

Original Article

# Herd Forecasting and Acceptance Analysis of Sustainable Meat Production through 3D-Bioprinted Meat from Fish Stem Cell

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## Abstract

**Background:** Sustainable production and consumption have been targeted in this study through the lens of 3D bioprinted fish meat using their stem cell. Adopting recent developments from Steakholder Foods Ltd., the cruelty-free and slaughter-free process has been seen as promising for future meat sources.

**Methods:** This study employed a consumption intention analysis to assess acceptance and forecast the general population using an integrated machine learning algorithm comprising a neural network and long short-term memory, implemented in MATLAB R2021a. Using an established integrated framework of the health belief model and values, beliefs, and norms theory, combined with the theory of planned behavior, the researcher employed a purposive sampling approach among 738 valid respondents.

**Results:** It was seen that self-efficacy, perception of environmental concern, perceived values, personal beliefs, ecological worldview, health beliefs, and norms affected the positive consumption intention.

**Conclusion:** It was implied that high positive pro-environmental impact and perceived value were dominant variables affecting the herd acceptance of 3D bioprinted fish meat. This further implicated the need for slaughter-free and cruelty-free alternative food sources. Further policy and implications on sustainable production and consumption were developed.

## Keywords

3D-bioprinted fish meat, consumption intention, long short-term memory, neural network, sustainable production and consumption

## INTRODUCTION

The need for sustainable meat production has been widely recognized due to several political, environmental, and economic concerns. With the rise of hunger and poverty, there is an evident need for sustainable and responsible consumption and production, particularly as the global population is projected to increase by 78 million per year (Sadigov, 2022). Despite several efforts to provide food, the battle over production and scarcity remains a grey area that researchers are trying to resolve.

To date, several studies have already addressed some areas in an effort to close the gap. However, most of which cover the scientific production aspect, and little attention is paid to consumers. That is, despite efforts to develop and promote the different products, the consumption intention among consumers was somewhat neglected. For the production to be sustainable, the consumption intention should be analyzed to understand the needs and perceptions of consumers.

Studies, such as those by [Dutta et al. \(2022\)](#), have investigated the potential of bio-ink for 3D printing of meat. With the application of gelatin and alginate for additional protein nutrition, their study still showed that both slaughter-free and customization were limited—modifications made by [Niu et al. \(2024\)](#) highlighted the use of sodium alginate and gelatin with starch. These were added to bio-printed meat for cell growth. Despite positive output, the strength of the meat output still needs improvement. In an attempt to promote their work, [Rubio et al. \(2018\)](#) analyzed in vitro cell-based cultivation. However, this had yet to be established for large-scale production, making it a benchmark, and may not be sustainable at all.

[Steakholders Food Ltd. \(2023\)](#) (Figure 1) has developed a method for sustainable food production that employs slaughter-free and cruelty-free practices. The company considered obtaining stem cells from fish and using them to mimic the overall texture of fish meat. Evident from related studies, there are countries that either accept or reject the thought of consuming processed and lab-made meat. For example, a study by [Engel et al. \(2024\)](#) presented that Nordic countries have a favorable psychological implication on these types of meat. There is also evidence that Chinese people have a positive intention for consuming these types of meat ([Zhu et al., 2024](#)). However, references suggested a health-related risk perception that may undermine the effect of consumption intention. For example, a third of the 673 surveyed Americans were willing to try, and others may only try it just once ([Wilks & Phillips, 2017](#)). This means that varying insights, perceptions, and intentions may be obtained among different communities, social groups, and countries.



Figure 1. *Steakholder Foods' (2023) 3D Bioprinted Meat*

As a reflection of the newly developed production method and lack of assessment of consumption intention and acceptance, the objective of this study was to assess and forecast the acceptance of 3D bioprinted fish meat from stem cell culture. Specifically, a neural network-based decision support system was implemented to identify significant variables and predict overall consumption intention among Filipino consumers. This created a more generalized output for implications. Specifically, the neural network fitting analysis was performed, integrating the optimum parameters with the long short-term memory for forecasting. This study is one of the first to assess the factors affecting the acceptance of 3D bioprinted meat in the Philippines, as there are currently only two assessments. Moreover, this study addressed the limitations of the tools used, such as the low to no significance level of the factors due to multiple paths or the presence of mediating factors, thereby creating a more accurate analysis.

