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Estimation and management of shrimp processing waste in organised shrimp processing sector in India: Opportunities and challenges

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Abstract

This study was conducted to estimate the magnitude of processing waste produced in the organised shrimp processing sector of India in order to assess the opportunities available for its utilisation. The estimation of magnitude of shrimp processing waste was based on secondary data and its management was based on primary data collected through surveys at processing plants. The organised shrimp processing sector in India generated a large volume of shrimp processing waste at a growth rate of 12% during 2000-2018. The quantity of shrimp processing waste generated ranged from 1.2 to 4.6 lakh t, which can be utilised to produce 6712 to 27453 t of chitin alone. However, our study indicated that 75% of the total waste generated remained either unused or managed unscientifically, even when there is huge demand for chitin and its derivatives in the domestic as well as in the international market. The case studies from chitin producing plants revealed that some costs were incurred in the procurement of shrimp processing waste as a secondary raw material for the production of chitin. Thus forming a link between shrimp processing plants and chitin and its derivatives producing plants would improve the supply of quality raw material and improve utilisation of processing wastes. The number of chitin and its derivatives producing plants are too few in India to fully accommodate the large volume of shrimp processing waste generated every year. Therefore, infrastructure development in the chitin and associated industry with active support from government organisations to overcome the burden of initial investment is needed urgently, which can in turn encourage entrepreneurship development in the sector for diversified applications.

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Introduction

The Indian seafood export industry has been growing quickly over the past decades in terms of export quantity and foreign exchange. India has exported 17.4 lakh t of fish and fishery products worth USD 8094 million in 2022-23. Shrimp based products are the major contributors to the total seafood export from India, both in terms of quantity and value, with 7.2 lakh t of frozen shrimp export in 2022-23. This accounts to almost 45% of total export quantity in 2022-23 (MPEDA, 2023). Shrimp processing generates enormous quantity of waste from the organised shrimp processing sector in India, which could be 40-60% of the whole shrimp weight (Anon., 2005). Shrimp processing waste is thought to create an environmental and health nuisance to terrestrial and aquatic inhabitants if not treated and discarded scientifically (Xu *et al.*, 2013).

One way to manage shrimp processing waste is to develop value added byproducts, considering that it is a secondary raw material that can be used for developing high-end value added byproducts (Mathew, 2010). Chitin and its derivatives are one of the major value added products, which can be developed using shrimp processing discards (Madhavan and Nair, 1974). Chitin can be used as a base material to develop other associated derivatives like chitosan, carboxymethyl chitosan, glucosamine hydrochloride and chitooligosaccharides, which has high potential for use in nutraceutical, food, textile, paper, pharmaceutical and agriculture sectors (Kalpana *et al.,* 2015; Hamed *et al.,* 2016).

One of the major problems in chitin production is the bulk usage of different types of chemicals in the production process. The treatment of effluents in the end process of chitin production is still considered as a major problem as the discharge of chemical residues directly to natural water bodies causes health issues to both humans and aquatic animals (Abhilash and Saleena, 2011; Munoz *et al.,* 2018). The immediate solution to minimise the levels of chemical contents in the effluent residues is the implantation of chemical effluent treatment plants (ETP). This would bring down the levels of chemicals within the permissible limits as prescribed by government or nodal agencies (MoEF&CC, 1993). Another method is to replace the chemical process with enzymatic process, but again sustainable technological developments have to occur to confirm with yield and other qualities of chitin and associated products in the enzymatic process (Caruso *et al.,* 2020). Understanding the existing process flow of chitin production unit gives an idea about the utilisation of raw material and technology being used for the production of the end product.

The demand for chitin in the global market is expected to reach 2492 million USD in 2027 from 893 million USD in 2017, which is nearly 3.3 times growth in terms of value (FMI, 2020). This indicates that chitin and its derivatives are going to have a greater demand in the future in view of its potential applications in different fields. As India is progressing towards economic development and doubling farmer's income, much emphasis has been laid on 'wealth from waste'. To improve shrimp processing waste utilisation in the Indian context, estimation of the quantity of shrimp processing waste generated annually in the organised shrimp processing sector is essential along with an understanding of its management. The present study was undertaken to estimate the availability of secondary raw material from the organised shrimp processing sector in India for the development of chitin and associated derivatives along with a pathway analysis of shrimp processing waste discard, procurement, process and development of value added byproducts through different case studies.

