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PRIORITIZING STRATEGIES FOR PHYTOBIOTIC UTILIZATION IN SMALLHOLDER POULTRY FARMING USING AN INTEGRATED SWOT–PESTEL–AHP FRAMEWORK

Sri Purwanti [1,2*], Jamilah [1], Gemini Alam [3], Abdul Alim Yamin [1], Ichlasul Amal [4], Jasmal Ahmari Syamsu [1,5], Eric Lim Teik Chung [6] and Muhammad Umair Asghar [7]

[1]Faculty of Animal Science, Universitas Hasanuddin, Makassar, Indonesia
[2]Poultry Nutrition and Feed Research Group, Universitas Hasanuddin, Makassar, Indonesia
[3]Faculty of Pharmacy, Universitas Hasanuddin, Makassar, Indonesia
[4]Animal Feed Technology Study Program, Faculty of Vocational Studies, Universitas Hasanuddin, Makassar, Indonesia
[5]Center of Research and Development for Livestock Resources and Tropical Animals, Universitas Hasanuddin, Makassar, Indonesia
[6]Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, Malaysia
[7]Department of Animal Nutrition and Feed Management, Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland

**Corresponding author*: sripurwanti@unhas.ac.id

ABSTRACT

Phytobiotics have the potential to be used as feed additives to support healthier, safer, and more sustainable poultry production. However, their use on smallholder poultry farms is still influenced by farmers' readiness, economic feasibility, technical support, field evidence, partnerships, product access, and regulatory clarity. This study aims to formulate and determine the priority strategy for using phytobiotics as feed additives on smallholder poultry farms by integrating PESTEL-TOWS and the Analytical Hierarchy Process (AHP). The research uses a mixed-methods approach, including farmer and stakeholder questionnaires, observations, supporting interviews, FGDs, expert validation, and AHP assessments. Respondents comprised 20 smallholder poultry farmers, 20 stakeholders, and 9 experts. The data were analyzed descriptively to identify internal and external factors, then formulated into 24 alternative strategies through PESTEL–TOWS matching. The alternative strategies are then prioritized using AHP based on the dimensional weight of the PESTEL and the local weight of the TOWS strategy. The results of the study show that the economic dimension gained the highest weight, followed by the social and technological dimensions. The five core priority strategies are the development of phytobiotic products in small packaging and an economical use model; practice-based training; preparation of technical SOPs for use; the use of policy support and partnerships for education and mentoring; and the development of local phytobiotic products that are compatible with commercial feed and combination feed. The dominance of the WO strategy indicates that the initial stage of phytobiotic utilization should focus on addressing farmers' internal weaknesses through external opportunities, particularly economic access, technical capacity, mentoring, SOPs, and product compatibility.

Keywords: Phytobiotic; Feed additive; Smallholder poultry farming; PESTEL; SWOT; AHP; Priority strategy.

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1. INTRODUCTION

Smallholder poultry production plays an important role in providing animal protein, generating household income, and strengthening the economy of small-scale farming. However, this production system still faces pressure regarding feed efficiency, livestock health, production costs, product safety, and market demand for healthier and more sustainable cultivation practices (Swamilaksita & Sukandar, 2023; Kehinde, 2026). In modern poultry nutrition systems, feed additives are used to support productivity, digestive tract health, feed efficiency, livestock welfare, and to reduce environmental impact in production (Perera & Ravindran, 2025). At the same time, interest in natural feed additive alternatives is growing due to restrictions on the use of antibiotic growth promoters, residue concerns, and concerns about antimicrobial resistance (Abd El-Hack et al., 2022; Jambwa et

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al., 2023; Rodrigues et al., 2025). Studies on natural feed additives have demonstrated their potential to improve intestinal morphology, digestive tract development, nutrient absorption efficiency, and overall gut health, all of which are important biological mechanisms that support poultry productivity and health (Auza et al., 2021). Previous sustainability assessment further indicated that phytobiotic adoption provides strong ecological and economic benefits but remains constrained by institutional, technological, and social factors, highlighting the need for well-prioritized implementation strategies (Purwanti et al., 2025). This situation creates an important entry point for phytobiotics as natural feed additives that may support safer, healthier, and more sustainable poultry production.

Phytobiotics or phytogenic feed additives are plant-derived products containing bioactive compounds that can enhance gut health, immunity, production performance, product quality, and feed utilization efficiency in poultry. Numerous studies have reported their positive effects on poultry performance, meat quality, gut microbiota, and health status (Aljumaah et al., 2020; Jahja et al., 2023; Khatun et al., 2023; Fonseca et al., 2024; Javanmiri et al., 2024), making them promising alternatives in antibiotic-free production systems due to their antioxidant, antimicrobial, and anti-inflammatory properties (Alem, 2024). However, their efficacy varies across materials and production systems, and is influenced by formulation and delivery technologies, resulting in inconsistent outcomes under commercial conditions (Martinez et al., 2020; Irawan et al., 2021; Nantapo & Marume, 2025). These limitations may pose biological, technical, and economic barriers to the adoption of phytobiotics in smallholder poultry farming.

The potential of phytobiotics does not automatically guarantee their successful adoption in smallholder poultry farms. Implementation at the farmer level is influenced by technical knowledge, experience with feed additives, perceived benefits, product availability, price, mentoring, field evidence, and the product's technological suitability for existing feed practices. Studies on chicken farmers in Ethiopia show that phytogenic feed additives are available and have been used at the farmer level, but their use still faces undefined dosage issues and the need to verify their benefits for chicken performance (Yegrem et al., 2025). From an innovation adoption perspective, farmers' decisions to adopt phytobiotics are influenced by their perceived benefits, compatibility, complexity, and practicality (Rogers, 2003). In smallholder poultry systems, adoption is often constrained by limited technical knowledge, uncertain economic returns, inadequate input supply, weak extension services, and poor alignment with existing farming practices (Glover et al., 2019; Davis et al., 2021; Pawera et al., 2024; Oli et al., 2025). Therefore, effective adoption strategies must address both farmer-level readiness and broader political, economic, social, technological, environmental, and regulatory factors.

The development of phytobiotics as feed additives requires a strategic approach that addresses both technical and non-technical factors. The PESTEL framework can be used to identify external factors derived from political, economic, social, technological, environmental, and legal dimensions. These external factors can then be combined with the internal strengths and weaknesses through SWOT analysis, while the TOWS matrix provides a structured basis for formulating SO, WO, ST, and WT strategy alternatives. The use of PESTEL–SWOT has been developed in various strategy studies because it connects macroenvironmental mapping with strategy formulation based on strengths, weaknesses, opportunities, and threats (David et al., 2019; Vardopoulos et al., 2021; Bimo et al., 2022; Dioba et al., 2025). However, the formulation of many alternatives creates further analytical needs. For this reason, the Analytical Hierarchy Process (AHP) is relevant because it allows expert judgments to be converted into priority weights through pairwise comparisons and consistency assessment.

