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Original article

From Waste to Wealth: A Mixed-Methods Study on the Challenges and Opportunities for Chitin Extraction in Oman's Shrimp Processing Industry

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Abstract

The volume of by-products produced by the shrimp industry in the Sultanate of Oman is approximately 6,000 tonnes annually, posing environmental risks while representing a lost economic opportunity. These by-products, contain a lot of chitin that can also play an important role in the Oman's Vision 2040, as far as the circular economy and economic diversification are concerned. This study employs a mixed-methods approach, combining quantitative surveys of 373 fishermen and qualitative interviews with five, to evaluate the sector's readiness, current preservation and extraction practices, and the key barriers hindering valorization.

The quantitative survey of 373 fishermen and qualitative interview of five production managers, The mixed-methods approach used in this study represents a key methodological strength, as it enables a comprehensive understanding by integrating quantitative and qualitative insights. The quantitative findings indicated that the mean scores of capacity (mean = 3.18), waste conservation (mean = 3.23), and extraction capacity (mean = 3.04) are not high, and this is very opposite to the high level of perceived barriers (mean = 3.57). These qualitative data support a high preference for freeze-drying as the method of preserving the quality of chitin that is economical but viable in comparison with other less efficient techniques, such as hot air drying (60 o C). Other environmental issues that have been linked with the practice of chemical extraction include wastewater pollution. These obstacles are the absence of a regulatory environment and insufficient financing. In conclusion, technological, regulatory, and financial barriers restrict the use of shrimp by-products in Oman. It suggests what is to be recommended on how to develop an effective regulatory framework to provide support on high-tech dry processing (freeze-drying), to invest in research to develop other more sustainable extraction methods (enzymatic hydrolysis), and to convert this waste source into a strategic resource.

Keywords: Shrimp By-Products, Valorization, chitin, Chemical Extraction, Sustainability

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INTRODUCTION

Over the last few years, the sustainable shrimp industry has gained growing significance in the global arena, showing significant progress and an increase in the production of aquaculture (Hosney et al., 2022). The substantial shell waste generated by shrimp aquaculture constitutes a significant environmental issue, given its slow biodegradation and the resulting long-term ecological consequences (Rashmi et al., 2016). By-products, constituting approximately 40–50% of total shrimp weight, are a rich source of chitin, a versatile biopolymer with applications in pharmaceuticals, food, cosmetics, and environmental technologies (Olatunde & Benjakul, 2020). The world is working towards the valorization of these by-products to solve food waste, minimize environmental pollution, and promote economic sustainability (Socas-Rodríguez, 2021). The functional characteristics of chitin, including biocompatibility and antimicrobial activity, are key factors that contribute to its application in industry but are extremely sensitive to processing, especially drying and extraction (Ghorbel-Bellaaj et al., 2018). Regardless of the increased focus on marine by-product valorization, optimization of these processes under the conditions of resource scarcity is under-researched.

The shrimp industry has produced an estimated 6,000 tons of by-products every year in the Sultanate of Oman, which is mainly tiger, white, and Indian shrimp, with the support of a robust aquaculture sector producing more than 4,500 tons of shrimp annually (Ministry of Agriculture, Fisheries Wealth, and Water Resources, 2023). Among such by-products are shells and heads that are usually thrown away, aggravating the environment while wasting potential economic gains. Recovery of chitin by processing shrimp waste may align with Oman's Vision 2040 goals of Oman's sustainable economic diversification. Nevertheless, the effects of drying processes (e.g., freeze-drying, hot air drying) and extraction (e.g., chemical, biological) on the functional properties of chitin, including porosity and molecular integrity, are not well known in the Omani context.

Considering the literature in the present era, we observe that processing parameters are crucial in the quality of chitin. As an illustration, high temperatures of drying can lead to the destruction of the molecular structure of chitin and the inability to use it in high-value products (Yuan et al., 2019). Freeze drying does not modify the properties of chitin, but it is highly costly to commercialize in the third world countries (Silva et al., 2018). In addition, another problem that contributes to the absence of valorization in Oman is technological infrastructure, regulatory uncertainty, and unawareness of the industry. Such processes and dilemmas in processing of shrimp in Oman have not been examined in an integrated manner which is a gap in knowledge. In this study, the researcher aims to evaluate the current practice and potential of the valorization of by-products of shrimps into chitin and the identification of the most critical technological, regulatory, and financial challenges that can hinder the process in the Sultanate of Oman. By means of surveys of fishermen and interviews with experts in the industry, a mixed-method design was applied in the study to evaluate the preparedness, waste conservation system, extraction techniques, and challenges of valorization of Oman in this regard. The results aim at informing

sustainable measures to establish a chitin-based industry, as part of the economic and environmental goals of Oman.

