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Research article

Strategic insights for sustainable growth of mushroom farming industry in Bangladesh: A comprehensive evaluation using SWOT-AHP and TOPSIS frameworks

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ABSTRACT

Mushroom farming using agri-waste as substrates can offer a sustainable solution to the food security challenges of inadequate and imbalanced diets. Developing strategies to exploit the potential of the mushroom industry fully is yet to be explored in Bangladesh. We, thus, conducted this study to investigate the challenges and opportunities associated with mushroom farming, as well as the characteristics of farms and employees engaged in this industry. A directional stepwise multiple regression analysis showed self-motivation, spawn cost, farm size, and training are the key influencing factors driving profitability. Farm surveys identified SWOT factors with 24 sub-factors cross-validated with expert consultations. The sub-factors were categorized as beneficial (strength and opportunities) and cost (weakness and threats) to formulate the SWOT strategies using the Grey-TOPSIS method. Results indicate a favorable scenario exists for the industry in Bangladesh, with significant opportunities (group weight 0.53) and minimal threats (group weight 0.09). We proposed 12 strategic alternatives for the sustainable growth of this industry. This top-ranking strategy is not only to secure funding (relative closeness, $C^{+} = 0.87$) but also to provide more accessible loan options envisioning a strategic expansion of business operations in Bangladesh. The evaluation highlighted the significance of collaboration with other mushroom farmers to maximize the gain in marketing that will substantially expand the local demand ($C^{+} = 0.697$). Besides, product diversification is also underscored as an important strategy for the growth of the industry. These prioritized SWOT strategies lay the groundwork for policy development, aiding decision-makers in steering the mushroom industry towards sustainable growth for developing countries like Bangladesh. Promoting such an eco-friendly industry will generate ample opportunities for women's employment and appreciable profit while contributing to environmental improvement through recycling agri-waste.

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1. Introduction

By 2050, the global population is projected to reach 10 billion [1,2], a significant increase from the 7.7 billion inhabitants in 2019 [3]. This surge in population is anticipated to intensify the food demand by ~40 % [2,4]. Due to intensive farming, the agri-food sector contributes nearly 17.3 billion tons of CO_2 annually, constituting 35 % of anthropogenic greenhouse gas emissions [5]. Amidst this scenario, an alarming 1.3 billion metric tons of fruit and vegetable waste are generated annually [6] throughout the supply chain, encompassing harvesting to marketing. Moreover, about 14 % of the world's food is lost during production before it reaches retail [7]. This percentage is expected to rise further with the expanding population, necessitating the extensive utilization and recycling of non-sustainable environmental resources. Otherwise, this waste often ends up in landfills, contributing to greenhouse gas emissions and exacerbating global warming. In alignment with the 2030 agenda for Sustainable Development Goals [8], strategies have been devised to address new challenges and opportunities to reduce food loss and waste. These initiatives seek to enhance the efficiency of natural resource utilization and align with the broader sustainable development goals. There is a growing recognition of the potential of fruit and vegetable wastes in mushroom production. These wastes, often overlooked, are now being explored for their ability to enhance mushroom yield while positively influencing their nutritional composition and contributing to climate change mitigation.

In light of the global challenges posed by food waste and malnutrition, developing countries like Bangladesh face significant food security challenges [9] due to inadequate and imbalanced diets. Mushrooms, rich in protein, vitamins, and minerals, offer a potential solution to address malnutrition [10]. As an agro-based nation, Bangladesh annually generates substantial lignocellulosic byproducts from various agro-industries [11]. While some of these byproducts are utilized as livestock feed or in the compost industry, others are treated as waste, leading to environmental issues when burned or disposed of. Leveraging these agro-industrial wastes for mushroom cultivation presents a dual benefit: combating malnutrition and mitigating environmental pollution [11].

Building on the potential of agri-waste use for sustainable mushroom cultivation, it is important to recognize the natural and cultivated sources of mushrooms in Bangladesh. A variety of mushrooms naturally grow in various environments, including forests, moist soils, decomposing organic debris, and wooden stumps, particularly during the rainy season. Bangladesh's tropical, moist, deciduous forest region has a climate and flora that support the growth and reproduction of diverse mushroom species. Mushrooms can also be cultivated using a variety of affordable and easily accessible substrates, such as sawdust, rice straw, sugarcane bags, corncobs, hyacinth, banana leaves, paper trash, and used cotton. Over 50 million metric tons of paddy rice straw in Bangladesh are produced annually. Which could be a potential source of mushroom production; for example, at present, India is producing almost 240,000 tons of mushrooms just using agricultural residues like straw [12]. This approach would not require cutting back on animal feed. Even without access to a lot of land, mushrooms can be grown in small areas by stacking them vertically, offering a practical solution for densely populated countries like Bangladesh, where expanding arable land for agriculture is nearly impractical. Despite the large production gap in vegetables, Bangladesh produces only 3.73 million tons annually against a demand of ~13.25 million tons [13], the mushroom section remains largely underdeveloped. This underdevelopment persists despite the global mushroom market's expected growth of 6.74 %, from 15.25 million tons in 2021 to 24.05 million tons in 2028 [14]. The neglect of this highly potential economic sector could be attributed to a lack of pragmatic research to illuminate its prospects and inform strategic policy development in the country.

Given the untapped potential of mushroom farming in Bangladesh, it is noteworthy that currently, only about 0.15 million people are involved in mushroom farming in the production and marketing process. In this scenario, mushroom farming may offer a new hope for Bangladesh, where 7.5 % of males and 3.5 % of females in the labor force are unemployed, according to the World Bank [15]. Factors such as gender, education, and farm owners' experience, growers' training, marketing channels, post-harvest processing, and labelling of the products have significantly affected the success of mushroom farming in the country [16–18]. Identifying the potential constraints and finding the strengths is critical for expanding the mushroom industry in Bangladesh. This expansion would not only meet the country's nutritional needs and national demand but also support entrepreneurs in generating income through the proper use of agri-waste. Previous studies have addressed the prospects and challenges of mushroom farming in Bangladesh [16,18,19], and have even explored automated farming through IoT and machine learning [20]. Some other studies have focused on health risks from heavy metals in mushrooms [21], the effect of light conditions on yield [22], the use of agri-waste as substrates [11]. While these studies sufficiently advocate for mushroom farming and consumption, no study to date has explored the potential strengths, opportunities, and constraints from a sustainable perspective that could facilitate the expansion of the mushroom industry in the region.