Based on this description, this study aims to formulate and prioritize strategies for the utilization of phytobiotics as feed additives in smallholder poultry farming through an integrated PESTEL–TOWS–AHP approach. Specifically, this study identifies farmers' internal readiness, analyzes external strategic factors using the PESTEL framework, formulates strategy alternatives through PESTEL-based TOWS matching, and determines priority strategies using AHP. The findings are expected to provide a more operational basis for directing phytobiotic development toward strategies that are technically feasible, economically accessible, socially acceptable, institutionally supported, and aligned with field-level implementation needs in smallholder poultry farming.

2. MATERIALS AND METHODS

2.1. Research Design

In accordance with the research flow shown in Fig. 1, primary data were obtained through farmer questionnaires, stakeholder questionnaires, field observations, supporting interviews, focus group discussions, and expert validation. Farmer questionnaire data were used to assess the internal readiness of smallholder poultry farms (strengths and weaknesses), and stakeholder questionnaire data were used to identify external strategic factors based on the PESTEL dimensions.

Quantitative data were analyzed descriptively using frequency tabulation, percentages, mean scores, and score indices. The transformation of farmer questionnaire findings into internal SWOT factors was carried out through a staged interpretive process. The farmer questionnaire was designed to assess internal conditions relevant to phytobiotic adoption, rather than to function as a direct SWOT checklist. It consisted of 32 items, which were organized into seven domains: respondent and farm characteristics (6 items), feeding and production practices (4 items), phytobiotic knowledge (4 Likert-scale items), perceptions of phytobiotics (5 items), constraints to phytobiotic use (5 items), adoption interest and opportunities (4 items), and supporting environment (4 items). Internal Strengths (S) and Weaknesses (W) were derived from the directional meaning of questionnaire domains, descriptive response patterns, and contextual interpretation. Farm characteristics and feeding-practice items were used to interpret the enabling or limiting features of the production system, such as the rearing system, feed source, farm scale, and previous feed-additive experience. Knowledge, perception, adoption-interest, and support-environment items were interpreted as potential Strengths when their scores or response patterns indicated readiness, positive perception, willingness to adopt, access, or support, and as Weaknesses when they indicated limited knowledge, uncertainty, limited access, or insufficient support. Constraint items were interpreted in the opposite direction, with higher scores indicating greater internal weaknesses or adoption barriers. The preliminary internal factors were then triangulated with stakeholder FGDs and expert validation before being used in the PESTEL-based TOWS matching stage.

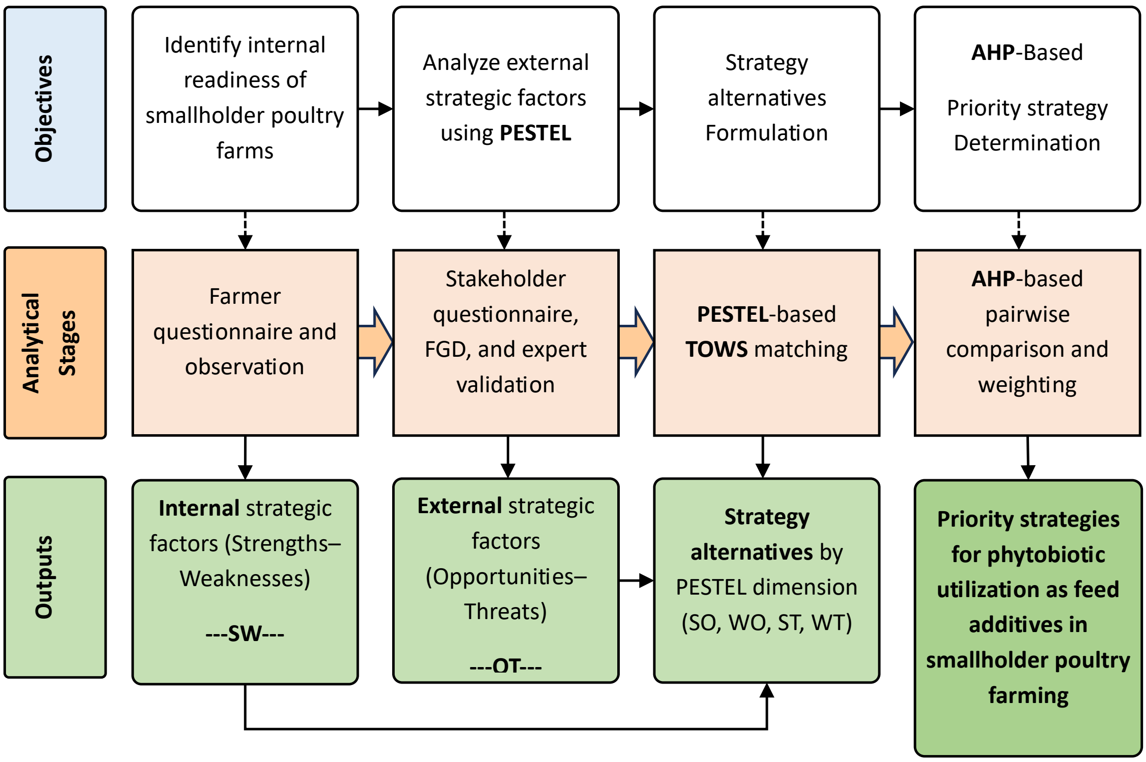

Fig. 1: Analytical workflow for formulating and prioritizing phytobiotic utilization strategies in smallholder poultry farming using PESTEL–TOWS and AHP.

External Opportunities (O) and Threats (T) were derived from the stakeholder questionnaire, which was structured according to the six PESTEL dimensions. In contrast to the farmer questionnaire, which was used to identify internal Strengths and Weaknesses, the stakeholder questionnaire was designed to capture external enabling and constraining conditions affecting phytobiotic utilization. Within each PESTEL dimension, items reflecting policy support, partnership potential, local raw material availability, market opportunities, technology transfer, sustainability pressure, standardization, and certification prospects were interpreted as sources of Opportunities. Conversely, items reflecting weak implementation support, cost and scale constraints, limited technical facilities, insufficient field evidence, unclear standards, weak oversight, or regulatory uncertainty were interpreted as sources of Threats.

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The resulting strategy alternatives were subsequently evaluated using the Analytical Hierarchy Process (AHP). Expert-based pairwise comparisons were conducted to determine the relative importance of PESTEL dimensions and the priority of TOWS strategy alternatives within each dimension. The final priority strategies were determined using global AHP weights, obtained by multiplying the weight of each PESTEL dimension by the local weight of each strategy alternative.

2.2. Research Respondents, Sampling, and Data Collection

The respondents consisted of three purposively selected groups. The first group included 20 smallholder poultry farmers from various poultry enterprises, with flock sizes ranging from approximately 500 to more than 5,000 birds. Data from this group were collected through interview questionnaires to describe farm characteristics, feeding practices, feed additive use, knowledge, perceptions, constraints, adoption interest, and supporting conditions for phytobiotic utilization. The second group consisted of 20 stakeholders involved in phytobiotic development, feed systems, poultry farming, technical assistance, policy support, and livestock product value chains. This group included poultry farmers, extension officers, feed industry representatives, local government representatives, and academics. Data were collected using semi-closed questionnaires to identify external strategic factors based on PESTEL dimensions, and the results were further verified through focus group discussions and supporting interviews.

