments with respect to Hardness 1, Hardness 2 and Gumminess. While values of Cohesiveness, Springiness, Chewiness and Stiffness showed no significant difference ($p > 0.05$), hardness 1 and 2, of the VT 10 sample exhibited identical values with that of control (TM) while VT 5 and VT 10 were significantly different ($p \leq 0.05$). The increase in hardness of thermally processed shrimp meat is attributed to the denaturation and coagulation of myofibrillar proteins and collagen, which lose their water holding capacity (Mizuta *et al.*, 1999; Chalida *et al.*, 2008). Gumminess, the force required to break down a semi-solid food for swallowing is attributed to be associated with hardness (Haghshenas *et al.*, 2014) and in the present study showed identical values between VT 5, VT 10 and TM, while VT 15 showed a significantly different value. The TPA evaluation indicates that VT 10 is the ideal tumbling time for generating matching textural hardness and gumminess with traditional marination for 2 h. Other important textural properties such as Cohesiveness, Springiness, Chewiness and Stiffness showing no significant difference between the treatments also points out that a shorter duration of vacuum tumbling generates similar textural properties for white shrimp meat.

Colour parameters

The instrumental evaluation of colour (Fig. 1) indicated that TM and VT 10 showed almost identical L^* , a^* and b^* values. The entire test values were significantly different ($p < 0.05$) for L^* , a^* and b^* values. Similar observations regarding hardness and gumminess from TPA, VT 10 portion reported identical values with TM regarding a^* and b^* values, while all the three tumbled portions were identical to TM with respect to L^* values. The ideal colour for fried and other dry thermal processes like grilled commodities after marination or coating is expected to be golden brown which is caused by non-enzymatic browning involving an amino-carbonyl

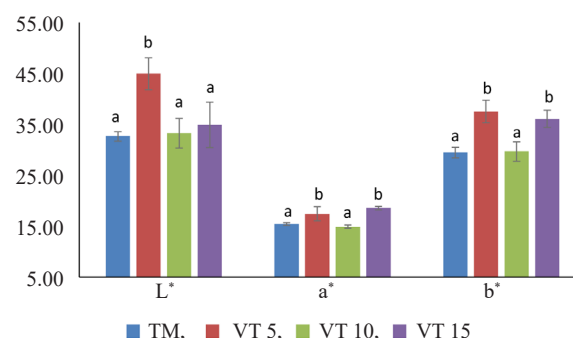


Fig. 1. Colour parameters of marinated and deep fried shrimps. (TM: Traditionally marinated, VT 5: Vacuum tumbling 5 min, VT 10: Vacuum tumbling 10 min and VT 15: Vacuum tumbling 15 min)

interaction (Mayumi *et al.*, 2011). It also depends on the temperature as well as the duration of pre-treatment (Giri *et al.*, 2013). It is also attributed to the lack of moisture in the capillary space of dehydrated shrimp meat through which carotenoid oxidising enzymes are transported which ultimately results in the formation of astaxanthins (Akonor *et al.*, 2016). The levels of L^* , a^* and b^* values in the present study indicate that the vacuum tumbled portions are processing identical golden brown colour expected from traditionally marinated and deep-fried shrimp products.

Acceptability of sensory attributes of deep-fried vacuum tumbled marinated shrimps

It has been observed that food cannot be evaluated solely based on instrumental texture or colour properties. Flavour, is a combination of taste and aroma which interacts and persuades one to like or dislike a food product (Chen and Engelen, 2012; Guichard *et al.*, 2017). The absence of receptors and saliva makes the instrumental analysis incomplete in completely understanding the food acceptance dynamics (Christian *et al.*, 2010; Peyron and Woda, 2016). Hence the organoleptic evaluations of food, especially a fried RTE product such as shrimp with characteristic features are important. The results of the sensory evaluation of vacuum tumbled shrimp portions (VT 5, VT 10 and VT 15) and traditionally marinated control (TM) are represented in Fig. 2. VT 10 and VT 15 were superior to TM with respect to flavour, texture, overall appearance and overall acceptability scores while

Table 3. Texture profile analysis (TPA) of deep fried shrimps marinated by vacuum tumbling process and traditional marination

Treatment	Hardness1(N)	Hardness2 (N)	Cohesiveness	Springiness (mm)	Gumminess (kgf)	Chewiness (kgf mm ⁻¹)	Stiffness (kgf mm ⁻¹)
TM	120.05±1.74 ^a	108.99±5.88 ^a	0.44±0.06	5.83±0.77	4.95±0.62 ^a	27.05±2.46	8.58 ± 0.13
VT 5	140.25±4.55 ^b	123.74±5.72 ^b	0.40±0.02	5.21±0.82	5.76±0.45 ^a	29.89±4.15	8.78±1.59
VT 10	120.93±7.46 ^a	111.49±1.58 ^a	0.41±0.06	5.22±1.33	5.08±0.96 ^a	27.32±10.90	7.96±1.70
VT 15	160.40±5.25 ^c	141.38±4.56 ^c	0.42±0.03	4.14±0.84	7.14±0.33 ^b	29.64±6.88	7.02±1.29

Data presented as mean±SD (n=6). Values bearing different superscripts in the same column are significantly different ($p \leq 0.05$).

(TM: Traditionally marinated control; VT 5: Vacuum tumbling 5 min; VT 10: Vacuum tumbling 10 min and VT 15: Vacuum tumbling 15 min).

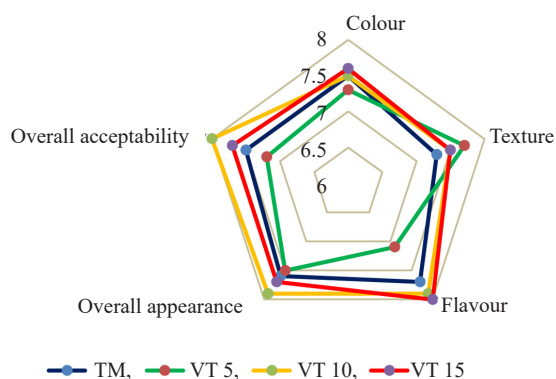


Fig. 2. Sensory characteristics of marinated and deep fried shrimps.(TM: Traditionally marinated, VT 5: Vacuum tumbling 5 min, VT 10: Vacuum tumbling 10 min and VT 15: Vacuum tumbling 15 min)

identical regarding colour. VT 5 was inferior to all other treatments including control but showed an increased score regarding texture. The sensory evaluation study of deep-fried, vacuum tumbling assisted marinated white shrimp meat and traditionally marinated control established that the vacuum tumbling especially VT 10 process produced a product with identical or even more superior sensory characteristics when compared to traditional marination.

Evaluation of the effect of vacuum tumbling assisted marination on the textural, colourimetric, biochemical and sensory acceptability of deep-fried Indian white shrimp demonstrated that the vacuum tumbling in general and especially for 10 min (VT 10) generated considerable beneficial effects for the product. The VT 10 process produced a fried shrimp product with superior moisture and protein content while effectively reducing the oil uptake and further increasing the nutritional and health quotient of the product. The VT 10 process also reported identical colourimetric and textural parameters on par with the traditional marination process within a considerably lesser duration of marination time. The study categorically ascertains that the vacuum tumbling process could be adopted as a CCP for the production of deep-fried shrimp RTE products adding lesser processing time, lower oil uptake and better sensory acceptability qualities to the process.

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