Materials and methods

Shrimp is mainly pre-processed as head-on and shell-on (HOSO), headless and shell-on (HSO), headless and shell-less (HS), peeled deveined (PD) and peeled un-deveined (PUD) forms. Species-wise secondary data on shrimp exported under these categories were collected from Marine Products Export Development Authority of India (MPEDA) for the period 2000 to 2018. The year-wise quantity of shrimp processing waste generated was estimated based on the proportion of waste generated under different categories of shrimp products, which is given in Table 1. Total shrimp processing waste was obtained by summing up the waste generated for different types of processed shrimp products.

The compound growth rate of total quantity of shrimp processing waste was computed using Malthus model given in Equation (1). The parameters were estimated by Levenberg-Marquardt algorithm using ordinary least square (OLS) method given in SAS 9.3. The goodness of fit of the model was assessed by coefficient of determination (R2) and root mean square error (RMSE).

$$Y_t = Y_0(1+r)^t \; e_t \quad \text{.......................................}(1),$$

where 'Y_t' is the total shrimp processing waste at time 't', 'Y_0' is the initial value, 'r' is the growth rate, t is the time and e_t is the error term assumed to follow normal distribution with mean '0' and constant variance σ^2 (Seber and Wild, 2003). The estimated parameters of the fitted model were then used to compute the expected values in the future.

To understand the shrimp processing waste management in seafood processing plants, purposive sampling was employed to select the shrimp processing plants from Kerala, Andhra Pradesh and Gujarat. The shrimp processing waste management practices of selected processing plants were assessed by a questionnaire-based survey. The questionnaire was designed, developed and validated through a pilot study and primary data on different waste management practices were collected from 25 shrimp processing plants. Data on different modes of shrimp processing waste management and demand for shrimp processing waste as a secondary raw material were collected, compiled, tabulated and statistically analysed using SAS 9.3.

Shrimp processing waste is considered as a raw material for the production of chitin and its derivatives including chitosan, chitooliogosaccharides, glucosamine hydrochloride, glucosamine sulphate and other salts of chitosan, but the same is not used to its potential for the development of value added byproducts. To understand the existing pathway of chitin supply chain, a few case studies based on survey of two chitin, one chitosan and one glucosamine producing plants were conducted to understand the production process and post-production residue management. Information like mode of procurement of raw material, quality of raw material, mode of transportation and type of effluent treatment plant in place were incorporated in the questionnaire.

Results and discussion

The estimated annual shrimp processing waste ranged between 1.2 and 4.6 lakh t from organised shrimp processing plants in India during the period of 2000-2018. During the year 2000, the major pre-processed shrimp item was HL, which generated maximum share of processing waste (99%). Later, the composition changed to PD and PUD items, together accounting for almost 61% of total shrimp processing waste followed by HL (22%) and HLSO (16%) by the year 2018. The total quantity of shrimp processing waste along with percentage contribution by different processed items is depicted in Fig. 1.

The quantity of shrimp processing waste generated during the period 2000 to 2010 was almost stable except for the year 2005,

Table 1. Waste generation profile of different process of shrimp products

Shrimp products	Proportion of waste*
Head-on and shell-on (HOSO)	0.00
Headless and shell-on (HSO)	0.35
Headless and shell-less (HS)	0.50
Peeled deveined (PD)	0.50
Peeled un-deveined (PUD)	0.50

*The proportion of waste generated is calculated for processing one kg shrimp. The proportion was arrived by separately quantifying the parts and calculating based on the style of processing.

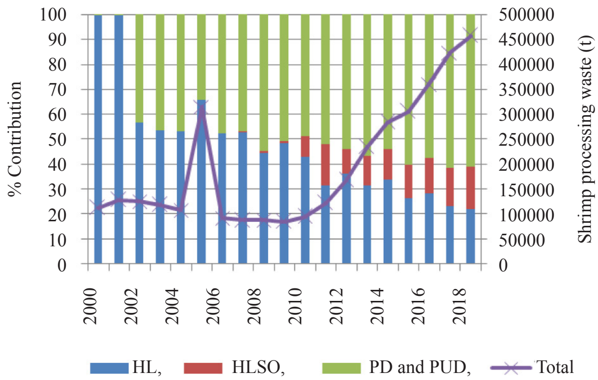

Fig. 1. Quantity of shrimp processing waste generated annually (product and year-wise)

but later exhibited exponential growth during the period 2010 to 2018, which may be attributed to the introduction and expansion of the culture of pacific white shrimp, *Penaeus vannamei* in India. The R^2 value of the fitted model was 0.86 and the corresponding RMSE value was 70720. The R^2 value was close to 1, which indicates that the model fitted significantly well to the data. The average compound growth rate of shrimp processing waste was estimated to be 12% per year (Table 2).