The use of 20 farmer respondents and stakeholder respondents was considered appropriate for this exploratory strategic assessment because the data collection was intended to provide a diagnostic baseline of farmer readiness and stakeholder perspectives, rather than to estimate population parameters. Respondents were purposively selected as information-rich cases, given their direct involvement in poultry farming, feeding practices, feed additive use, technical assistance, policy support, feed systems, or phytobiotic development. In qualitative and mixed-methods research, sample adequacy is commonly assessed by the relevance and depth of information obtained, as well as the extent to which additional interviews yield little new information, rather than by statistical representativeness alone (Guest et al., 2006; Patton, 2014; Creswell, 2018). Guest et al. (2006) also showed that thematic saturation in qualitative interviews can occur within the first twelve interviews, although sample adequacy still depends on the study purpose, participant relevance, and the depth of information obtained.

The third group involved nine experts representing five stakeholder groups: two experts from government/policy institutions, two from academia, two from the feed industry, two phytobiotic researchers, and one smallholder poultry farmer. These experts were engaged to validate strategic factors, assess strategic alternatives, and provide pairwise-comparison judgments for the AHP stage. The number of experts was considered adequate because expert-based strategic analysis emphasizes the relevance, diversity, and credibility of expertise rather than large sample size. In decision-making and Delphi-based evaluations, relatively small expert panels can provide reliable judgments when participants are selected based on clear expertise and direct relevance to the problem being assessed (Dalkey, 1969; Adler & Ziglio, 1996; Hsu & Sandford, 2007). In the AHP stage, the reliability of expert judgments was also assessed using the consistency ratio, in line with the principle that the acceptability of pairwise comparison data depends on both judgment consistency and expert relevance (Saaty & Özdemir, 2014).

2.3. Analytical Procedures and Strategy Prioritization

2.3.1. PESTEL-Based External Environment Analysis: PESTEL (Political, Economic, Social, Technological, Environmental, and Legal) analysis is used to identify external environmental factors that affect the use of phytobiotics as feed additives on smallholder poultry farms (Dioba et al., 2025). This approach aims to provide an overview of macro-level conditions that can be opportunities or obstacles to the development of feed technology based on natural ingredients. The PESTEL analysis was carried out based on the results of a stakeholder questionnaire that included statements on the political, economic, social, technological, environmental, and legal dimensions. Stakeholder questionnaire items were rated on a five-point Likert scale and analyzed using average score and score index.

The initial results of the PESTEL analysis were verified and deepened through stakeholder FGD to ensure the suitability of the interpretation of external factors with the context of phytobiotic development in smallholder poultry farms. External factors are not drawn solely based on the highest score, but through the directional interpretation of the meaning of the statement as a driving or inhibiting factor. Statements with a high average score and positive meaning are grouped as opportunities, while statements that indicate risks, limitations, or implementation prerequisites are grouped as Threats. The grouping forms the basis for preparing the opportunity and threat components of the SWOT analysis.

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***2.3.2. PESTEL-TOWS-Based Strategy Formulation*:** SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis (Kurttila et al., 2000; Dioba et al., 2025) was used to identify internal and external factors influencing the use of phytobiotics as feed additives in smallholder poultry farms. The internal factors analyzed in this study include various aspects arising from the poultry business's internal conditions and the use of feed technology. Meanwhile, external factors identified in the PESTEL analysis included macro-environmental conditions that can present opportunities and threats for the development of phytobiotic-based feed additive technology.

The identified internal and external factors are then used in the strategy-matching stage through a SWOT matrix based on the PESTEL dimensions. In this stage, the internal factors of farmers in the form of Strength (S) and Weakness (W) are matched with external factors in the form of Opportunity (O) and Threat (T) in each dimension of PESTEL, namely Political (P), Economic (EK), Social (SOC), Technological (TE), Environmental (EN), and Legal (LG). The technical structure of the matching is shown in Table 1.

Table 1: Technical structure of the PESTEL-based SWOT matching stage for formulating phytobiotic utilization strategies

EF	O						T					
IF	P	EC	SOC	TE	EN	LG	P	EC	SOC	TE	EN	LG
S	Alt.St SO_{P1} .... Alt.St SO_{Pn}	Alt.St SO_{EC}	Alt.St SO_{soc}	Alt.St SO_{TE}	Alt.St SO_{EN}	Alt.St SO_{LG}	Alt.St ST_{P}	Alt.St ST_{EC}	Alt.St ST_{SOC}	Alt.St ST_{TE}	Alt.St ST_{EN}	Alt.St ST_{LG1} …. Alt.St ST_{LGn}
W	Alt.St WO_{P1} … Alt.St WO_{Pn}	Alt.St WO_{EC}	Alt.St WO_{soc}	Alt.St WO_{TE}	Alt.St WOE_{N}	Alt.St WO_{LG}	Alt.St WT_{P}	Alt.St WT_{EC}	Alt.St WT_{SOC}	Alt.St WT_{TE}	Alt.St WT_{EN}	Alt.St WT_{LG1} … Alt.St WT_{LGn}

S = Strength; W = Weakness; O = Opportunity; T = Threat. PESTEL dimensions consist of Political (P), Economic (EC), Social (SOC), Technological (TE), Environmental (EN), and Legal (LG). Alt.St = Alternative strategy.

The SO strategy is formulated by matching the breeder's internal strengths with external opportunities across each dimension of PESTEL. The WO strategy is developed by leveraging external opportunities to overcome farmers' internal weaknesses. The ST strategy is formulated by using internal forces to respond to external threats, while the WT strategy is directed at minimizing internal weaknesses and anticipating threats in each dimension of PESTEL. To avoid ambiguity between PESTEL dimensions and SWOT components, this study uses specific codes for each PESTEL dimension.

***2.3.3. AHP-Based Strategy Prioritization*:** Prioritization of alternative strategies was carried out using the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method that arranges problems into hierarchies, compares elements in pairs, calculates priority weights, and tests the consistency of expert assessments (Saaty, 2008). AHP was relevant to use in this study because alternative strategies generated through PESTEL–TOWS needed to be ranked based on their relative importance. The integration of SWOT/TOWS with AHP is also widely used in strategy studies to transform qualitative formulation results into more operational quantitative priorities (Kurttila et al., 2000; Vardopoulos et al., 2021).

The AHP hierarchy in this study consists of three levels. The first level is the main goal and priority strategy for using phytobiotics as feed additives on smallholder poultry farms. The second level consists of six PESTEL dimensions as criteria: political, economic, social, technological, environmental, and legal. The third level consists of four alternative TOWS strategies for each PESTEL dimension: SO, WO, ST, and WT. Comparisons of alternative strategies were conducted within each PESTEL dimension, rather than comparing all 24 strategies directly in a single matrix (Fig. 2).