Given the previous overlook of the mushroom section in Bangladesh, there is a clear need to incorporate expert opinions and employ suitable tools to develop pragmatic strategies. Moreover, previous studies often lacked adequate inclusion of expert insights and did not use advanced analytical tools required for formulating effective policies. For instance, the Analytic Hierarchy Process (AHP) is widely used by researchers and policymakers across various disciplines, such as Forestry [23], GIS [24], Economics [25] to support informed decision-making. AHP is particularly useful in SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis as it provides a structured and systematic approach to prioritize and evaluate the importance of various factors within each category. This process allows experts to assign numerical weights to different elements based on their relative significance, facilitating more objective and consistent decision-making. On the other hand, TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) aids in ranking and selecting the most suitable strategies within the SWOT framework. By considering both the positive and negative aspects of each strategy, TOPSIS enables a comprehensive evaluation that accounts for all potential outcomes, helping to identify the most effective and balanced strategy.

It is pivotal to appraise the mushroom industry in Bangladesh by employing advanced analytical tools to suggest a way forward for its sustainable growth. To this end, this study aims to identify the driving factors contributing to the annual profit of the mushroom

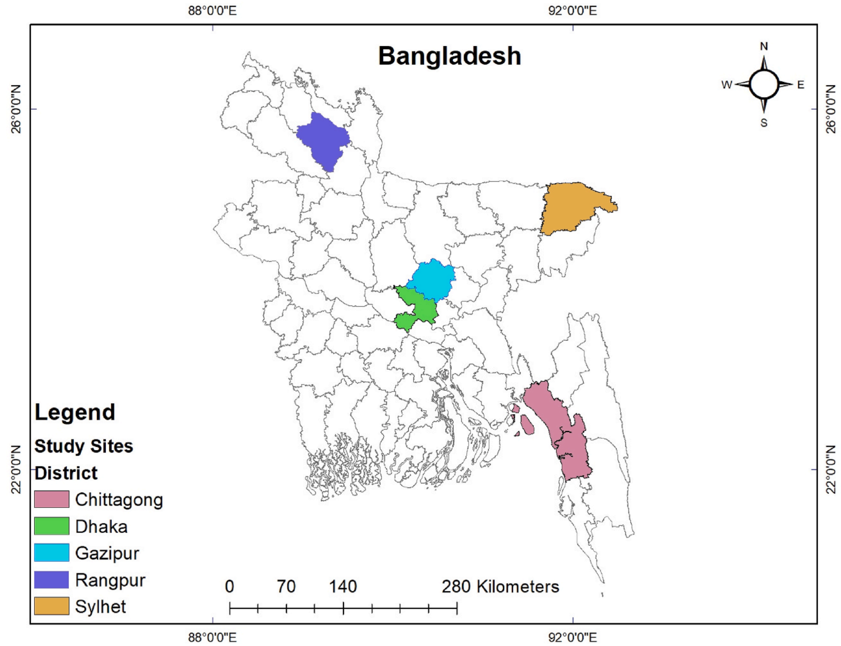

Fig. 1. Map of the study area.

Table 1
SWOT factors identified from the field by interviewing the local farmers, workers, and spawn producers.

SWOT	Factors
STRENGTHS **(S)**	**S1** Local weather support and biomass wastage as substrates
	S2 Family labor support
	S3 Employment generation, particularly for women
	S4 Own food security
	S5 Vertical farming (less land require)
WEAKNESSES **(W)**	**W1** Narrower loan access
	W2 No sorting/grading
	W3 No labelling
	W4 Influence of middleman
	W5 Lack of coordination in marketing
	W6 Quality of seed/spawn
	W7 Difficult to ship fresh mushroom
	W8 Lack of technology
OPPORTUNITIES **(O)**	**O1** Diverse breed
	O2 Grow all over the year
	O3 Does not require a temperature-controlling facility
	O4 Free training facility and options for recycling the substrate
	O5 Accessible information to start a farm
	O6 Low capital requirement
	O7 Good health-promoting values
THREATS **(T)**	**T1** Phobia and superstition
	T2 Perishable
	T3 Low market demand
	T4 Food habit

industry, assess its strengths, weaknesses, opportunities, and threats (SWOT), and explore potential alternatives to address the identified SWOT factors and prioritize them using the TOPSIS method. The findings of this study can provide valuable insights to entrepreneurs and policymakers in Bangladesh, helping them make informed decisions about expanding the mushroom industry and optimizing agri-waste management in the region.

Table 2
SWOT strategies developed after consultation with experts and mushroom businessmen.

	Strength	Weakness
Opportunities	**S5O2**: Implement year-round vertical farming techniques to increase production and profit. **S2O3**: Provide free training to family members to further improve mushroom cultivation skills. **S3O5**: Collaborate with other mushroom farmers to coordinate marketing efforts and increase market demand.	**W1O4**: Partner with organizations to secure funding and provide more accessible loan options. **W2O6**: Improve quality of seed/spawn to increase production and reduce costs. **W7O1**: Develop packaging and transportation methods to expand sales of fresh mushrooms.
Threats	**S3T3**: Diversify mushroom products and marketing to appeal to broader markets and increase demand. **S2T4**: Implement marketing and sales strategies to reduce the influence of middlemen. **S4T4**: Provide consumers with clear information on mushroom consumption's benefits to overcome food habits.	**W1T3**: Develop marketing strategies to overcome limited market demand and increase sales. **W3T1**: Address superstitions and misconceptions through community education and outreach efforts. **W4T3**: Implement quality control measures to uphold consumers' expectations.