The unique contribution of this study is the employment of a mixed-methods framework analyses the technological, regulatory and financial aspects of chitin production in the shrimp processing industry in Oman. To our knowledge this study is the first to analyze in detail conservation and extraction scheme, and associated regulatory and financial limitations, within the Omani shrimp processing industry.

MATERIAL and METHOD

Study Population and Sample

This study targeted two population groups in the Sultanate of Oman: the 20.472 shrimp fishermen are mostly concentrated in the Al Sharqiyah and Al Wusta governorates, and production managers from 14 shrimp processing companies. A randomized controlled sampling was used to select a sample of 373 fishermen based on the sample size formula introduced in the book by Cochran, which gave a 95% confidence level and a 5% margin of error, which gives enough statistical power to represent the population (Cochran, 1977).

Concerning the processing companies, The sample was purposively selected from five senior production managers with prior experience in shrimp by-products, ensuring they possessed in-depth insight into industry practices. Although the sample size may appear limited, qualitative research does not aim for statistical generalization but rather for data saturation—that is, the point at which no new meaningful information emerges and further analysis yields diminishing returns. In this study, saturation was reached after five separate interviews, during which key themes and topics began to recur. This approach is consistent with established qualitative research guidelines, which suggest that a sample of 5–10 participants can be sufficient for exploratory studies, particularly when participants are highly knowledgeable experts involved in developing core infrastructure within a specialized sector (Braun & Clarke, 2012).

Data Collection Instruments

Questionnaire

A structured questionnaire was developed to evaluate four dimensions critical to shrimp by-product valorization in the Sultanate of Oman: (1) readiness to valorize shrimp by-products, (2) shrimp by-product preservation processes, (3) extraction and functional properties of chitin, and (4) challenges hindering valorization. The questionnaire consisted of two parts: Part 1 collected demographic information (gender, years of experience, specialization, job title, and governorate), and Part 2 comprised 23 statements across the four dimensions, rated on a five-point Likert scale (1=strongly

disagree, 5=strongly agree). Items were adapted from prior studies on marine by-product valorization (Olatunde & Benjakul, 2020) and tailored to the Omani context through expert consultation.

A pilot test involving 30 fishermen was conducted to assess the clarity of the questionnaire items and the reliability of the measurement instruments. This sample size is consistent with methodological recommendations, which suggest that 20–30 participants are sufficient for preliminary reliability testing (Bujang, Omar, and Baharum, 2018).

Internal consistency was evaluated using Cronbach's alpha coefficient. In addition, construct validity was assessed through Pearson correlation coefficients between individual items and their corresponding dimensions.

Semi-structured Interviews

Semi-structured interviews were conducted with five production managers to gain in-depth insights into the effects of drying and extraction processes on chitin quality and barriers to valorization. A qualitative sample of five production managers was purposively selected based on their expertise. This size was deemed sufficient to achieve data saturation on industry practices and barriers within the Omani context (Braun & Clarke, 2012). A guide with 10 open-ended questions was developed, covering topics such as current preservation practices, preferred technologies (e.g., freeze-drying vs. hot air drying), environmental impacts of chemical extraction, and regulatory challenges. Questions were informed by the literature (Ghorbel-Bellaaj et al., 2018) and validated by a review committee, achieving 80% consensus on clarity and relevance after two rounds of revisions.

The audio-recorded interviews were carried out with the consent of the participants and were conducted in Arabic, and the transcripts were translated into English by a certified translator and checked by another reviewer.