Pairwise comparisons were conducted using the AHP fundamental scale of 1–9. Expert judgment data were processed using AcideLogicAHP version 4.2.8 through the group decision-making panel. Individual pairwise-comparison judgments from the nine experts were aggregated using the geometric mean method for each element of the pairwise-comparison matrices. This aggregation was applied both to the comparison among the six PESTEL criteria and to the comparison among the four TOWS strategy alternatives within each PESTEL dimension.

The aggregated matrices were then used to calculate priority weights for the PESTEL criteria and local priority weights for the TOWS strategy alternatives. Judgement consistency was assessed using the maximum lambda value (λmax), consistency index (CI), and consistency ratio (CR), with a CR value of ≤ 0.10 as the acceptable consistency limit. The global weight of each strategy was then calculated by multiplying the weight of the PESTEL dimension by the local weight of the TOWS strategy on that dimension. All 24 strategy alternatives were then ranked based on their global weight. To formulate a more focused and operational

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strategy, the five strategies with the highest global weight were selected as core priority strategies, while the other alternatives were positioned as supporting strategies for the advanced implementation stages. The detailed aggregated pairwise comparison matrices and weighting calculations underlying these priority values are presented in the supplementary.

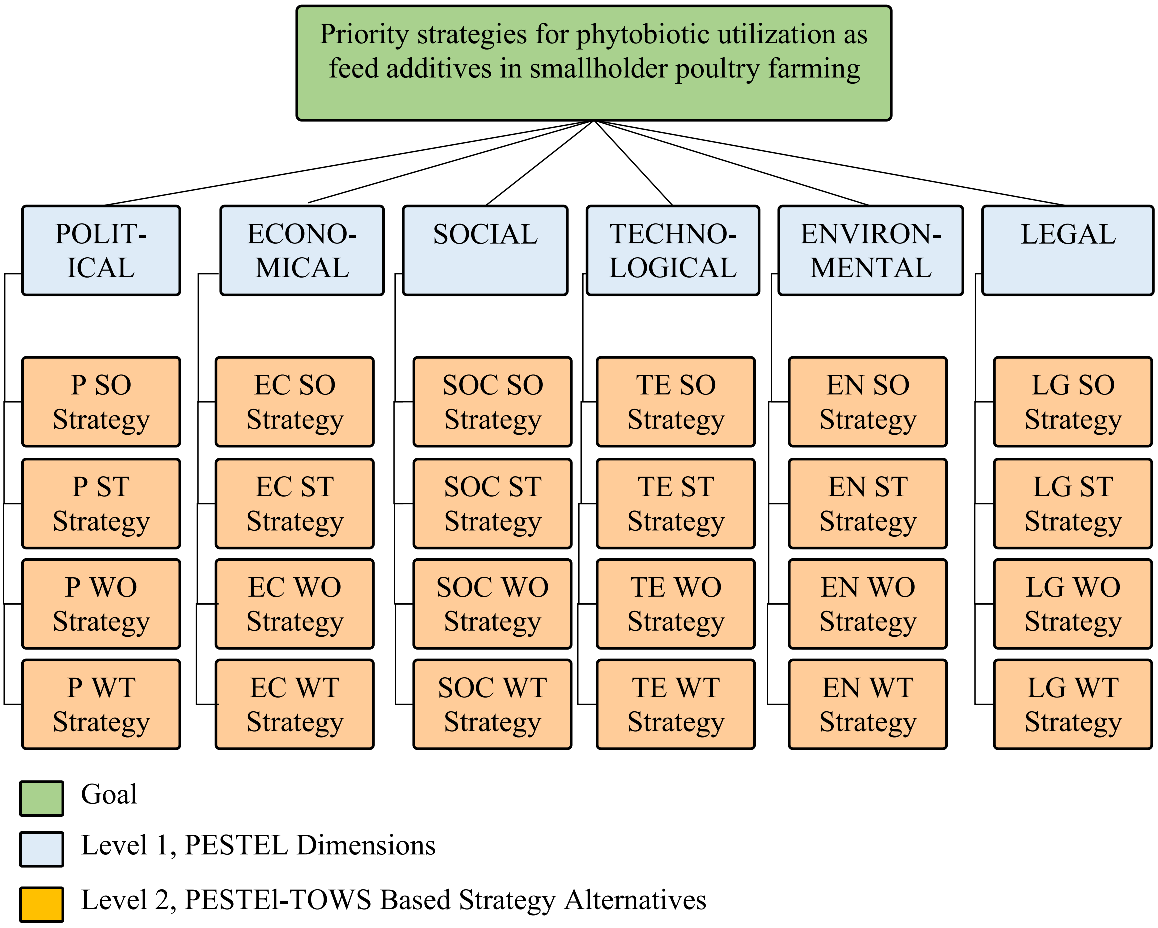

Fig. 2: AHP hierarchy for prioritizing PESTEL–TOWS strategies for phytobiotic utilization as feed additives in smallholder poultry farming.

3. RESULTS AND DISCUSSION

3.1. Farmers' Readiness for Phytobiotic Adoption

The survey results (Table 2) show that respondents come from several types of poultry businesses, including broilers, laying hens, local chickens, and ducks. This composition shows that the research is not limited to a single poultry commodity but reflects the variation in smallholder poultry businesses relevant to the use of feed additives. The scale of livestock population also varies, ranging from small-scale to more than 5,000 birds, so that respondents can be understood as smallholder poultry business actors with varying levels of business capacity.

Regarding rearing practices, most respondents have adopted intensive and semi-intensive systems. This pattern shows that rearing activities are relatively controlled, especially in feeding and daily management. The feeding practice also shows the dominance of commercial and combination feeds, indicating that farmers have become quite accustomed to feed inputs from outside the business system. The use of feed additives was relatively common among respondents, with antibiotics being the most widely used, followed by herbal products and probiotics. This pattern suggests that farmers already have practical experience with feed additives, providing an initial entry point for introducing phytobiotics. However, phytobiotics have not yet become an established practice in farmers' feeding management.

The general overview indicates an initial basis for phytobiotic development, particularly through farmers' experience with feed additive use, relatively controlled rearing systems, and the use of commercial or combined feed. However, variations in farm scale and the limited use of herbal/phytobiotic products suggest that the

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introduction of phytobiotic products should be tailored to farmers' technical capacity, feeding practices, and enterprise characteristics.

3.2. Strategic Conditions for Phytobiotic Utilization

Preliminary internal factors derived from the farmer questionnaire, field observations, and supporting interviews were reviewed through stakeholder FGD to confirm their contextual relevance and classification as Strengths or Weaknesses. The agreed factors were subsequently validated by the expert panel and retained as final internal strategic factors for the PESTEL-based TOWS matching stage. These factors are presented in Table 3.