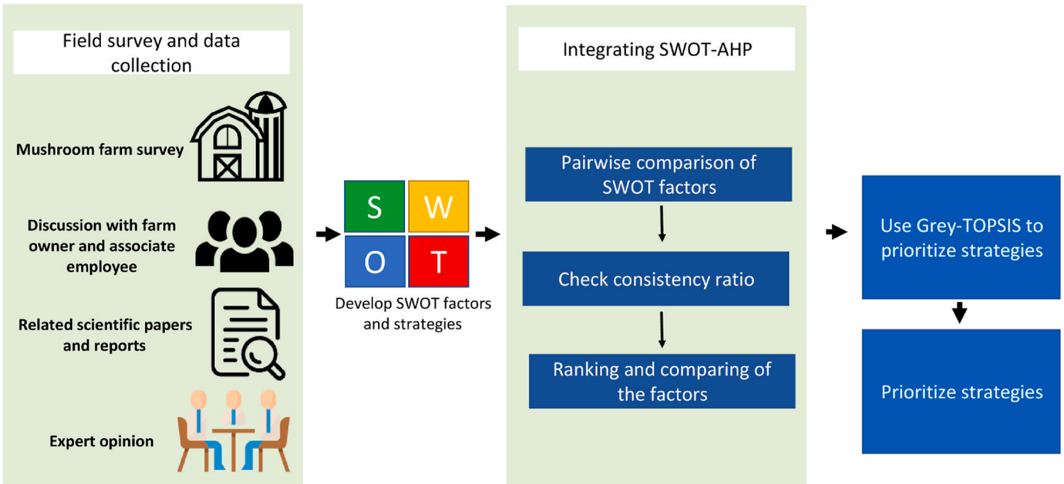

Fig. 2. The framework evaluates the strengths, weaknesses, opportunities, and threats using the Analytic Hierarchy Process for Bangladesh's Mushroom industry.

2. Materials and methods

2.1. Data collection

A total of 120 interviewees working in the mushroom industry, including 40 entrepreneurs, were randomly selected for a questionnaire survey conducted in 5 districts (Chattagram, Dhaka, Gazipur, Rangpur, Sylhet) of Bangladesh (Fig. 1). More than half of the mushroom enterprises are situated in Dhaka district. A sample of 60 respondents was drawn from Dhaka, 30 from Gazipur, and 10 from each of the Rangpur, Sylhet, and Chittagong districts. Among the 40 entrepreneurial owners, 20 were from Dhaka, 11 from Gazipur, and 3 from Rangpur, Chittagong, and Sylhet. All respondents were selected randomly. Face-to-face interviews were conducted using a semi-structured questionnaire to collect data for this study (Supporting information, Q1).

Knowledge of mushroom cultivation was selected as a key factor in the questionnaire, alongside other factors such as age, education, family size, attitudes towards mushrooms as food, training duration, capital, farm structure, profit, and family involvement. Respondents' educational attainment was assessed based on the number of years of schooling completed, with a score assigned for each year of completion. Training duration was measured by the number of days respondents spent receiving training on mushroom cultivation from various sources. The questionnaire focused on several themes, including identifying the advantages and disadvantages of mushroom cultivation, evaluating institutional support provided by governmental and non-governmental organizations, assessing production and labor costs, and exploring producers' self-motivation for continuing mushroom farming. Agricultural experts were also interviewed to gain a better understanding of these themes. To develop SWOT factors for the mushroom industry in Bangladesh, interviews were conducted with mushroom cultivators, wholesalers, and spawn producers (Table 1). These factors are cross-checked with experts and existing literature.

2.2. SWOT strategies

The SWOT strategy matrix is formulated using the sub-factors outlined in Table 1 by experts and upon consultation with farm owners. Table 2 illustrates the formulation of 12 strategies, with 3 strategies identified within each combination.

2.3. Determining driving factors

In order to identify suitable models for predicting the driving factors of profit, we conducted a directional stepwise multiple regression analysis. This approach, known as "bidirectional stepwise regression," begins by including all variables significantly related to the outcome. The best model was selected based on the Akaike Information Criterion (AIC), a measure of model quality. This method allows for the inclusion of continuous and categorical explanatory variables, making it suitable for the current analysis. Initially, 16 variables obtained from the questionnaire were considered as predictors to evaluate the factors influencing profit.

2.4. AHP-SWOT and Grey-TOPSIS

The Multi-Criteria Decision-Making (MCDM) approach integrating Analytical Hierarchy Process (AHP), TOPSIS, and SWOT analysis, was employed to assess the relative importance of each SWOT factor and to evaluate how effectively these factors are integrated into resource planning and strategic assessment. Additionally, alternative strategies were determined and ranked accordingly. The overall framework of this study is illustrated in Fig. 2.

For SWOT-AHP analysis, the first and crucial step involved identifying the SWOT factors. These factors were determined following the steps outlined in Fig. 2. The Saaty (1987) scale, ranging from 1 to 9 were used to compare variables, indicating the relative importance of each factor. The Consistency Ratio (CI) was used to check for bias, with each factor assigned a value according to the Saaty scale. After completing the pair-wise comparisons, the eigenvalue approach, as described in Eqs. (1)–(5),was used to estimate the relative priority of each factor within its respective SWOT group. The reciprocal matrix, commonly known as the Saaty matrix, is presented alongside the pairwise comparison outcomes in a square matrix (Eq. (1)), where the elements m_{ij} Indicate the preference of object X_i over X_j, with $m_{ij} > 0$. For i = j, the diagonal elements in the Saaty matrix are equal to 1, such as, $m_{ij} = 1$ [26,27].

$$M = (m_{ij})\ \text{nxn} = \begin{bmatrix} \frac{E_1}{E_1} & \frac{E_1}{E_2}\cdots\cdots\cdots & \frac{E_1}{E_n} \\ \frac{E_2}{E_1} & \frac{E_2}{E_2}\cdots\cdots\cdots & \frac{E_2}{E_n} \\ \frac{E_3}{E_1} & \frac{E_3}{E_2}\cdots\cdots\cdots & \frac{E_3}{E_n} \\ \cdots & \frac{E_i}{E_j}\cdots\cdots\cdots & \cdots \\ \frac{E_n}{E_1} & \frac{E_n}{E_2}\cdots\cdots\cdots & \frac{E_n}{E_n} \end{bmatrix} \tag{1}$$

The vector nE is produced when the matrix represented by Eq. (1) is multiplied by E (the transpose of the vector of weights).