Covering Sustainable Development Goal (SDG) 12 – responsible production and consumption (SDG 12) - a thorough analysis of people's acceptance was undertaken through an assessment of consumption intention. This would enable developers and industries to apply proper production for 3D bio-printed meat. In accordance, this could indirectly relate to SDG 9 since further sustainable innovation and infrastructure are in place for these types of technologies. This could help promote an innovative and sustainable country. Moreover, there are indirect relationships between SDGs, such as those between SDG 14 and 15. That is, less animal cruelty, slaughter-free, and animal welfare are promoted through the stem-cell production of meat. Specifically, a holistic framework for development was considered and analyzed using concepts from the theory of planned behavior, values-beliefs-norms theory, and the health belief model, employing machine learning algorithms.

Several practical and theoretical implications can be applied and extended to related studies, government officials, and developers for the proper advertisement, promotion, and establishment of 3D bio-printed meat as a future sustainable meat source. This would enhance climate action, as pro-environmental behavior is evaluated, targeting SDG 13, as well as promoting zero hunger (SDG 2) and, if possible, SDG 1 for no poverty once distinct and proper proliferation is established.

## METHODS

### Data Representation

For the analysis, this study employed a purposive sampling approach, utilizing 738 valid samples disseminated and collected across social media platforms, including Facebook, X (formerly Twitter), Instagram, and a face-to-face survey conducted using Google Forms. Before the data collection process, the respondents' consent form for voluntary participation was collected, and they were ensured of their anonymity, in accordance with the Privacy Act of the Philippines, Republic Act 10173. Only those knowledgeable about 3D bio-printed fish meat were considered in this study, having a relevant background and understanding. This was also accompanied by a short video that explained 3D bioprinted meat, featuring a report video from [Steakholder Foods \(2023\)](#). Those who were not familiar with or did not consider the video answered "no" and were directed to the end of the survey. A diverse group of young individuals (18-20 years old) comprised 12.887%, followed by 57.19% of adults (21-40 years old), and 29.95% of older generation participants (41 and above). The participants were predominantly female (51.49%) and male (48.51%). The majority of whom are either college (49.46%) or high school (48.78%) graduates, employed (50.95%), or students (37.53%).

### Data Processing

The analysis in this study involved the use of a neural network (NN) and the integration with long short-term memory (LSTM). That is, the parameters obtained from the optimization process of NN analysis were deemed to be optimum and were utilized for the LSTM analysis, as depicted in Figure 2. Recent developments and studies have implicated on the use of machine learning as this could easily assess nonlinear relationship models, larger frameworks, and provide better accuracy in assessment ([Jamshidi et al., 2020](#)). The researcher employed a filtering approach on the pre-processing technique using correlation analysis. Following the study of [German et al. \(2022\)](#), a weak correlation of 0.20 was the minimum threshold for significance, so long as the p-value is less than or equal to 0.05. To this end, all measure items adopted from the study by [Mendoza et al. \(2024\)](#) were deemed significant and underwent mean calculation as a data aggregation technique. The output of which were the input variables, while the target variable (output) was a rescaled consumption intention variable from the summed measure item output of its construct.