Table 2: Characteristics of farming enterprises and feeding practices among smallholder poultry farmers

Variable	Category	Frequency (n)	Percentage (%)
Type of poultry raised	Broiler	5	25.0
	Layer	5	25.0
	Native chicken	6	30.0
	Duck	4	20.0
Flock size per cycle	< 500 birds	6	30.0
	500–1,000 birds	2	10.0
	1,001–5,000 birds	5	25.0
	> 5,000 birds	7	35.0
Poultry farming experience	< 2 years	6	30.0
	2–5 years	5	25.0
	6–10 years	3	15.0
	> 10 years	6	30.0
Rearing system	Intensive	11	55.0
	Semi-intensive	7	35.0
	Traditional	2	10.0
Main feed type	Commercial feed	12	60.0
	Self-formulated feed	1	5.0
	Mixed feed	7	35.0
Feeding frequency	Once a day	2	10.0
	Twice a day	11	55.0
	Three times a day	6	30.0
	>three times a day	1	5.0
Feed additive use	Yes	19	95.0
	No	1	5.0
Type of feed additive used*	Antibiotics	19	95.0
	Probiotics	6	30.0
	Herbal	7	35.0
	Others	2	10.0

Percentages are calculated based on the total number of farmer respondents (n = 20). *Multiple responses were allowed for the type of feed additive used; therefore, percentages in this section do not total 100%.

Table 3: Derivation of Internal SWOT Factors

Farmer Questionnaire Domain	Derived Strengths (S)	Derived Weaknesses (W)
Feed and feed additive practices	S1. Farmers are already familiar with feed additive use	W2. Herbal/phytobiotic products have not yet become a dominant practice.
Feeding system and feed source	S3. Commercial and combined feed use is relatively dominant	W6. Farm management remains experience-based and varies across farm scale and poultry type
Rearing system and farm management	S2. Rearing systems are relatively controlled	W6. Farm management remains experience-based and varies across farm scale and poultry type
Knowledge and technical information	S1. Farmers are already familiar with feed additive use	W1. Technical knowledge of phytobiotic use remains limited; W3. Technical information and education remain insufficient
Perception of phytobiotics	S4. Perceptions of phytobiotic safety and benefits are relatively positive	W5. Doubts remain regarding the consistency of phytobiotic use outcomes
Adoption interest and support environment	S5. Interest in phytobiotic adoption is relatively strong	W4. Extension and advisory support remains weak; W5. Doubts remain regarding the consistency of phytobiotic use outcomes

S1–S5 denote internal strength factors, while W1–W6 denote internal weakness factors. Repeated codes indicate that the same internal factor is supported by more than one internal strategic domain.

Preliminary external factors derived from the PESTEL-based stakeholder assessment were reviewed in stakeholder FGDs to confirm their strategic significance and classification as Opportunities or Threats. These factors were retained based on contextual relevance, directional meaning, and agreement in the FGD, and were subsequently validated by the expert panel. The final derivation of external strategic factors is presented in Table 4.

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3.3. Strategy Alternatives for Phytobiotic Feed Additive Use

The internal and external strategic factors presented in Tables 3 and 4 served as the basis for the TOWS matching stage. In this stage, strengths and weaknesses were matched with opportunities and threats within each PESTEL dimension to generate four types of strategy alternatives: SO, WO, ST, and WT. The SO strategies were formulated by leveraging internal strengths to capitalize on external opportunities (Table 5).

Table 4: Derivation of external strategic factors from PESTEL-based stakeholder assessment

PESTEL Dimension	Derived Opportunities (O)	Derived Threats (T)
Political (P)	O1. Policy support for natural feed additives; O2. Partnership opportunities among government, universities, and business actors	T1. Weak field-level implementation facilitation T8. Risk of commercialization without adequate technical assistance
Economic (EC)	O3. Availability of local phytobiotic raw materials; O4. Market potential for healthier and safer poultry products; O5. Financing or investment support	T2. Variation in farm scale may limit efficiency; T3. Raw material prices and investment needs may constrain adoption
Social (SOC)	O2. Partnership opportunities among government, universities, and business actors; O4. Market potential for healthier and safer poultry products	T4. Knowledge gaps and readiness barriers in changing feeding practices
Technological (TE)	O6. Technology transfer and formulation innovation	T5. Limited technical facilities, testing facilities, and trained personnel; T6. The benefits of phytobiotics still require empirical validation
Environmental (EN)	O3. Availability of local phytobiotic raw materials; O7. Support for more sustainable poultry production	T6. The benefits of phytobiotics still require empirical validation
Legal (LG)	O8. Opportunities for product standardization and certification	T7. Unclear standards, legality, and product oversight; T8. Risk of commercialization without adequate technical assistance

O1–O8 denote external opportunities, while T1–T8 denote external threats derived from the PESTEL-based stakeholder assessment. Repeated codes across PESTEL dimensions indicate that the same factor is supported by more than one dimension.

Although several alternatives in Table 5 are conceptually related, they were retained as separate analytical strategies because each alternative was derived from a specific TOWS combination within a distinct PESTEL dimension. In the implementation interpretation, however, closely related strategies were treated as complementary components of broader strategic domains, such as economic access, farmer capacity strengthening, technical application guidance, partnership-based advisory support, and product compatibility.

3.4. Priority Structure of Phytobiotic Strategies

Expert judgments were used to compare the importance of PESTEL criteria and the TOWS strategy alternatives within each PESTEL dimension. Before calculating the priority weights, the consistency of pairwise comparison judgments was assessed using the consistency ratio (CR). This step was necessary to ensure that the expert evaluations were sufficiently coherent and suitable for further AHP analysis.

Table 6 shows the mean CR values for PESTEL criteria comparisons ranged from 0.0616 to 0.0906 across stakeholder groups, while the mean CR values for TOWS strategy alternatives ranged from 0.0573 to 0.0738. The overall mean CR was 0.0759 for PESTEL criteria and 0.0675 for TOWS strategy alternatives; both values were below the commonly accepted threshold of 0.10. These results indicate that the expert judgments were generally consistent. Although the maximum CR reached 0.1093, the deviation was marginal and did not indicate severe inconsistency.

The AHP weighting results indicate that the economic dimension received the highest weight at 22.14%, followed by the social dimension at 19.82% and the technological dimension at 17.75%. The political dimension gained 14.82%, the legal 14.17%, while the environmental dimension gained the lowest weight at 11.30%. At the strategy-alternative level, the five highest global weights were obtained by EC-WO (9.30%); SOC-WO (8.04%); TE-WO (8.01%); P-WO (6.11%); and EC-SO (5.54%) strategy (Fig. 3). Together, these five top-ranked strategies accounted for 37.00% of the total global weight across the 24 PESTEL–TOWS strategy alternatives. This cumulative weight indicates that the early implementation agenda is concentrated on a limited set of strategic priorities, particularly economic access, practice-based training, technical SOPs, policy–partnership support, and product compatibility with existing feeding practices.