Procedures

The period of data collection was between January and March 2024 in the governorates of Al Sharqia and Al Wusta. The fishermen received questionnaires in the field, of which 373 of the responses were valid (out of 377) after discarding the incomplete questionnaires. Face-to-face interviews were also carried out and recorded using audio information with the consent of the participants and then transcribed verbatim (Silva et al., 2018; Ghorbel-Bellaaj et al., 2018).

Data Analysis

The Statistical Package of the Social Sciences (SPSS, version 26) was used to analyze quantitative data from the questionnaires. Responses were summarized by calculating descriptive statistics (frequencies, percentages, means, and standard deviations). Responses were summarized by calculation of descriptive statistics (frequencies, percentages, means, and standard deviation). The responses on the Likert scale were grouped into 1.00–1.80 (very low), 1.81–2.60 (low), 2.61–3.40

(moderate), 3.41–4.20 (high), and 4.21–5.00 (very high) categories. Pearson correlation coefficients were the internal consistency measure of reliability, as well as the alpha of Cronbach, which was the measure of instrument reliability. The Likert scale answers were classified into five interpretive scales (very low to very high) in accordance with the methodological guidelines of the Likert-type data (Boone and Boone, 2012; Koo and Yang, 2025).

The thematic analysis framework by Braun and Clarke (2012) was used to analyze the qualitative data of interviews. This was done in the following manner: (1) getting acquainted with the data by reading it over and over again, (2) coding the answers into meaningful units, (3) categorizing the codes into a theme, (4) revising the themes against raw data, (5) naming and defining the themes, and finally, (6) putting together a narrative report. Two independent researchers cross-validated the themes to be reliable.

Ethical Considerations

The study was approved by the Ethics Committee of University of Carthage, Institut National Agronomique de Tunise, PV-IAA10112025. Informed consent was obtained from all participants, ensuring anonymity and confidentiality. Participants were informed of their right to withdraw at any time without consequences.

RESULTS

Reliability and Validity Analysis

The results of the pilot test are presented in Table 1. Cronbach's alpha coefficients ranged from 0.827 to 0.867 for three of the four dimensions. However, the dimension related to shrimp by-product preservation processes yielded a lower reliability coefficient ($\alpha = 0.383$).

Furthermore, Pearson correlation coefficients between items and their respective dimensions ranged from 0.716 to 0.856, all statistically significant at $p < 0.01$.

Table 1. Dimensions and number of Items of the questionnaire

Dimension	Number of Items	Example Item	Cronbach's Alpha
Readiness to Valorize Shrimp By-Products	6	Oman has sufficient infrastructure for shrimp by-product valorization."	0.867
Shrimp Waste Preservation Processes	5	Freeze-drying is commonly used to preserve shrimp waste in my region."	0.3834
Extraction and Functional Properties of Chitin	6	"Chemical extraction methods ensure chitin purity."	0.827
Challenges Hindering Valorization	6	"Lack of investment hinders shrimp by-product valorization."	0.851

Note: Items were rated on a five-point Likert scale (1=strongly disagree, 5=strongly agree).

Table 1 shows that Cronbach's alpha coefficients are high (0.827-0.867) in three of the four dimensions, indicating high internal consistency in the instruments.

Study Population

Data in table 2 refers to a summary of the human characteristics of the quantitative sample. Most of the sample (52.3%) had 5 to 10 years of experience and were employed in the shrimp import and export (40.2%), waste management jobs (34.6%), and in the Ash Sharqiyah Governorate (57.4%). The specialization results showed that 24.1% of those employed in this sector work in shrimp fishing, 35.7% in shrimp farms, and 40.2% in import/export. This distribution reflects the economic and geographical diversity of Oman's shrimp industry.

Table 2. Demographic Characteristics of the Quantitative Sample (n=373)

Variable	Category	Frequency	Percentage (%)
Years of Experience	Less than 5 years	178	47.7
	5 to less than 10 years	195	52.3
Specialization	Shrimp fishing	90	24.1
	Shrimp farming	133	35.7
	Import/export of shrimp	150	40.2
Job Title	Fisherman	123	33.0
	Waste management officer	129	34.6
	Administrative officer	121	32.4
Governorate	Al Sharqia	214	57.4
	Al Wusta	159	42.6

* Note: Gender is not reported since all the participants were men (100%).