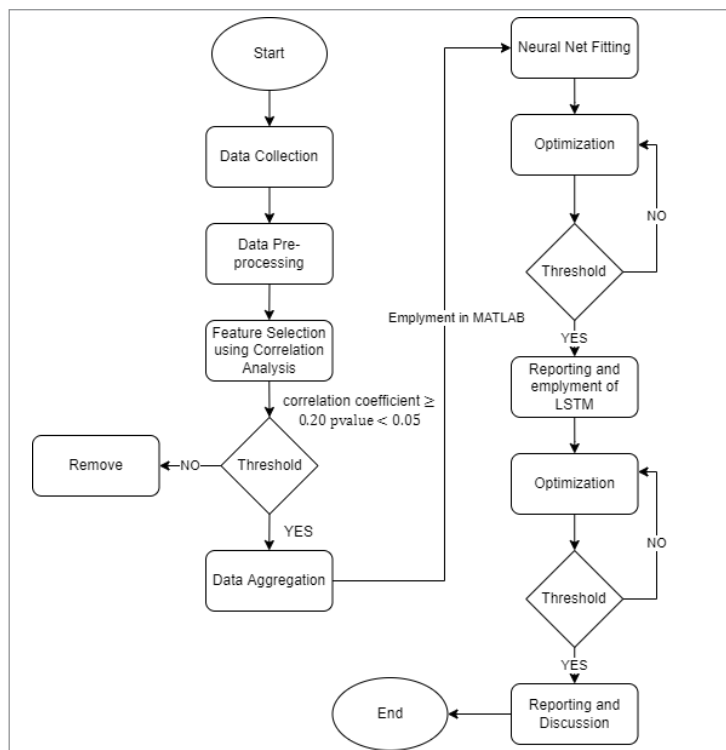


Figure 2. Process Flowchart

## Data Optimization

For this study, the researcher utilized both NN and LSTM in MATLAB R2021a, following the survey by Öztürk and Başar (2022). After the data cleaning process and pre-processing using a filtering approach based on correlation analysis, 49,446 data points were selected for the optimization process. That is, the hidden layer nodes of 10, 20, and 30, alongside different training, validation, and testing ratios of 70:15:15, 80:10:10, and 90:5:5, were considered. The researcher considered the Levenberg-Marquardt algorithm for the parameter tuning (Öztürk & Başar, 2022). The highest  $R^2$  output was used as the optimal parameter output, which was then employed for the LSTM output following a 250-epoch analysis (Ong, Mendoza, et al., 2024). This integration ensures that the prediction output would be the indication of a significant variable and forecasting with high accuracy and low error rate.

## RESULTS

The neural network fitting output is presented in Figure 3, where a 92.68% overall representation of consumption intention was obtained through the  $R^2$  output. Using a training: validation: testing ratio of 80:10:10, a 91.12% accuracy of prediction was obtained at 10 hidden layer nodes and the neural network architecture is presented in Figure 4.

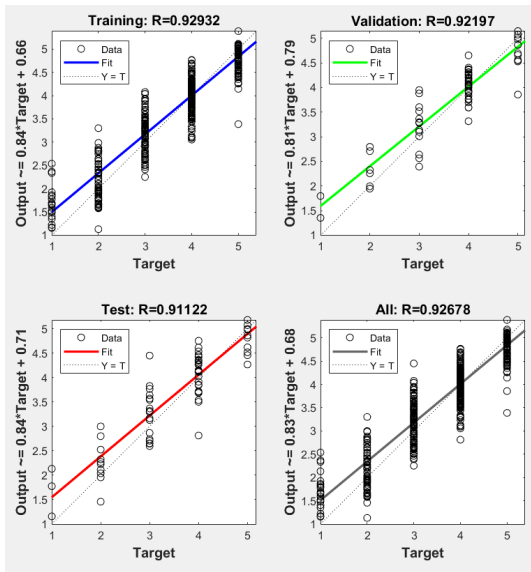


Figure 3. Neural Network Fitting Output

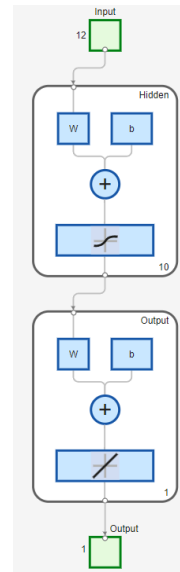


Figure 4. Neural Network Architecture

The process undergoing the LSTM run is presented in Figure 5. The figure presents the total run time of 11 minutes and 31 seconds, which prompted an overall root mean square error of 1.3910. Further establishment of LSTM output from observed and forecasted with updates are presented in Figure 6 and Figure 7 with reduction in RMSE from 1.391 to 0.12291. Fig. 8 depicts the initial LSTM output that implicates the initial forecast (orange) based on the observed data currently obtained (blue). However, LSTM as a recurrent neural network, updates the forecasted output to create an optimum pattern as depicted in Figure 7 (Ong, Mendoza, et al., 2024). With the reduced RMSE, the stored information was then considered to actually forecast the target objective, consumption intention of 3D bioprinted meat as depicted in Figure 8. That is, the final LSTM forecast is presented in Figure 8. It could be posited that a forecasted positive high consumption intention is seen among the general Filipino population.

Majority surpassed the neutral threshold and prompted a positive inclination of consumption intention (around 3.5 to 4.5). This implicates that further respondents may have a positive behavior and acceptance for consuming 3D bioprinted fish meat. Further analysis using the SHAP package (German et al., 2022) implicated that it is people's self-efficacy that prompted the high consumption intention, followed by perception of environmental concern, perceived values, personal beliefs, ecological worldview, health belief, and norms (Table 1). The study of German et al. (2022) set a minimum threshold for significance at 60% and the results have shown that all are greater than the minimum limit.