The top five strategies are concentrated in the economic, social, technological, and political dimensions, while environmental and legal strategies did not appear among the top five priorities. The ranking pattern also shows a strong tendency toward weakness-oriented strategies. Four of the five highest-ranked alternatives are WO strategies, and this pattern continues in the top-ten list through LG-WT and LG-WO. This suggests that expert judgments placed greater emphasis on addressing internal limitations than on exploiting strengths alone by leveraging available external opportunities. The dominance pattern of the WO strategy shows that policy

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opportunities, partnerships, availability of local raw materials, technology transfer, and educational support need to be directed to address limitations at the farmer level. The main strategic focus is on strengthening technical knowledge, mentoring, access to economic products, and clarity in phytobiotic application practices. The absence of environmental and legal strategies from the top five should not be interpreted as a lack of relevance, but rather as an indication that these dimensions may become more prominent after basic economic, technical, and adoption-related constraints are addressed.

Table 5: Alternative Strategies for Phytobiotic Development Derived from PESTEL-Based SWOT Matching

PESTEL	Alternative Strategies	Alternative Strategies	Alternative Strategies	Alternative Strategies
PESTEL	SO Strengths-Opportunities	WO Weaknesses-Opportunities	ST Strengths-Threats	WT Weaknesses-Threats
Political (P)	P-SO: Integrating farmers who are already familiar with feed additives into government–university–business partnership programs. (S1, S5, O1, O2)	P-WO: Utilizing policy support and partnerships to strengthen technical education and farmer advisory support. (W1, W3, W4, O1, O2)	P-ST: Positioning feed additive users as early adopters to reduce the risk of weak field-level facilitation and promotion without adequate technical assistance. (S1, S5, T1, T8)	P-WT: Establishing minimum advisory mechanisms before expanding phytobiotic promotion. (W1, W3, W4, T1, T8)
Economic (EC)	Developing locally based phytobiotic products that are compatible with commercial feed and combined feed. (S1, S3, O3, O5)	Developing small-package products and economical use models to expand access for smallholder farmers. (W2, W3, O3, O5)	Developing flexible phytobiotic application models for different farm scales and lower investment requirements. (S2, S3, T2, T3)	Developing simple, affordable, and easy-to-apply formulations that fit farmers' technical limitations and variations in farm scale. (W1, W2, W6, T2, T3)
Social (SOC)	Utilizing farmers' positive perceptions and adoption interest to strengthen the image of poultry products based on natural feed additives. (S4, S5, O4)	Conducting practice-based training to overcome limited knowledge and technical information. (W1, W3, O2, O6)	Using highly interested farmers as initial examples to encourage changes in feeding practices. (S4, S5, T4)	Developing group-based advisory support to reduce knowledge gaps and readiness barriers in changing feeding practices. (W1, W3, W4, T4)
Technological (TE)	Developing phytobiotic formulations that can be easily mixed into the feed already used by farmers. (S1, S3, O6)	Preparing technical SOPs on dosage, mixing, timing of administration, and application forms of phytobiotics. (W1, W3, O6)	Utilizing controlled rearing systems to test simple phytobiotic technologies at the farm level. (S2, S3, T5, T6)	Avoiding product commercialization before simple technology packages and technical advisory support are available. (W1, W3, W4, T5, T8)
Environmental (EN)	Strengthening the position of phytobiotics as natural feed additives to support safer and more sustainable poultry production. (S4, S5, O7)	Developing sustainability-oriented demonstration plots to strengthen farmers' confidence in the benefits of phytobiotics. (W5, O7)	Using intensive and semi-intensive systems as sites for measurable validation of phytobiotic benefits. (S2, T6)	Limiting environmental and performance claims until adequate field evidence is available. (W5, T6)
Legal (LG)	Directing farmers' adoption interest and positive perceptions toward the use of phytobiotic products that meet quality and safety standards. (S4, S5, O8)	Preparing phytobiotic use guidelines aligned with product standardization requirements. (W1, W3, O8)	Developing farm-level records of phytobiotic use as a basis for compliance and quality verification. (S2, S3, T7)	Establishing minimum standards for ingredients, dosage, composition, labeling, and advisory support to prevent the risk of misuse. (W1, W4, T7, T8)

SO, WO, ST, and WT indicate strategy combinations derived from strengths, weaknesses, opportunities, and threats. PESTEL dimensions indicate the external context from which each strategy was formulated. Codes S, W, O, and T refer to the internal and external strategic factors presented in Tables 3 and 4.

Table 6: Consistency assessment of AHP judgments for PESTEL criteria and local strategy comparisons

Stakeholder group	n	Mean CR	Mean CR	Max CR
Stakeholder group	n	PESTEL (Level 1)	PESTEL–TOWS (Level 2)	Max CR
Government/Policy institution	2	0.0616	0.0687	0.1068
Academia	2	0.0694	0.0573	0.1025
Phytobiotic researcher	2	0.0690	0.0631	0.1077
Feed industry	2	0.0845	0.0719	0.1093
Smallholder poultry farmers	1	0.0803	0.0705	0.1086
Overall Consistency	9	0.0759	0.0675	0.1093

CR = consistency ratio. PESTEL criteria refer to pairwise comparisons among the six PESTEL dimensions. TOWS strategy alternatives refer to pairwise comparisons among SO, WO, ST, and WT alternatives within each PESTEL dimension.

The predominance of WO strategies can be interpreted as a structural mismatch between the availability of external opportunities and farmers' internal readiness to evaluate and incorporate phytobiotics into their existing production practices. In diffusion of innovation theory, adoption is influenced by the perceived relative advantage, compatibility, complexity, trialability, and observability of an innovation (Rogers, 2003). The ranking pattern suggests that these attributes have not yet been translated into sufficiently clear and credible value propositions for farmers. Meijer et al. (2015) conceptualized agricultural technology uptake as an interaction between intrinsic

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factors, including knowledge, attitudes, and perceptions, and extrinsic conditions surrounding the potential adopter. Glover et al. (2019) also argue that technological change in smallholder agriculture should be understood as a situated sociotechnical reconfiguration rather than a simple binary transition from non-adoption to adoption. Such a pattern is also consistent with the long-established view that adoption of agricultural innovations varies across farmers and production contexts because decision-making is shaped by heterogeneous resources, information, risk, and socioeconomic conditions (Feder et al., 1985).