Quantitative Results

Responses from 373 fishermen were measured using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree) and categorized into five levels: very low (1.00–1.80), low (1.81–2.60), moderate (2.61–3.40), high (3.41–4.20), and very high (4.21–5.00) (Table 3).

Table 3. Summary of Questionnaire Responses by Dimension (n=373)

Dimension	Number of Items	Mean	Standard Deviation	Response Level
Readiness to valorize shrimp by-products	6	3.18	0.848	Moderate
Shrimp waste preservation processes	5	3.23	0.562	Moderate
Extraction and functional properties of chitin	6	3.04	1.081	Moderate
Challenges hindering valorization	6	3.57	0.895	High

*Note: The responses were rated based on a five-point Likert scale (1=strongly disagree, 5=strongly agree).

Outcomes (Table 3) show medium preparedness (mean=3.18) and preservation (mean=3.23), which implies a sufficient but limited valorization capacity. Functional properties and extraction were lower (mean=3.04), indicating diversity in technical knowledge or practices. The highest ratings were given to challenges (mean=3.57), and it showed that there are considerable barriers to implementation. The findings indicate that there is a moderate capacity and a big challenge of shrimp by-product valorization in Oman.

Qualitative Results

A semi-structured interview with five production managers indicated four main themes related to the valorization of shrimp by-products (tabel 4). First, regarding technologies, freeze-drying was identified as the most suitable procedure to maintain chitin quality because it preserves molecular integrity, although its high cost remains an obstacle. Second, for preservation practices, hot air drying (60°C) is currently used; it is low-cost but negatively affects the functional quality of chitin. Third, concerning environmental impact, chemical extraction using HCl and NaOH poses hazards and risks wastewater contamination, highlighting the need for alternative, more sustainable methods. Fourth, investment and regulatory barriers were identified, including unclear regulations and limited investment; managers emphasized the importance of government subsidies and training. While the quantitative score of readiness (M = 3.18) represents a moderate outcome, qualitative findings reveal high costs, less efficient processes, and a lower level of readiness.

Even though the quantitative measure of readiness (M = 3.18) is a moderate result, qualitative data demonstrate high costs and less efficient methods, which concentrate on the low level of readiness. Such topics are consistent with the quantitative data regarding the issues that had the greatest score (Table 4), and they included the critical barriers to shrimp by-product valorization

Table 4. Themes from Semi-Structured Interviews

Theme	Description	Example Quote
Preferred Technologies	Preference for freeze-drying due to quality preservation.	"Freeze-drying maintains chitin purity but is too expensive."
Preservation Practices	Reliance on hot air drying.	"We use hot air drying at 60°C; it's cheap but less effective."
Environmental Impacts	Concerns about chemical extraction pollution.	"Chemical methods produce wastewater that's hard to manage."
Regulatory Barriers	Lack of clear regulations and investment.	No clear policies exist for chitin processing plants."

DISCUSSION

The high Cronbach's alpha values obtained for three dimensions indicate strong internal consistency, confirming the reliability of the measurement instruments. In contrast, the low reliability coefficient observed for the shrimp by-product preservation processes dimension may be attributed to the heterogeneity of real-world practices. This variability likely reflects the absence of standardized preservation methods, leading to inconsistent responses among participants. Consequently, findings related to this dimension should be interpreted with caution and considered exploratory. In this context, qualitative data provide valuable complementary insights, offering a deeper understanding of the diversity of preservation practices.

Additionally, the significant Pearson correlation coefficients demonstrate strong associations between items and their intended dimensions, thereby supporting the construct validity of the instrument.

The results of this research showed a medium degree of preparation (mean = 3.18) and waste conservation procedures (mean = 3.23), and a lower mark in the extraction and functional characteristics of chitin (mean = 3.04). Conversely, obstacles were the most rated (mean = 3.57), which indicates a considerable impediment to the valorization of shrimp by-products in Oman. The current findings highlight the potential as well as the obstacles in the development of a sustainable chitin industry in the Sultanate.

The moderate scores in readiness and preservation show that the foundation is present, which makes possible the valorization, but technological and infrastructural constraints limit its potential. Namely, although the average score in the Shrimp Waste Preservation Processes was moderate (mean = 3.23), the low internal consistency of the same (alpha=0.3834) indicates that there is no standardized preservation procedure in the industry. This statistical result agrees with the qualitative data, which points to an ad-hoc approach where some managers use basic icing while others rely on less effective hot air drying at 60°C.