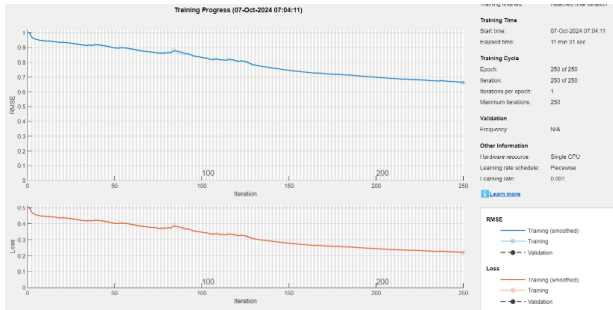


Figure 5. LSTM Run

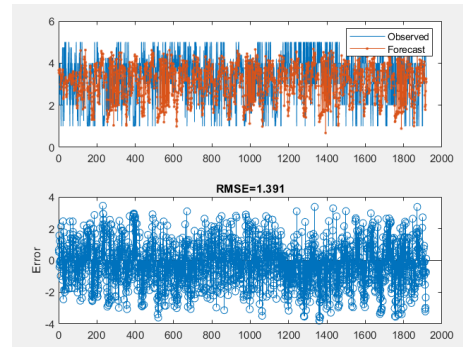


Figure 6. Initial Forecasting

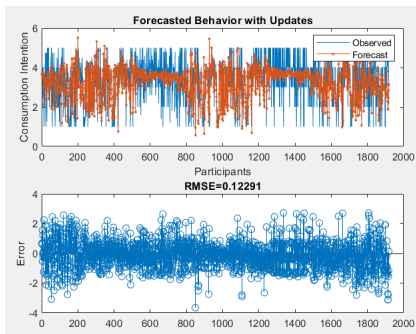


Figure 7. Updated Forecasting Output

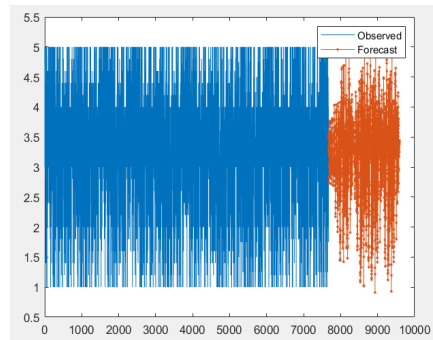


Figure 8. Long Short-Term Memory Final Output

## DISCUSSION

Depicted in Table 1 are the significance levels of the different interrelated variables. As evidenced, self-efficacy had the highest significant effect on consumption intention, based on a normalized score of 100% importance. This is because people perceived that they have the ability and confidence to understand and acquire knowledge of 3D bio-printed fish meat as a new food source. They are confident in exploring and navigating to access accurate information regarding it. According to [Stakeholder Foods \(2023\)](#) and [Lanz et al. \(2024\)](#), the production and consumption of 3D bio-printed fish meat are developed to not only provide an innovative solution to food source problems but also address carbon emission and environmental issues. This promotion helps establish a positive sense of self-efficacy among consumers, leading to a high intention to consume and increased acceptance ([Caulier et al., 2020](#)).

Table 1. Score of Importance

Variable	Code	Importance	Normalized Importance
Self-efficacy	SE	0.097	100.0%
Awareness of Consequences	AC	0.094	96.4%
Perceived Benefits	PB	0.091	93.4%
Altruistic Values	AV	0.093	95.0%
Egoistic Values	EV	0.088	90.1%
Biospheric Values	BV	0.085	87.3%
Openness to Change	OC	0.082	83.9%
Health Concerns	HC	0.080	82.3%
Ecological Worldview	EW	0.078	80.1%
Subjective Norms	SN	0.077	78.6%

Table 1. *Continued*

Variable	Code	Importance	Normalized Importance
Perceived Barriers	BAR	0.073	75.4%
Personal Norms	PN	0.062	63.7%

Second, it was seen that AC is highly significant based on the normalized score of importance of 96.4%. The researcher has deduced that people are intrigued, optimistic, and believe that 3D bio-printed fish meat contributes to a positive impact on the environment. They are eager to embrace it and see the potential of this production and consumption as something that could help make the Earth livable. As explained by [Wittenberg et al. \(2018\)](#), AC triggers personal behavior as the negative impact of animal cruelty on food production is evident among consumers. This is deduced to be something that helps reduce the carbon footprint and emissions associated with food production and consumption. Moreover, [Ong, Arriola, et al. \(2024\)](#) suggested that AC influences people's beliefs about creating a production process that does not negatively impact livestock, and in turn, helps the environment.