The yield of chitin from fresh shrimp shell waste is expected to be 4-6% of weight of the raw material (Mathew, 2010) and based on the estimates from the study, it was assessed that large quantity of raw material was available to produce about 27453 t of chitin alone. Based on the estimated parameters of the fitted model, the forecasted values indicated that about 4.95 to 9.78 lakh t of shrimp processing waste will be potentially available in India (Table 3) during the period 2019-2025.

The major species of shrimps processed in the organised shrimp processing sector in India were *Metapenaeus affinis, Metapenaeus monoceros, Parapenaeopsis stylifera, Penaeus vannamei, Solenocera crassicornis* and *Penaeus indicus*. Based on the production capacity, the average quantity of shrimp processing waste generated ranged from 240 to 12000 t per year, which indicates that huge amount of

Table 2. Estimated regression coefficients with R^2 and RMSE

Parameters	Estimates		R^2	RMSE
	Values	Standard error		
Y_0	51354	15690	0.86	70720
r	0.12	0.02		

Table 3. Forecasted values of shrimp processing waste generated

Year	Forecasted values (t)	95% Confidence limits	
		LCL	UCL
2019	495376	70641	1643734
2020	554821	75586	1906731
2021	621399	80877	2211808
2022	695967	86538	2565697
2023	779483	92596	2976209
2024	873021	99078	3452402
2025	977784	106013	4004786

LCL- Lower confidence limits; UCL - Upper confidence limits

shrimp processing waste is being generated every year in India. The study revealed that 23% of shrimp processing plants sell shrimp processing waste as a secondary raw material to the industry for the development of value added byproducts, whereas 64% of plants manage the shrimp processing waste through contractors or agents. More details are given in Fig. 2. The results also revealed that about 41% of plants see a demand for shrimp processing waste as a secondary raw material. About 52% of plants expended some cost in the management of shrimp processing waste. The major problems in shrimp processing waste management reported are: Storage and icing of shrimp processing waste, Less demand as a secondary raw material, No proper guidelines for waste management including transportation, Smell during drying of waste and Additional cost involved in storage.

Primary data from the two chitin producing plants were collected and both have adopted conventional demineralisation and deproteinisation process using acid and alkali, respectively for the production of chitin. The generic process flow of chitin production adopted by the plants is given in Fig. 3.

Both the firms collected fresh shrimp processing waste directly from shrimp processing plants without assessing the quality of raw material. The average operational cost (price of shrimp processing waste, transportation, chemicals, electricity and manpower) to process 1 t of shrimp processing waste in order to produce chitin ranged from ₹1700 to 3000. The developed product, chitin, was mainly intended as a raw material for nutraceutical and pharmaceutical applications of both domestic and international markets. The inputs involved for the commercial production of chitin were acid, base, solvents and water. The plant has to utilise 8000 to 10000 l of bore well water to process 1 t of raw material for the production of chitin. Water usage was mainly for making acid and alkali solution for demineralisation and deproteinisation process and washing of the residual chemicals. The processed shell was then sun dried to obtain chitin. The residues from chitin production were treated using effluent treatment plants before the treated water is discharged.

Primary data on one chitosan producing plant from Kerala was also collected. The firm first converts the shrimp processing waste into chitin, which is used as a raw material for the production of chitosan and follows standard alkali (NaOH) process with a capacity to process upto 340 kg chitin. On an average 38235 l of alkali is required to process 1 t of chitin with an approximate input

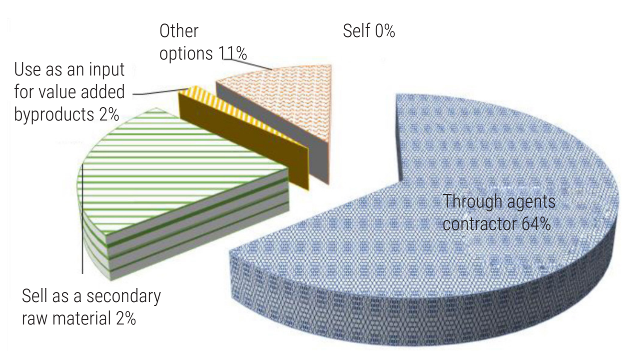

Fig. 2. Percentage-wise mode of shrimp processing waste management by processing plants (n=25)