The same results were provided by Yuan et al. (2019), who demonstrated that high-temperature drying processes can degrade the molecular structure of chitin, which makes it less suitable in the context of high-value applications. Although freeze-drying was unanimously recognized by the stakeholders as the best way to preserve molecular integrity and porosity of chitin, its high cost is a limitation to its universal application. This finding is consistent with the study by Ghorbel-Bellaaj et al. (2018), who noted the high preservation ability of freeze-drying, and Silva et al. (2018), who emphasized cost-related challenges in developing economies. The lack of uniform, high-quality preservation practices immediately compromise the quality of the chitin produced, affecting its market value.

The relatively low score for extraction and functional properties (mean = 3.04) reflects the heavy reliance on conventional chemical extraction methods, primarily using hydrochloric acid (HCl) and sodium hydroxide (NaOH). While these methods are efficient in producing high-purity chitin, qualitative interviews identified considerable environmental risks through wastewater pollution. These findings corroborate previous research by Olatunde and Benjakul (2020), who underlined the limitations of chemical extraction and the urgent need for sustainable alternatives. Enzymatic extraction, for instance, has been suggested as a more environmentally friendly method that preserves chitin quality, but it requires significant technological investment and skilled workforce training (Socas-Rodríguez, 2021).

The highest score for challenges (mean = 3.57) underscores the importance of addressing systemic barriers, such as regulatory ambiguity and insufficient investment. These constraints mirror global patterns, where the absence of clear regulatory frameworks and financial incentives often impedes the valorization of marine by-products (Socas-Rodríguez, 2021). This is directly supported by the qualitative findings, where production managers specifically cited a lack of clear policies for processing plants. As highlighted by Braun and Clarke (2012), tackling such challenges requires multi-level strategies involving policymakers, industry leaders, and research institutions.

First, the adoption of freeze-drying technology in the industry can be facilitated through targeted subsidies and strategic investments, enabling the production of high-quality chitin suitable for pharmaceutical and food applications. Second, further research and development should prioritize hybrid drying technologies and enzymatic extraction methods, aiming to optimize cost, efficiency, and environmental sustainability. Third, the establishment of national regulations and standardized guidelines for chitin processing would strengthen investor confidence and support the localization of specialized valorization facilities. The study also revealed that freeze-drying represents the most effective method for producing high-quality chitin, although it is more expensive than hot air-drying. While the current market in Oman does not yet indicate a willingness to pay premium prices for freeze-dried chitin, the findings suggest that targeted government support could promote strategic investments,

particularly for pharmaceutical and food applications, and help establish a niche market willing to accept the higher cost.

In general, this research adds to the worldwide marine by-product valorization literature and elucidates the specific challenges of the Omani environment. Oman Vision 2040 envisions transforming shrimp by-products into a strategic resource for economic diversification and environmental sustainability by integrating technological innovations and policy interventions.

Implications

The findings can be applied to the production of shrimp in Oman. Freeze-drying choice is one of the demand requests of the intervention of the government in the form of a subsidy to the cost of production, to produce good quality chitin for pharmaceutical and food use. Such barriers as cited by managers could be eliminated through regulatory clarity, perhaps through a harmonized standard of chitin processing. The issues of the environment associated with the chemical extraction point to the need to shift towards biotechnological approaches and the corresponding training of the industrial representatives. In theory, the current research would add to the literature on chitin valorizations within resource-poor settings and provide an example of a combination of quantitative and qualitative results.

SWOT Analysis

The quantitative survey with subsequent qualitative interviews was the foundation of the SWOT analysis, which reflected the approach of the study. The existing SWOT (Figure 1) implies that Oman may well be an attractive place to establish a sustainable chitin valorization enterprise, due to the presence of the resource and the policy facilitation. Nonetheless, the industry is still financially and materially challenged. With these weaknesses, which could be addressed through special subsidies, legal policies, and technological development of drying/extraction, may result in improvement of shrimp waste management as a strategic bioeconomic prospect. Collaborate Institution? Academic and industry collaboration is needed to combat existing threats and ensure sustainability in the long term.