Third, PB was seen to promote consumption intention, as depicted by a 93.4% score of importance. This is because people are seeking safer and healthier meats, advocating for sustainable production and consumption, and wanting to minimize overall animal cruelty, slaughter, and harm. Aligning with the study of [Petrovic et al. \(2015\)](#), European countries account for a total of 30% of greenhouse gas emissions due to traditional food consumption. In accordance, 40% is observed among Asian countries, with the Philippines experiencing a 10% increase compared to last year's data ([Panda & Yamano, 2023](#)). This implies that people are aware of the consequences, leading to the promotion of alternative and environmentally sustainable food sources. [Tibrewal et al. \(2023\)](#) suggested that the growing number of consumers aware of the negative implications of environmental aspects triggers the sustainability movement in different countries and among their people. Therefore, people are striving to help by considering more sustainable alternatives.

Fourth, high regard for AV was noted with a normalized score of importance at 95%, as it is believed to promote a revolutionized and innovative food industry, address ethical and environmental issues, and potentially reduce the issue of food scarcity. Contrary to the findings of [Ong, Arriola, et al. \(2024\)](#), they presented that AV was insignificant. That is, they implied that people do not consider others when choosing this type of innovative production. Despite this, it could be implied that people would still have the intention to consume 3D bio-printed fish meat, as it revolutionizes sustainable and innovative food production. [Hartmann et al. \(2017\)](#) suggested that people still consider moral values when forming consumption intentions. Since the overall implied context of AV in this study is the ethical and environmental impact, reduction of food scarcity, and sustainability, there is still an unconscious consideration of the herd mentality. This led to the following significant variable, EV, as it is deemed a significant variable since 3D bio-printed meat is considered the future of meat. Enjoying food without animal harm promotes an ethical and environmentally friendly food system and could have a positive impact on the world.

In addition, BV was evidently significant (87.3%), as this may promote the reduction of animal agriculture needs, mitigate the negative impact on the planet, reduce pollution, and decrease the ecological footprint caused by production. A highlight of this study is comparable to that of German consumers, as studied by [Lanz et al. \(2024\)](#). This posits that Filipino consumers are more inclined toward the environmental impact, leading to a positive BV because of pro-environmental behavior. According to their findings, German consumers expressed a willingness to consider 3D bio-printed fish meat as an alternative food source due to its sustainable and positive environmental impact. This implies a positive herd movement, wherein technological innovation to reduce food scarcity, alternative food sources, and sustainable actions on production and consumption are primary indicators ([Auyeskhani et al., 2024](#); [Tibrewal et al., 2023](#)).

Last on the values aspect is the OC (83.9%) – highlighting people's curiosity, thrill of the potential taste and texture, openness to new options, and attraction to and anticipation of the benefits of 3D bioprinted fish meat. [Anders et al. \(2023\)](#) explained that shaping the beliefs and attitudes of people in the field of sustainable food sources is critical for acceptance of the innovation. It is evident that when people are presented with evidence on the availability and ethical alternatives to food sources, a positive acceptance of consumption is observed, likely due to their openness and diverse value orientations ([Mendoza et al., 2024](#)).

Among health-related beliefs, HC was high, with a normalized score of 82.3% indicating that they are concerned about the aftermath of consuming meat. However, they would consider it if it were made and

produced in a clean and controlled environment, is safe and hygienic, and would be accepted if it is assured for financial and health stability. Being a relatively new technology, the consolidation of concerns among the majority is evident (Godoi et al., 2015). So long as people are assured of the health and safety, alongside the ethical production, there will be positive implications and acceptance of 3D bioprinted fish meat. This assurance would lead to positive herd mobility (Martin et al., 2016).

EW was also deemed significant among the variables (80.1%), in the context of supporting the natural world, with respect to animals and the environment, promoting animal welfare, and protecting the planet. This result aligned with Suchyta (2021). Moreover, Mendoza et al. (2024) noted that Filipinos tend to prioritize sustainable production due to its positive impact on reducing animal cruelty, slaughter, and the overall positive effect on the planet. There is a growing positive environmental consciousness among Filipinos that promotes the intention to consume and accept 3D bioprinted fish meat.

SN was depicted to have a significant effect on the consumption intention of 3D bioprinted fish meat (78.6%). A herd decision will be considered, wherein, once society accepts it, consumers will also consider it. They would also feel responsible for considering it once it becomes normal for everyone, and the opinions of others are greatly valued for their acceptance. The herd acceptance is evidenced in the study by Ong, Arriola, et al. (2024), wherein the norms are primary drivers of the continued development of these innovative food sources. Farrow et al. (2017) explained that once the community evidently starts consuming and has a positive notion of these technological advancements, societal positive validation is evident. Therefore, the sought implication of acceptance and societal fit would lead to a positive consumption intention and acceptance of 3D bioprinted fish meat.