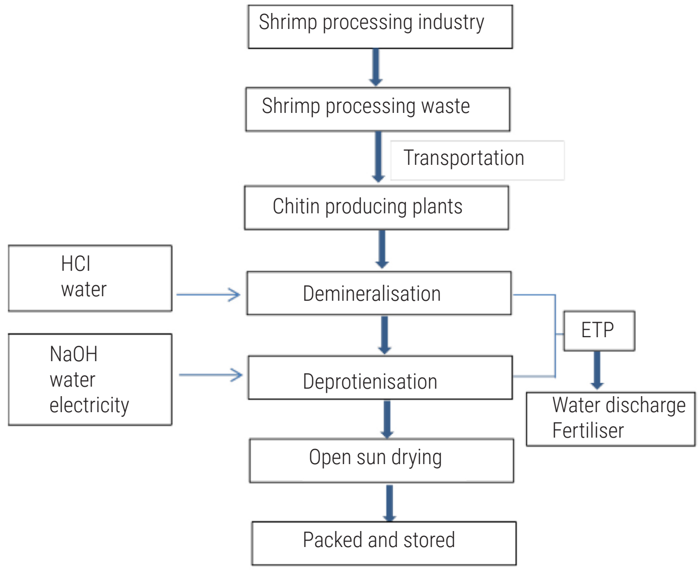

Fig. 3. Process flow of chitin production by the plants

cost of ₹3,25,000 with three manpower. Potable water was used to wash the treated material with almost 7 washes, which requires almost 205882 l of water. The product is dried under sun in a shed with transparent cover on the top for 36 h. The chitosan produced is assessed for quality parameters like viscosity, moisture, ash, turbidity, degree of de-acetylation and molecular weight. The alkali is usually recycled in chitosan production otherwise used as input upon dilution in deproteinisation process during chitin production.

Glucosamine plant in Andhra Pradesh which was surveyed in this study, procures either shrimp processing waste directly from shrimp processing plants and converts into chitin or chitin directly as a raw material for the production of glucosamine. The chitin was then transported to glucosamine production unit after assessing the quality parameters like calcium content. The raw material is being used to make two different products namely, glucosamine hydrochloride and glucosamine sulphate. There is a demand for the product from both domestic and international markets mainly for nutraceutical and pharmaceutical applications. The average cost for production of 1 kg glucosamine hydrochloride of United States Pharmacopeia (USP) grade was ₹700 and European Pharmacopoeia (EP) grade was ₹840, respectively. The average cost for production of 1 kg glucosamine sulphate of USP grade was ₹620 and EP grade was ₹660. The inputs used for the production were acid, base, charcoal and solvents and average cost of inputs for production of 1 kg glucosamine hydrochloride was ₹520 plus documentation and certification cost. The average quantity of water consumed for 1 t glucosamine hydrochloride production was 3000 l of purified water from reverse osmosis system. The product was dried in fluid bed drier and quality parameters like yield, moisture, ash and degree of hydrolysis of the final product were assessed. On an average, 3 days of 16 skilled and 5 non-skilled staff manpower was required for processing 1 t of raw material for the production of glucosamine hydrochloride.

The questionnaire-based survey results revealed that nearly 75% of shrimp processing waste is simply unutilised and discarded unscientifically which creates lot of environmental problems. The main reason was less demand for shrimp processing waste as a secondary raw material for the production of value added byproducts. Government of India (GoI) is emphasising on flagship programmes like "Wealth from Waste" for better and effective utilisation of waste (Niti Ayog, 2019; ICAR, 2020) and organisations like MPEDA promote processing of edible and non-edible products from shrimp waste (MPEDA, 2020). According to FMI (2020), the demand for chitin and its derivatives in the global market is expected to increase 3.3 times by 2027. This indicates that value added byproducts from shrimp processing waste will have greater demand in the future. Despite this, the chitin and associated industry in India have taken only a back seat in the past, as evidenced by the too few numbers of organised industries for the production of chitin and its associated derivatives in India.