The formulation for the eigenvalues is:

$$ME = n\ .\ E = \lambda_{max}\ .\ E \tag{2}$$

Here, n represents the number of rows or columns, $E = (E_1, E_2, E_{3,}, \ldots., E_n)^T$, and $\lambda_{\max}$ is the trace of matrix M or the eigenvalue. The largest eigenvalue of a reciprocal matrix is always greater than or equal to the number of rows or columns (n). The CR and confidence interval (CI) for each comparison matrix were computed as key components of AHP analysis:

$CR = \left(\frac{CI}{RI}\right)\ .\ 100$, where CI is the consistency index,

$$CI = \frac{\lambda_{max} - 1}{n - 1} \tag{3}$$

The random index (RI) depends on the matrix's dimensions (n). If the CR exceeds 0.1, the pair-wise comparisons are deemed inconsistent, necessitating revision of the comparisons to achieve the target value. According to Catron et al. [28], the overall priority of each factor is determined by Eq. (4), where i represents the number of elements within a SWOT category and j corresponds to the four groups (strengths, weaknesses, opportunities, and threats):

$$\text{Global priority of factor}_{ij} = \text{factor priority value}_{ij} \text{ x SWOT category scaling value} \tag{4}$$

Subsequently, to determine the decision matrix of Grey-TOPSIS (MGT), each alternative was evaluated based on four categories: compatibility with local weather conditions, potentiality to increase production and profit, feasibility of implementation, and potential impact on food security. These evaluations were based on a Grey linguistic scale, as listed in the supplementary files (S1) (S1, Table-S1.1) (S1, Table-S1.2). The decision matrix can be expressed by the following matrix (Eq. (5)), where $\otimes A_{ij}^{y}$ represents the evaluation score of alternative strategies based on the grey scale provided by the expert (y), with y taking values from 1 to 4, and so on. In addition, the Grey evaluation of alternatives (i) based on the decision-makers is represented as $\otimes A_i^y = [\otimes A_{i1}^y, \otimes A_{i2}^y, \otimes A_{i3}^y, \dots\dots\dots\dots\dots\dots, \otimes A_{im}^y]$.

$$M^{TG} = \begin{bmatrix} \otimes A_{11}^y & \otimes A_{12}^y \dots\dots\dots & \otimes A_{1m}^y \\ \otimes A_{21}^y & \otimes A_{22}^y \dots\dots\dots & \otimes A_{2m}^y \\ \otimes A_{31}^y & \otimes A_{32}^y \dots\dots\dots & \otimes A_{3m}^y \\ \dots & \dots\dots\dots & \dots \\ \otimes A_{n1}^y & \otimes A_{n2}^y \dots\dots\dots & \otimes A_{nm}^y \end{bmatrix} \tag{5}$$

After normalizing the MGT matrix using Eq. (6) for benefit and Eq. (7) for cost type criteria, the positive ideal solution (R_i^{S+}) and negative ideal solution (R_i^{S-}) are determined using Eq. (8) and Eq. (9), respectively:

$$\otimes f_{ij} = \frac{\otimes A_{ij}}{max_i\ (\overline{A}_{ij})} = \left(\frac{\underline{A}_{ij}}{max_i\ (\overline{A}_{ij})}\ ;\ \frac{\overline{A}_{ij}}{max_i\ (\overline{A}_{ij})} \right) \tag{6}$$

$$\otimes f_{ij} = 1 - \frac{\otimes A_{ij}}{max_i\ (\overline{A}_{ij})} = \left(1 - \frac{\underline{A}_{ij}}{max_i\ (\overline{A}_{ij})}\ ;\ 1 - \frac{\overline{A}_{ij}}{max_i\ (\overline{A}_{ij})} \right) \tag{7}$$

$$R_i^{S+} = \left\{ \left(max_i\, \overline{f}_{ij} \mid \mathrm{j}\ \epsilon\ \mathrm{J} \right), \left(min_i\, \underline{f}_{ij} \mid \mathrm{j}\ \epsilon\ \mathrm{j}' \right) X \mid \mathrm{i}\ \epsilon\ \mathrm{n} \right\} = [f_1^+, f_2^+, f_3^+, \dots\dots, f_m^+] \tag{8}$$

$$R_i^{S-} = \left\{ \left(min_i \underline{f}_{ij} \mid \mathrm{j}\ \epsilon\ \mathrm{J} \right), \left(max_i\, \overline{f}_{ij} \mid \mathrm{j}\ \epsilon\ \mathrm{j}' \right) X \mid \mathrm{i}\ \epsilon\ \mathrm{n} \right\} = [f_1^-, f_2^-, f_3^-, \dots\dots, f_m^-] \tag{9}$$

To rank the strategies, we computed the distance of each positive and negative ideal solution using Eq. (10) and Eq. (11), respectively. The weight of the j^{th} criterion, denoted by w_j, was considered in both equations, and the Euclidean distance function (value 2) was used. The final ranking was obtained using Eq. (12) to determine the relative closeness. We used Euclidean, Minkowski, and Manhattan distances for sensitivity analysis to calculate the similarity measures between the alternatives and the ideal solution. This analysis provided insights into the impact of criteria weight changes on the ranking of the alternatives. The AHP and Grey-TOPSIS analyses were conducted using the Python environment.

$$K_i^{d+} = \left\{ 1/2 \sum w_j \left[\left| f_j^{d+} - \underline{f}_{ij}^d \right|^p + \left| f_j^{d+} - \overline{f}_{ij}^d \right|^p + \right] \right\}^{1/p} \tag{10}$$

$$K_i^{d-} = \left\{ 1/2 \sum w_j \left[\left| f_j^{d-} - \underline{f}_{ij}^d \right|^p + \left| f_j^{d-} - \overline{f}_{ij}^d \right|^p + \right] \right\}^{1/p} \tag{11}$$

$$C_i^+ = \frac{K_i^-}{K_i^+ + K_i^-}, (\mathrm{i} = 1, 2, 3 \dots \mathrm{n}) \tag{12}$$