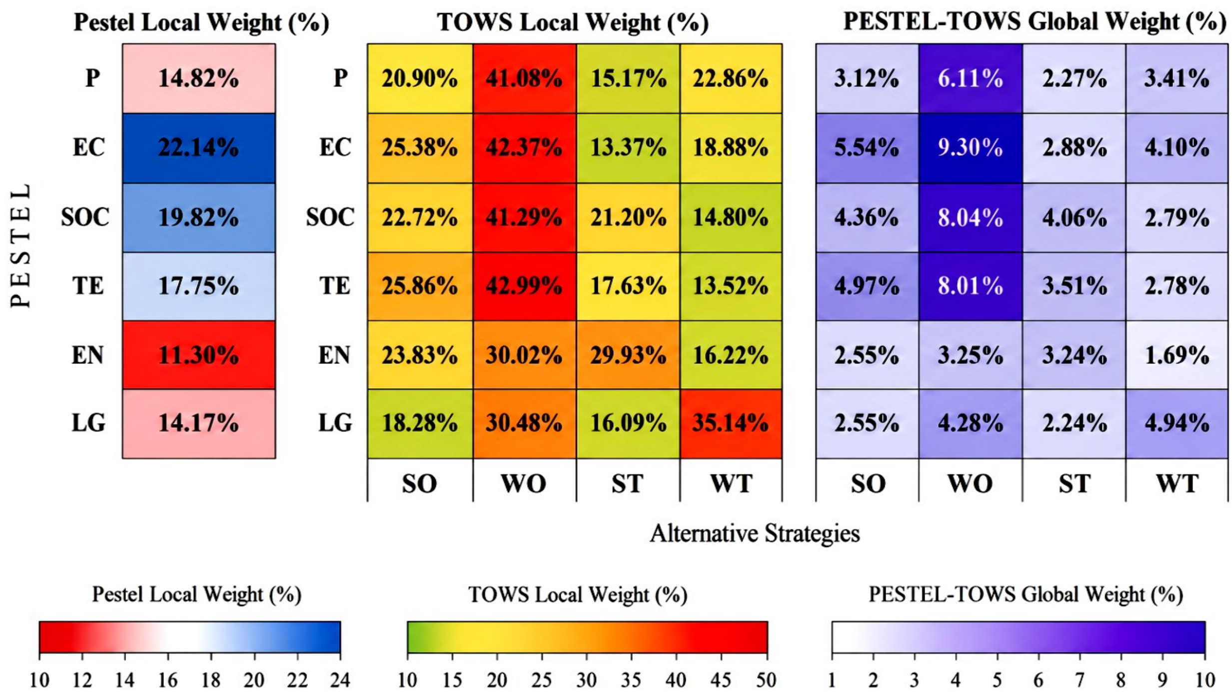

Fig. 3: Heatmap of AHP-derived PESTEL dimension weights and global priority weights of PESTEL–TOWS strategy alternatives in phytobiotic utilization as feed additives.

3.5. Core Strategies for Phytobiotic Early-Stage Utilization

Based on the global weighting of AHP results, the five strategies with the highest weights were identified as core priority strategies for using phytobiotics as feed additives on smallholder poultry farms. The five strategies are:

1. Developing small-package products and economical use models to expand access for smallholder farmers (EC-WO).
2. Conducting practice-based training to overcome limited knowledge and technical information (SOC-WO).
3. Preparing technical SOPs on dosage, mixing, timing of administration, and application forms of phytobiotics (TE-WO).
4. Utilizing policy support and partnerships to strengthen technical education and farmer advisory support (P-WO).
5. Developing locally based phytobiotic products that are compatible with commercial feed and combined feed (EC-SO).

Developing small-package products and economical use models to expand access for smallholder farmers ranked highest in the AHP results. This strategy addresses the fact that herbal products or phytobiotics have not yet become the dominant practice in farmers' feed management (W2), while technical information and education on their use remain limited (W3). At the same time, there are opportunities in the form of local phytobiotic raw materials and potential financing or investment support for product development (O3 and O5). Indonesia has diverse indigenous herbal potentials such as temulawak, turmeric, lemongrass, ginger, cloves, garlic, and so on (Sapsuha et al., 2023; Sumadja et al., 2025; Wijayanti & Wijayanti, 2026). However, Windisch et al. (2008) suggest that the use of *phytogenic feed additives* requires attention to the efficacy, safety, and character of active ingredients, not just the availability of plant materials. This is certainly related to the biological mechanisms in

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livestock, so the form of application is important for its use (Brenes and Roura 2010). The potential of local raw materials needs to be translated into simple, economical, and easy-to-test products for farmers. Small package sizes, practical dosages, clear estimates of use costs, and compatibility with commercial and mixed feeds can help reduce initial barriers for farmers who are not yet accustomed to using phytobiotics. Glover et al. (2019) argue that technological change in small-scale farming systems is shaped by the fit between technology design, user conditions, and practical responses in the field. From an economic perspective, Devaux et al. (2018) emphasize that agricultural innovation can deliver greater benefits for smallholders when linked to inclusive value chains, capacity support, institutional arrangements, and adequate market access.

Product affordability should, however, be distinguished from farm-level profitability. Empirical studies provide indications that phytobiotic use can improve economic efficiency through reduced feed requirements, lower production costs, or reduced mortality. A meta-analysis of nine commercial-scale broiler trials reported that phytogenic supplementation reduced feed use by approximately 35 g per kilogram of body weight produced, although no consistent effects were observed on final body weight, feed intake, mortality, or overall production efficiency (Martine et al., 2020). Agbetuyi et al. (2024) also reported that replacing soybean meal with 3% Moringa oleifera leaf powder reduced production cost by approximately 3.3% per bird, while Kalia et al. (2018) found that phytogenic supplementation increased net returns partly through lower mortality. However, these economic benefits are not uniform. Nantapo et al. (2024) showed that higher Moringa inclusion increased feed costs and reduced economic efficiency, despite improvements in several biological indicators. These contrasting findings indicate that the return on phytobiotic use depends on the relationship between additive cost, inclusion level, feed savings, mortality reduction, production response, and market value of the resulting product.

Conducting practice-based training to address limited knowledge and limited access to technical information was identified as the second-priority strategy, underscoring the need to strengthen farmers' knowledge and improve access to technical information on phytobiotic applications in poultry production. This strategy departs from the condition that farmers' technical knowledge of phytobiotics remains limited (W1) and that the available technical information and education are inadequate (W3). At the same time, there are partnership opportunities among the government, universities, and business actors to strengthen the farmer education process (O2), as well as opportunities for technology transfer and formulation innovation to support the more applicable delivery of knowledge (O6). The implication of this strategy is that farmer training should move beyond general awareness-raising and be designed as practical learning. Training materials need to cover the types of phytobiotic materials, their expected benefits, dosage, mixing methods, timing of administration, application forms, and limits of use. This is important because the use of phytobiotics requires technical accuracy and is inseparable from feed formulation, rearing conditions, and the specific characteristics of the active ingredients. Farmer involvement in the design, testing, and scaling of agricultural innovations should also be adjusted to innovation readiness and user readiness (Pawera et al., 2024). In this context, extension and advisory services have a strategic role in facilitating innovation by addressing social, institutional, and technical barriers to adoption (Davis et al., 2021). More interactive extension approaches can strengthen smallholders' access to information, although their effectiveness still depends on digital literacy, infrastructure, and user capacity (Sen et al., 2025).

The strategy of preparing technical standard operating procedures (SOPs) for dosage determination, mixing procedures, administration timing, and phytobiotic application methods ranked third in the AHP results. This strategy addresses farmers' limited technical knowledge of phytobiotic use (W1) and insufficient technical information and education (W3), while leveraging opportunities for technology transfer and formulation innovation to develop practical guidelines for their use (O6). The implication is that phytobiotic development should be accompanied by clear, measurable SOPs compatible with existing feeding practices. This is essential because the effectiveness of phytogenic feed additives depends on botanical source, active compounds, dosage, application form, feed composition, and rearing conditions (Windisch et al., 2008; Brenes & Roura, 2010). Formulation technologies, ingredient combinations, fermentation, enzymes, or encapsulation may further improve efficacy, but these innovations still require practical guidance for farm-level application (Nantapo & Marume, 2025). Without SOPs, the use of phytobiotics may remain a trial-and-error process, leading to inconsistent outcomes and reducing farmers' confidence. Previous studies have shown that phytogenic or phytobiotic responses in broilers can vary across growth performance, nutrient digestibility, intestinal morphology, cecal microbiota, and biochemical parameters depending on ingredient type, extract form, and administration level (Murugesan et al., 2015; Zaikina et al., 2022).