To improve the utilisation of shrimp processing waste, the infrastructure for the production of chitin and its associated derivatives needs to be created, implemented, streamlined, improved and strengthened with due support from government schemes. Development of infrastructure incurs high initial cost, which may be a bottleneck for the development of entrepreneurship. The support through different government schemes would give confidence to the entrepreneurs to venture into commercial production of chitin and associated derivatives. The existing chitin production industry completely depends on the chemical process, which results in a lot of chemical residues at the end of the process. To manage this chemical residue, an efficient effluent treatment system is required (Benhabiles *et al.*, 2012; Abdulkarim *et al.*, 2013). Another problem in the conventional chitin producing unit is the huge amount of water use in the washing steps due to the chemical process. However studies have reported on environmentally friendly and economically viable chitosan production process, for *e.g.* from Ecuador (Riofrio *et al.*, 2021). An alternate solution to these problems is the replacement of the chemical process with an enzymatic process or a hybrid process, which confines to the yield requirements and other quality parameters of the end product as pointed out by Jo *et al.* (2008) and Sorokulova *et al.* (2009). Though, some research activities have taken place in this area by several researchers (Zhou *et al.,* 2010; Teng 2011; Kaur *et al.,* 2012; Arbia *et al.,* 2013; Mohammad *et al.,* 2013) and it should be further explored and strengthened to motivate more people to adopt these technologies. It was also witnessed from the survey that the eagerness to adopt newer technologies like enzyme employment in deproteinisation of shrimp waste is very low. Thus introducing newer technologies and encouraging the industrialists to adopt by organisisng teaching and training programmes is very essential.

In contrast, the results from the case study of two chitin plants indicates that there was some input cost involved in the procurement of shrimp processing waste as a secondary raw material for the production of chitin. So, apart from development of infrastructure and alternative process methods, there should be a centralised system to collect shrimp processing waste from the processing plants without affecting the quality of raw material to at least meet the minimum demand by existing chitin producing plants and also for the plants expected to come up in the future. Since the quality of final product is affected by initial quality of raw material (Renuka *et al.,* 2020), there should be formulation and implementation of standard operational procedures (SOP) for handling, storing and transportation of shrimp processing waste. Quality consciousness of the shrimp processors needs to be extended up to the processing waste, as their 'waste' is a 'raw material' for downstream processors.

Another issue would be the market availability of commercially produced chitin and associated derivatives. The major market of chitin and associated derivatives is oriented towards nutraceutical and pharmaceutical applications (Kalpana *et al.,* 2015). This needs to be diversified to other fields like agricultural, textile, paper, food and feed applications as pointed out by several workers (Aranaz *et al.* 2009; Pillai *et al.,* 2009; Dutta *et al.,* 2012; Zeng *et al.,* 2012). India, being an agrarian country, the chitin and associated derivatives based growth stimulants, nutrient formulations and pest control systems intended for agricultural production system would increase the demand for chitin and related products (Abu Hassan *et al.,* 2009; Dutta *et al.,* 2012). However, there exist fewer products having chitin derivatives in the formulation for agricultural uses. Fish production from aquaculture in India has superseded capture fish production and consequently, there is high demand for fish feed in aquaculture, wherein feed formulations from shrimp processing waste can be developed as it is also a good source of protein. In addition to the nutritional benefits, the shrimp protein or its derivatives (hydrolysates) could act as feed attractants. Similarly, Olsen *et al.* (2014) pointed out the opportunities to use certain byproducts from fish and shellfish processing waste directly as a food in the form of aquaculture feed. So, shrimp processing waste cannot be considered as a waste, but as a secondary raw material with huge potential for the development of value added byproducts.

The study revealed that only 25% of the total shrimp processing waste generated every year is being utilised for the development of value added byproducts, whereas 75% of the total shrimp processing waste is being unutilised. The supply chain analysis of chitin production units revealed that they procure raw materials from shrimp processing plants without assessing the quality of raw material. The process involved usage of huge amount of water during the process of chitin production especially during washing cycles as a consequence of chemical treatment to remove the residual alkali and acids. To the best of our knowledge, no chitin production unit employed advanced technologies like using enzymes, biofermentation or any other biotechnological approach which are assumed to be environmental friendly. The products developed are mainly intended for nutraceutical and pharmaceutical applications. There is need for product diversification to attract more entrepreneurial development in the chitin and chitin derivative industries

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