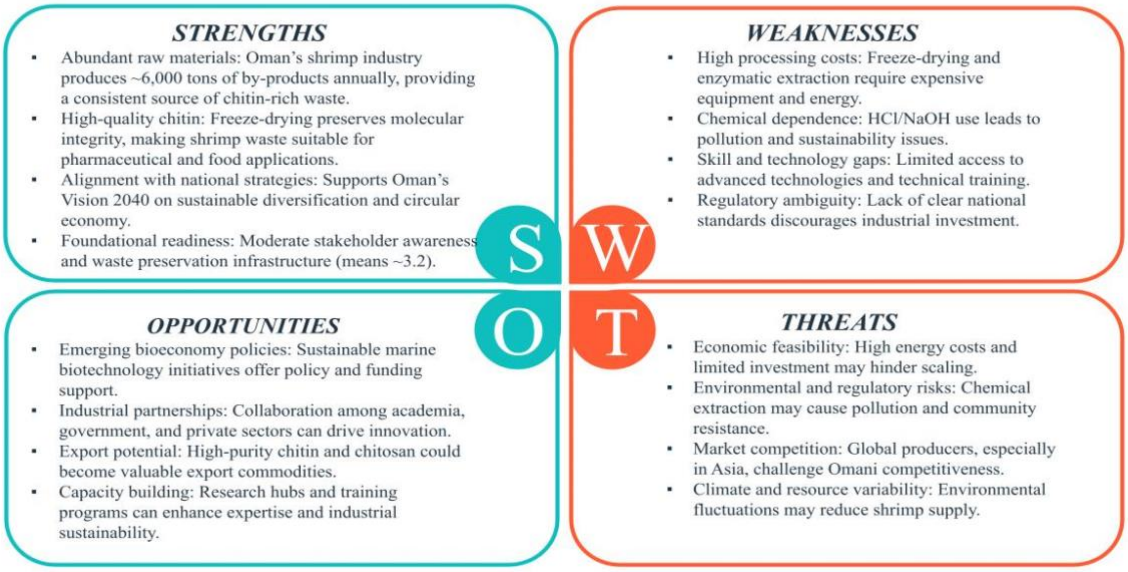

Figure 1. SWOT analysis of shrimp by-products valorization in Oman

CONCLUSION AND RECOMMENDATIONS

The results appeared to show a mix of existing readiness, preservation methodologies, and knowledge capacity of extraction, with a range of significant barriers to advancement. The qualitative interview findings supported the selection of freeze-drying technology for preserving the quality of chitin (although it is very costly, and the suitability for the practice of straw windowing seems not to be efficient as hot air drying). Another environmental concern (chemical extraction) and a regulatory hurdle were raised. The findings suggest the potential to establish a chitin-based enterprise in Oman; however, this potential is constrained by technical, regulatory, and financial barriers.

To address these challenges, the proposed measures include implementing policies for chitin processing that incorporate environmental considerations to reduce pollution, promoting freeze-drying technology to produce high-quality chitin for pharmaceutical and food applications, and developing training modules on sustainable recovery techniques such as enzymatic hydrolysis. Additionally, research and development on integrated drying methods are recommended to balance cost, quality, and environmental performance. These initiatives aim to transform shrimp waste in Oman into a sustainable economic and environmental resource, improving product quality while minimizing pollution, in alignment with the objectives of Oman Vision 2040.

Additional Declaration

Author Contributions

In this study, the contribution of the authors was equal; both authors contributed equally to the development of the research idea, data analysis, writing, and proofreading stages.

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Responsible Artificial Intelligence Statement

In this study, the artificial intelligence tool GEMINI was used in language editing and literature review stages. The artificial intelligence tool was used to correct language errors. We declare that we, as the authors, take full responsibility for the problems that may arise from the content produced by artificial intelligence.

Conflicts of Interest

The authors declare that there are no conflicts of interest related to the publication of this study.

Ethics Approval

In all processes of this study, the principles of Pen Academic Publishing Research Ethics Policy were followed. The study was approved by the Ethics Committee of the University of Carthage, Institut National Agronomique de Tunisie, PV-IAA10112025.

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