Utilizing policy support and partnerships to strengthen technical education and farmer advisory support ranked fourth in the AHP results. This strategy responds to farmers' limited technical knowledge of phytobiotic use (W1), insufficient technical information and education (W3), and weak extension and advisory support at the field level (W4). Policy support for natural feed additives can provide an enabling basis for phytobiotic development (O1), while partnerships among government, universities, and business actors can be directed toward

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more operational mechanisms for farmer education, training, and advisory services (O2). The implication of this strategy is that policy support needs to be translated into concrete facilitation at the field level. Davis et al. (2021) emphasized that modern agricultural extension should move toward innovation facilitation that addresses technical, social, and institutional barriers to adoption. This means that advisory services should help farmers understand dosage, mixing methods, timing of administration, product selection, and expected limitations of use. Such support is particularly important because farmers' willingness to adopt a new input is often shaped by the availability of trusted information, practical guidance, and confidence that the innovation is compatible with their farming conditions (Oli et al., 2025). Partnership-based facilitation also helps connect knowledge providers, policy actors, and users more directly. Pawera et al. (2024) noted that farmer involvement in the design, testing, and scaling of agricultural innovations needs to align with both innovation and user readiness.

The development of locally based phytobiotic products that are compatible with commercial feed and mixed-feed practices ranked fifth in the AHP results. This strategy builds on the assumption that farmers are already familiar with the use of feed additives (S1) and that commercial and combined feeds are relatively dominant in their feeding practices (S3). At the same time, the availability of local phytobiotic raw materials (O3) and potential financing or investment support can be directed toward developing products that are more applicable and aligned with farmers' existing feed management systems (O5). This strategy suggests that phytobiotic products should be developed to fit existing feeding practices among smallholder poultry farmers. Since many farmers use commercial or mixed feeds, phytobiotic products need to be easy to mix, dose, and apply, while local herbal resources should be translated into safe, stable, and practical formulations. This is important because phytogenic feed additives vary in their active compounds, biological effects, efficacy, and safety profile, and their performance depends on how they are processed and applied in the feeding system (Windisch et al., 2008; Brenes & Roura, 2010). The EC-SO strategy is also complementary to the EC-WO strategy. While EC-WO focuses on improving access through small-package and economical use models, EC-SO emphasizes leveraging existing strengths and opportunities to develop locally based products that fit farmers' current feeding routines. Technological change in small-scale farming is more likely to be accepted when product design aligns with user conditions and practical responses in the field (Glover et al., 2019). Therefore, local raw material availability and financing opportunities should be directed toward product models that are not only technically feasible but also compatible with commercial feed, mixed-feed practices, and the adoption capacity of smallholder poultry farmers.

The prevalence of WO strategies across most PESTEL dimensions suggests that the adoption of phytobiotic utilization in smallholder poultry farming still requires stronger prerequisites. External opportunities, including policy support, partnerships, local raw materials, technology transfer, and technical education, need to be directed toward addressing internal weaknesses, including limited knowledge, insufficient use of information, weak advisory support, restricted access to products, and uncertainty in application practices. This pattern is consistent with the view that the adoption of innovation among small-scale actors is often constrained by limited capacity, weak incentives, financing barriers, and mismatches between technology and user conditions (Sanga et al., 2026). Innovation diffusion may also proceed unevenly, excluding farmers or small enterprises when knowledge linkages, local networks, and institutional support are inadequate (McGuire et al., 2025; Duan et al., 2026). Therefore, the dominance of WO strategies suggests that the initial pathway for phytobiotic utilization should focus on access, capacity strengthening, advisory support, and product compatibility with farmers' existing practices.

The environmental and legal/regulatory dimensions remain important as supporting strategies at the advanced stage. Environmental considerations help strengthen the legitimacy of phytobiotics as natural feed additives that support safer, more sustainable poultry production. However, environmental and performance claims need to be supported by field evidence, as phytobiotic responses are influenced by ingredient type, dosage, application form, ration composition, and maintenance conditions (Murugesan et al., 2015; Zaikina et al., 2022; Nantapo & Marume, 2025). From a legal/regulatory perspective, the development of phytobiotics requires quality standards, safety, composition, labeling, dosage, and limits on claims of benefits that can be accounted for. Natural ingredients still require quality control and safety assessments because variations in active ingredients, potential contaminants, and differences in extraction processes can affect product risk and consistency (Dusemund et al., 2024; Karásková et al., 2015). Therefore, environmental and legal/regulatory strategies are more appropriately positioned as reinforcements at the consolidation stage, once economic access, training, technical SOPs, mentoring, and product compatibility have begun to take shape.

4. CONCLUSION

This study shows that the strategy of using phytobiotics as feed additives on smallholder poultry farms should be grounded in the link between the biological potential of natural ingredients and the practical conditions of implementation at the farm level. Farmer readiness, economic feasibility, technical support, partnerships, and clarity of application practices are important prerequisites for the more targeted use of phytobiotics. The internal factor assessment indicates that farmers already have an initial basis for adoption, as many are familiar with feed additive use, rely on commercial or mixed feeds, and have relatively positive perceptions and interest in adoption. However, limited technical knowledge, a lack of practical information, weak mentoring, and the lack of established use of phytobiotics remain the main obstacles.

PESTEL analysis indicates that phytobiotic development is supported by policy opportunities, cross-sector partnerships, local raw materials, technology transfer, market potential for healthy poultry products, and standardization. However, weak field facilitation, variations in business scale, investment needs, limited technical facilities, the need for empirical evidence, and unclear standards for product use and supervision remain obstacles to implementation.

Based on the PESTEL-TOWS match, this study formulated 24 alternative strategies that were then prioritized using AHP. The prioritization results show that the economic, social, and technological dimensions gain the highest weight. The five core priority strategies generated are the development of phytobiotic products in small packaging and an economical use model; practice-based training; preparation of technical SOPs for use; the use of policy support and partnerships for education and mentoring; and the development of local phytobiotic products that are compatible with commercial feed and combination feed.

The dominance of the WO strategy suggests that the initial stage of phytobiotic utilization should focus on addressing farmers' internal weaknesses by leveraging external opportunities. The early priorities are economic access, farmer capacity, advisory support, technical SOPs, and product compatibility with existing feeding practices. Environmental and legal/regulatory dimensions remain important as supporting strategies during the consolidation stage, particularly for strengthening evidence of benefits, safety, quality, labeling, use standards, and accountability of product claims.

Declarations

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