3. Results

3.1. General portrait of the local mushroom industry

The demographic analysis of respondents revealed that most individuals engaged in mushroom farming as entrepreneurs were male, accounting for 72 % of the total respondents. The remaining 28 % were female, who were involved in mushroom farming alongside their other domestic responsibilities, indicating that mushroom cultivation is not limited to males and is gradually becoming a popular practice among women. In terms of labour, more than 40 % of women work as labourers, and almost 2 people work as family labourers (Table S1.4. Furthermore, the study found that 27.5 % of respondents had no formal education, while 25.0 % had received a secondary education, and 2.5 % had graduated from university (Table S1.3). The lowest proportion of respondents (17.6 %) possessed a primary school certificate. These results suggest that mushroom farming is not only attracting individuals with lower levels of education but also higher educated people who may see it as a viable profession or business opportunity. The study also revealed that most of the respondents (82.5 %) had received training for a month from an institute located approximately 60 km away from their location. It was found that only 25 % of respondents attempted to obtain a loan to start their business, and out of those, only 5 % were successful in securing it. As a consequence, the vast majority of respondents (92.8 %) started their business using their own funds. This may be due to the complex paperwork and obstacles associated with obtaining a loan, making it a less attractive option for entrepreneurs, which may not be agreeable to the growth and expansion of small-scale industries.

Furthermore, as widely reported in the survey, the most critical factor for successful mushroom cultivation is the quality of spawn.

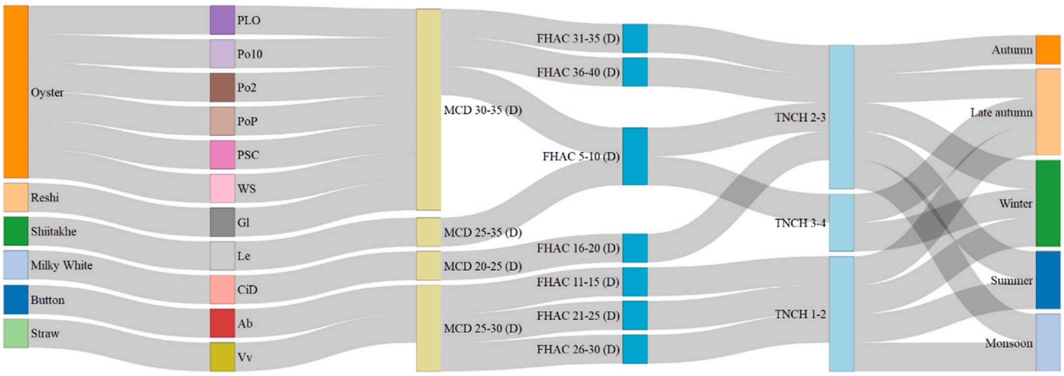

Fig. 3. Types of mushrooms with their variants cultivate in different seasons in Bangladesh. The width of bands connecting designation nodes is proportional to the number of respective categories flowing to the right. Colors differentiate mushroom names, variants, mycelium coating duration, first harvest after coating (FHAC), total number of commercial harvests (TNCH), and seasonal suitability. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Coefficient of multiple linear regression analysis showing the key factors impacting the profit of mushroom farms in Bangladesh. Signif. codes: 0 '***' 0.001 '**' 0.01 '*'.

	Estimate	Standard error	t value	P value	
Intercept	−5.081	1.24187	−4.092	0.000283	***
Self-motivation to continue the farming	1.5113	0.62427	2.421	0.02153	*
Duration of training	0.16834	0.04992	3.372	0.002016	**
Experience before starting farming	1.69478	0.6739	2.515	0.017307	*
Family labor	0.71497	0.22395	3.193	0.003226	**
Benefit-cost ratio	0.85181	0.34076	2.5	0.017932	*
Spawn cost	−1.166	0.31049	−3.759	0.000711	***
Post harvesting cost	0.74753	0.16931	4.415	0.000114	***
Farm size	0.41714	0.04367	9.553	9.45E-11	***

Although 37.5 % of the mushroom seed is collected from MDI and approximately 5 BDT is spent on purchasing per kg substrate, the quality of spawn remains unsatisfactory.

A total of 6 types of mushrooms (Oyster, Button, Shiitakhe, Straw, Reshi and Milky White) are cultivated across the country. Out of 11 varieties cultivated in the country, three oysters (Po2, Po10 and PSC) are cultivated throughout the year, while the rest are cultivated in specific periods of season. Button and Shiitakhe mushrooms are preferred to cultivate mainly during the winter season, while Milky White, Reshi, and Straw are grown in summer and rainy seasons (Fig. 3). The mycelium coating of these mushrooms varies from 20 to 35 days. Oyster and Reshi mushrooms generally require the lowest time (20–25 days) to coat the substrate, while the highest number of days (30–35) are needed for Button and Straw mushrooms. After substrate coating, oyster and Shitakhe mushrooms can be harvested within 5–10 days. Oyster mushrooms can be harvested 3–4 times that produce about 200–300g of fresh yield per packet, while Shiitakhe mushrooms yield around 150–200g at 1–2 harvest cycles. Button mushrooms produce the highest total yield (250–350) at 2–3 times of harvest, of which the first harvest started after 20–30 days of coating. On the other hand, Reshi mushroom requires longer days (30–40) to produce the first harvest; it yields the lowest amount of mushroom (40–50g) with a 3–4 times harvest cycle. Besides, straw mushrooms and Milky white mushrooms produce 250–300g and 155-150g of the fruiting body, respectively. The harvest cycle for Straw mushrooms is 2–3 times, with the first harvest being started after 10–15 days of coating, while for Milkey is 3–4 times, and the first harvest is after 15–20 days of coating.