In accordance, BAR was seen to have a significant effect on the consumption intention (75.4%). That is, no contamination issues or health violations should be reported for them to accept this innovative production. Because people aspire to reduce the cruelty and environmental impact of traditional meat consumption, they are optimistic and would embrace the transformative solution developed. Similar to the earlier HC findings, the need for validation of health and safety accord should be evident for people's consumption intention and acceptance (Godoi et al., 2015; Martin et al., 2016; Portanguen et al., 2019).

Lastly, PN was shown to be the least significant variable as the normalized score of importance was near the threshold of 60% (63.7%). This is because people consider that consuming this type of innovation is a responsibility, one that they need to adopt to become a better person, minimize ongoing negative environmental impact, and fulfill their moral obligation to help reduce global damage. Pakseresht et al. (2022) demonstrated a similar positive impact, with reasons primarily focusing on individual values and emotional aspects. People often believe that there is positive reasoning for the development of these sustainable food sources, yet resistance is still evident. Thus, it is implicated as one of the least significant variables. However, the overall results suggest this as significant, implying a positive overall attraction to the sustainable production and consumption of 3D bioprinted fish meat (Nordlund & Garvill, 2003).

There is a positive consumption intention due to their values, beliefs, norms, and environmental concerns. The forecast also had a positive impact and garnered agreement among the general public. In accordance, despite a low root mean square error of the final LSTM output (0.12291) and a high accuracy of neural network fitting ( $R^2 = 92.68\%$ ), future studies may opt to consider other machine learning tools to relate the factors, demographic characteristics, and future consumption intentions altogether. Moreover, interviews and related quantitative analysis may yield new findings, as well as inform consideration of other frameworks for sustainable production and consumption analysis.

Theoretically, it can be seen that the overall integrated model holistically assesses health perception, people's values, beliefs, and overall norms. This implies that the framework with high accuracy of prediction could be used to assess other consumption/production-related studies. Moreover, the overall sustainability behavior can be assessed using this framework; thus, future researchers could adopt or extend it. In addition, the identification of distinct variables through the neural network decision-based support system yielded significant output that could be easily interpreted compared to traditional statistics and multivariate analysis. This is beneficial for forecasting behavior in future research works.

On a practical standpoint, there is evidence to support the pro-environmental norms, beliefs, and overall acceptance of the 3D bioprinted fish meat among Filipinos. There is a societal acceptance and herd behavior that individuals would follow as long as health concerns, food handling, production, and safety are assured. Moreover, the results have highlighted the relationship between sustainable production and consumption, as well as the importance of proper information dissemination. To promote environmental technology and

sustainability, developers, innovators, industries, and the government could highlight the negative impact of continued consumption of slaughtered and traditional meat production and illustrate how current 3D bioprinted meat from stem cells could promote sustainable production. In accordance, a proper Layman's presentation of the process may help enlighten all individuals on the availability of this type of food manufacturing progression in the current generation. Making it available among developing countries, based on the findings, would be promising. This would help promote SDG 12, which focuses on sustainable production and consumption.

## CONCLUSION

The output presented that Filipinos are likely to accept the slaughter-free and cruelty-free production and may have high levels of consumption intention. People's inclination toward perceived environmental concern, personal beliefs, and perceived values heightens their positive behavior. Nonetheless, consideration of price and overall economic standing remains necessary when addressing sustainable production and consumption. That is, the final cost would still matter, regardless of whether consumption involved an actual action by people in the Philippines. Moreover, it was observed that social norms prevailed over personal norms. That is, herd behavior would imply a positive overall consumption of the developed 3D bioprinted fish meat from stem cells. This finding could be considered by developers, the industry, and the government to promote and establish the country's future meat source.

## Author Contributions

**Ong, A. K. S., & Redi, A. A. N. P.:** Conceptualization, Data curation, Validation, Formal analysis, Writing – original draft; Writing – review & editing.

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## Ethical Approval

This study was approved by the department ethics committee (FM-RC-22-01-01).

## Competing interest

The authors declare no conflicts of interest.

## Data Availability

Data will be made available by the corresponding author on request.

## Declaration of Artificial Intelligence Use

The authors did not consider the use of artificial intelligence in creating this article.

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