3.2. Driving factors of profit

Upon evaluating the regression coefficients, it is evident that some variables have a significant positive impact on monthly profit generation. The duration of the training and the number of family laborers significantly influence the farm's profitability (Table 3). This may be due to the fact that training and family involvement can increase overall efficiency and productivity. Additionally, the willingness to continue the business is a positive factor, indicating motivation is necessary for successful mushroom farming. The regression coefficient for farm size, post-harvesting cost, and benefit-cost ratio are also positively related to income and profit. This means larger farms with higher post-harvesting costs and better benefit-cost ratios tend to generate more profit. On the other hand, the regression coefficient for spawn cost is negative, which means that higher spawn costs can negatively affect profitability. This highlights the importance of cost management in mushroom farming. The model's R^2 value is 91.93 % (R^2 adjusted: 94 %), indicating that the model explains a significant proportion of the variability of the dependent variable, which is the monthly profit generated by

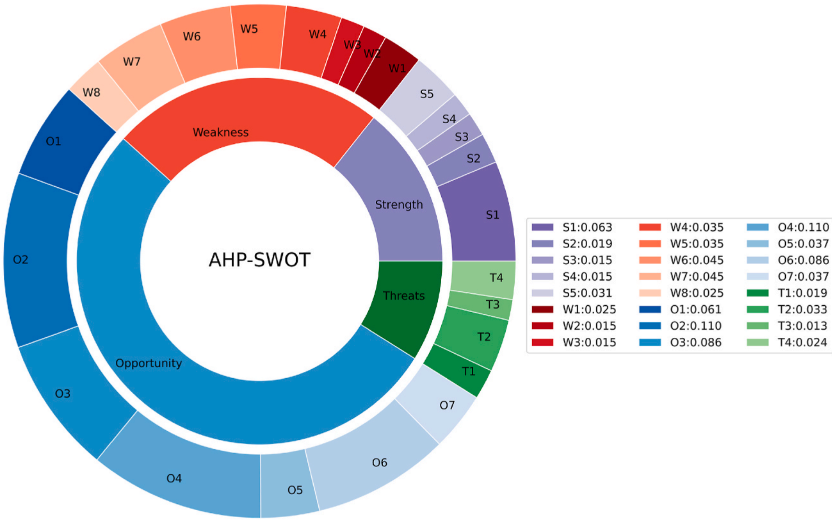

Fig. 4. Weight distribution of the SWOT dimensions and factors for the mushroom industry.

the farm.

3.3. SWOT-AHP

The pairwise matrix, constructed using the geometric mean of the factors, is presented in the supplementary tables S1.3-S1.6. In this section (Fig. 4), we depict the interelement connections of strengths, weaknesses, opportunities, and threats. For example, local weather support (S1) is considered 40 % more important than vertical farming (S5) and 33 % more crucial than employment generation for women (S3). Conversely, S3 is deemed 15 % more significant than S1 for the growth of the mushroom industry in Bangladesh.

Moreover, SWOT factors are weighted locally and globally to facilitate decision-making and strategy development. The SWOT rank was determined as O > W > S > T. Leveraging the opportunities in the mushroom farming sector, seizing more opportunities, and confronting threats will effectively mitigate weaknesses, fostering the industry's success. The ranked order of the strength factors is S1 > S5 > S2 > S3 > S4. In the first place, there is a need to vigorously explore the potential of mushroom farming by utilizing local weather and vertical farming, which supports higher production per area with the family support. Secondly, this approach empowers women through employment generation while ensuring nutritious food security.

Conversely, the ranked order of the weakness factors is W6 > W7 > W4 > W5 > W1 > W8 > W2 > W3. Issues such as spawn quality, challenges in supplying fresh mushrooms to distant places, middleman influence, and lack of market coordination leading to the impact of quarterly changes in sales and profit margin, hindering the normal operation of the farm. Additionally, the absence of automation and affordable technology is also a negative contributing factor. The lack of grading according to size, freshness, quality and labelling corresponds to conventional weakness in the exploration of mushroom farming in Bangladesh.

Progressively, the ranked order of the opportunity factors is O2 > O4 > O3 > O6 > O1 > O5 > O7. By expanding production throughout all seasons, providing training facilities with appropriate durations, ensuring easy access to startup information, and capitalizing on diverse breed growing opportunities in the existing natural environment, we can promote good health at a lower cost and offer technical support for farm development, bringing economic and social benefits to society.

In contrast to the strength and opportunity, the ranked order of the threat factors is extracted as T2 > T4 > T1 > T3. In Bangladesh, especially due to food habits, phobias, and superstitions about mushrooms, there is a significant challenge to expanding this farm. Simultaneously, low market demand is an obstacle to this industry's growth.

3.4. SWOT-strategies

In the assessment of SWOT strategies using the Grey-TOPSIS method, the evaluation focused on categorizing subfactors under strengths and opportunities as beneficial, attributing their significance to their elevated importance in the context of the mushroom industry. Conversely, weaknesses and threats were deemed as cost factors, signifying the potential negative impacts on the industry. This distinction allowed experts to approach each strategy with a nuanced understanding, considering the potential gains and costs associated with them. Experts evaluated each strategy based on AHP-SWOT outcomes. The overarching objective was to capitalize on existing strengths strategically, address identified weaknesses, explore promising opportunities, and effectively tackle potential threats.

The ranking results underscored the preeminent importance of forming partnerships with organizations. This top-ranking strategy aims not only to secure funding (relative closeness, $C^{+} = 0.87$) but also to provide more accessible loan options (W1O4), envisioning a

Table 4
SWOT strategy raking using Grey-TOPSIS methods for upgrading the mushroom industry in Bangladesh.

SWOT Strategies	Positive Distances (d^+)	Negative Distances (d^-)	Relative Closeness (C^+)	Rank
S2O3	0.252	0.172	0.406	12
S2T4	0.146	0.268	0.648	5
S3O5	0.112	0.258	0.697	2
S3T3	0.112	0.247	0.688	3
S4T4	0.120	0.233	0.659	4
S5O2	0.192	0.218	0.532	9
W1O4	0.044	0.298	0.871	1
W1T3	0.146	0.268	0.648	6
W2O6	0.234	0.182	0.437	11
W3T1	0.197	0.201	0.505	10
W4T3	0.146	0.225	0.608	7
W7O1	0.152	0.225	0.597	8

Table 5
Sensitivity analysis of SWOT strategy ranking using Manhattan, Euclidean and Minkowski distance measure.

SWOT strategy	Ranking Manhattan Distance (P = 1)	Ranking Euclidean Distance (P = 2)	Ranking (Minkowski Distance (p = 3)	Ranking (Minkowski Distance (p = 4)
S2O3	10	12	10	11
S2T4	5	5	5	5
S3O5	2	2	2	2
S3T3	3	3	3	3
S4T4	4	4	4	4
S5O2	9	10	9	9
W1O4	1	1	1	1
W1T3	6	6	6	6
W2O6	12	11	11	10
W3T1	11	8	12	12
W4T3	7	7	7	7
W7O1	8	9	8	8

strategic expansion of business operations in Bangladesh (Table 4). The imperative here is clear establishing robust collaborations with external entities to bolster financial resources and support accessibility to essential funding.

Moreover, the evaluation highlighted the significance of collaboration within the industry itself. The results indicated that collaborating with other mushroom farmers is essential to coordinate product marketing efforts (S3O5), thereby contributing to an increase in market demand ($C^+ = 0.697$). This collaborative approach acknowledges the interconnected nature of the industry and emphasizes the collective effort needed to fortify its market presence (Table 4). While the emphasis on partnerships and collaboration is evident, the results also shed light on the importance of product diversification (S3T3). This entails expanding the range of mushroom products and accompanying marketing strategies to appeal to broader markets and thereby increase overall demand. Simultaneously, a crucial aspect highlighted in the results is the necessity of providing clear and comprehensive information to consumers regarding the nutritional benefits of mushroom consumption (S4T4). This transparency is deemed vital in overcoming existing food habits and fostering a positive perception among consumers.

3.5. Sensitivity analysis

To assess the plasticity of the SWOT-strategy ranking, we employed Manhattan, Minkowski, and Euclidean distance functions to evaluate whether variations in the distance measurement operator impacted the study outcomes (Table 5). Observing the results, it becomes apparent that different p values influence the rankings of only a few alternatives. However, the overall impact is not substantial. Consequently, it can be inferred that the results are robust and can be considered reliable, with the variations in distance measurement having a limited effect on the final rankings.

4. Discussion

Developing potent strategies and realistic policies could popularize mushroom farming, providing a supplementary source of nutritious food in the diet. With this in mind, the study identified the key factors driving the industry and highlighted strategies for sustainable growth, particularly through the use of recyclable agri-waste.

4.1. Key drivers for mushroom industries

Mushroom cultivation has emerged as a promising enterprise due to its relatively low capital investment requirements [29]. One notable advantage is the flexibility to easily adjust the farm size based on available capital and labour resources. The availability of land and labour plays a crucial role in driving the profitability of mushroom cultivation (Table 3). Diverse scales of operations, ranging from small-scale family-run farms to larger enterprises heavily dependent on extensive land and labour, contribute to the variability in mushroom farming. The size of the farm proves to be a significant determinant of profitability (Table 3). Family-operated small-scale farms, where members actively engage in tasks such as substrate filling, nurturing, marketing, and harvesting, experience an augmented profit margin. This heightened involvement, particularly by women, not only enhances financial outcomes but also serves as a conduit for women's empowerment, fostering skills, financial independence, and self-respect.

Our findings are consistent with those of [30], who identified several key determinants of mushroom cultivation in Western Kenya. Spawn price, spawn quality, post-harvesting costs, marketing strategies, and storage facilities were critical factors influencing the success of mushroom cultivation in that region. Similarly, in Bangladesh, changes such as loan issues, spawn costs, and profit margins have discouraged some farm owners from continuing mushroom cultivation, negatively affecting overall profitability. The significance of training sessions in addressing the technical aspects of mushroom cultivation is evident. Farmers can significantly enhance their technical efficiency with at least one month of training regardless of their formal education. This observation holds not only for Bangladesh as also evidently reported in [19] but also for other regions, such as Vietnam [31], India [32], Turkey [33]. The success and profitability of mushroom cultivation are more influenced by practical training than by the farmers' prior experience in the field. The findings of [30,32,33] align with this perspective, highlighting the transformative impact of training on the overall success and profitability of mushroom cultivation.

Though the global demand and consumption of mushrooms are steadily rising, including in Bangladesh [34]. However, domestic mushroom production falls short of meeting the national demand, leading to substantial imports each year [35]. Due to high market demand, favorable climatic conditions, and a strong benefit-cost ratio, mushroom cultivation presents a profitable opportunity in Bangladesh. Nevertheless, cultivators encounter several challenges when initiating mushroom cultivation. Successful cultivation requires growers to possess at least a basic understanding of mushroom cultivation, undergo proper training, and secure sufficient capital. Unfortunately, there is a lack of training centers across the country, coupled with limited access to financial resources [35]. Moreover, additional constraints include the availability of high-quality spawn, inadequate equipment, insufficient storage facilities for harvested mushrooms, and reliance on traditional storage methods. As a result, farmers often feel compelled to expedite mushroom cultivation.

4.2. Towards sustainability in the mushroom industry

Exploring the potentiality of the mushroom industry in Bangladesh from a sustainability and waste utilization perspective reveals abundant opportunities and strategic strengths, though some inherent challenges warrant attention (Table 1). The industry is poised for sustainable growth due to a favorable balance between opportunities and threats (Fig. 4). Notably, the region's favorable climatic conditions present a significant advantage (S1, 0.63 global weight), ensuring optimal conditions for mushroom cultivation. Moreover, the ability to utilize biomass waste (S1) as substrates aligns with the ethos of sustainability, presenting the dual benefits of waste management and resource utilization [36,37]. Additionally, the prevalence of vertical farming practices (S5, 0.031 global weight) and the robust support from family labor (S2) underscore the resourcefulness within the sector. These strengths not only enhance operational efficiency but also align with the broader goal of sustainable and community-driven agriculture.

In pursuing sustainable practices, the mushroom industry benefits from access to free training facilities (Table 1). Studies [35,36] have shown that regardless of the farm owner's socio-economic background and educational level, proper training can lead to profitable outcomes. These training facilities present a valuable opportunity for knowledge dissemination and skill enhancement among cultivators, fostering a culture of continuous learning. The recycling of substrates further aligns with sustainable principles, reducing waste and promoting a circular economy within the industry [38,39]. However, despite these positive aspects, the industry faces weaknesses that require strategic attention. Challenges related to spawn quality, difficulties in transporting fresh mushrooms, and the influence of middlemen pose hurdles to the industry's optimal functioning (Fig. 4, Table 1). Addressing these issues, as identified in the SWOT strategy evaluation, is crucial for the industry's sustained growth.

4.3. Suggested strategies for mushroom industries

To boost the mushroom industry in Bangladesh, it is imperative to formulate strategies, a task that was accomplished in our study using TOPSIS modeling. The goal is to maximize the utilization of strengths and opportunities while minimizing weaknesses and threats faced by the industry. In Bangladesh, particularly for small-scale businesses, a major challenge is the lack of easy access to loans or funding, which differs significantly from countries like Nigeria [40] and Zimbabwe [41]. Our study identifies a paramount strategy (S2O3), emphasizing the need to partner with organizations or industries to secure funding and advocate for more favorable policies to streamline loan accessibility (Table 5).

Simultaneously, it is crucial to maintain sustainable production in parallel with collaborative efforts among mushroom farms. This collaboration addresses fragile marketing linkages and aims to produce standardized and reliable products, ultimately increasing market demand. The study [42], also recommends partnerships between mushroom agro-industry and raw material suppliers in Indonesia. Similar outcomes were found in mushroom entrepreneurship [43] in the Himalayan Region of West Bengal, India.

Customer preferences, particularly regarding mushrooms' nutritional and medicinal value, play a pivotal role in controlling market demand. The study [17], identified that rural residents often lack awareness of the nutritional benefits of mushrooms, sometimes avoiding them altogether due to misconceptions about poisonous fungi. Biswas et al. [44], found that training and awareness are

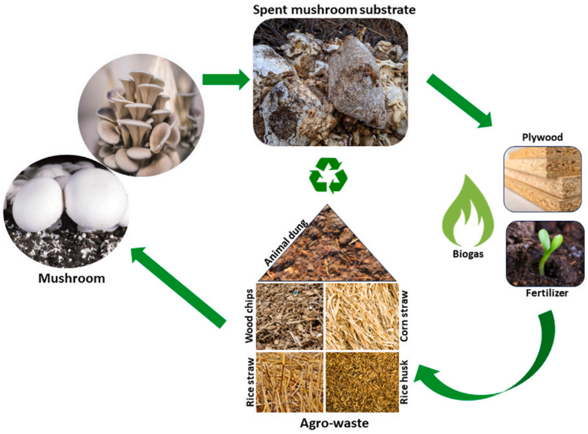

Fig. 5. Use agri-waste materials as a mushroom substrate and reuse them for fertilizer, biogas and other uses.

crucial in changing the perceptions about the edibility of mushrooms. Therefore, providing consumers clear information about mushroom consumption's benefits, as identified in the SWOT strategy (S4T4), is essential. This can be achieved through awareness campaigns or by producing mushroom-based cookies or cakes in collaboration with other food industries. Such initiatives not only reduce superstitions and misconceptions within communities but also contribute to market diversification (S3T3).

The influence of the middleman poses another constraint on profitability (S2T4), a situation similar to that observed in India [45] To address this, it is crucial to reduce the impact of middlemen by developing and implementing effective marketing and sales strategies. To ensure customer satisfaction, standardized product quality, proper packaging, and accurate labelling are also recommended. Additionally, maintaining a robust supply chain is essential, allowing producers to supply both fresh and dried forms of mushrooms in the market.

4.4. Recycling of waste/spent mushroom substrate

Various agricultural wastes, such as jute waste and rice straw, are used as raw materials in the mushroom industry. However, the generation of the waste mushroom substrate during the post-harvesting process presents a significant concern [46]. Recently, the increasing focus on circular and sustainable economies has sparked interest in recycling spent mushroom substrate (SMS). Adopting a zero-waste policy (Fig. 5) by recycling spent mushroom compost (SMC) not only minimizes waste but also creates a supplementary income stream for the mushroom industry. Several studies [46–49] have explored its applications as a fertilizer, soil conditioner, and in horticulture. It also holds promise in the renewable energy sector, where it can be used as fuel pellets or biofuel feedstock [50,51]. Furthermore, SMS can contribute to biogas production and serve as an effective adsorbent in wastewater treatment [52]. Moreover, SMS can be repurposed in the production of particle boards [53]. This presents a transformative opportunity (Fig. 5) for developing countries like Bangladesh, India, and Nepal, where sustainable practices drive both economic growth and environmental stewardship.

5. Conclusions

The increasing levels of agricultural and food waste pose significant environmental challenges, particularly in developing nations struggling with uncontrolled waste disposal. Expanding the mushroom industry offers a promising opportunity to address this issue through sustainable production. However, realizing this potential necessitates a comprehensive preliminary investigation into various aspects of strength and challenges involved. This study meticulously examines key factors essential for implementing strategies and policies that promote the intensive use of waste and cost-effective, sustainable mushroom production in Bangladesh. It underscores the importance of preparatory proceedings in shaping a robust framework for the mushroom industry in Bangladesh. Establishing a policy hierarchy provides a foundational guide and strategic roadmap for sustainable mushroom cultivation in the country. The analysis is specifically tailored to Bangladesh's socio-economic and political landscape, ensuring contextual relevance. Although the study primarily focuses on Bangladesh, its findings and policy framework hold potential applicability to countries facing similar socio-economic and political conditions. The transferability of the proposed strategy to such nations lies in its adaptability to diverse contexts. By addressing environmental concerns associated with waste disposal and promoting cost-effective mushroom cultivation, this approach could serve as a model for enhancing agricultural sustainability and economic development in Bangladesh and beyond.

Data availability

Data will be available upon request.

CRediT authorship contribution statement

Biplob Dey: Writing – original draft, Visualization, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Md Ahosan Habib Ador:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Mohammed Masum Ul Haque:** Writing – review & editing, Project administration, Investigation, Conceptualization. **Jannatul Ferdous:** Writing – review & editing, Resources, Methodology, Formal analysis, Data curation. **Md Abdul Halim:** Writing – review & editing, Resources, Project administration, Methodology, Investigation. **Mohammad Belal Uddin:** Writing – review & editing, Validation, Software, Resources, Project administration, Investigation. **Romel Ahmed:** Writing – review & editing, Validation, Supervision, Project administration, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36956.

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