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# Assessment of Pest Risk Management Gaps within a Systems Approach for Exporting Pineapple (Ananas comosus) from Bangladesh

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## ABSTRACT

A systems approach integrates various measures to manage pests throughout the production and export pathway. This study evaluated the alignment of existing pest risk management measures and assessed the gaps limiting implementation of a systems approach in the pineapple export pathway of Bangladesh. A structured interview schedule and questionnaire were used to collect data from the production to pre-shipment stages of pineapple. Descriptive statistics and gap analysis were used to evaluate the alignment and gap of the existing measures with the requirements of a system approach. The results found strong alignment of using pest-free suckers (98%), eco-friendly weed management (92%), sorting and grading of fruits (88%), standard phytosanitary certification (100%) and moderate alignment of proper transportation (70%), monitoring and inspection of consignment (62.5%) and presence of traceability system (62.5%). In contrast, production in pest-free areas, GAP implementation were absent, while sucker treatment (36%), implementing IPM (20%), regular pest surveys (36%) were revealed poor alignment. Component-wise gap assessment identified critical gap in implementing integrated measures (GI = 68.75%) and major gaps in preventive measures (GI = 60.00%) and harvest and post-harvest pest risks management (GI = 41.67%). Conversely, phytosanitary measures at the pre-shipment stage (GI = 7.14%) showed strong alignment with the requirements of a systems approach. The findings indicate that phytosanitary assurance relies predominantly on end-point pest risk management rather than integrated system through the pineapple export pathway. Strengthening pest risk management measures at production site, regular survey and technical capacity are essential to enhance export managing pest risks of pineapple.

**KEYWORDS:** Systems approach; pest risk management; pineapple export; integrated pest management (IPM); phytosanitary measures; pest risk analysis

## 1. INTRODUCTION

Pineapple (*Ananas comosus*), a member of the family Bromeliaceae, is a monoecious, monocotyledonous, monocarpic and xerophytic herbaceous perennial plant and its perennial in nature is propitiated through suckers (Das, 2021). It is referred to as the "queen of fruits" due to its excellent flavor and taste (Baruwa, 2014). Seventy per cent of the pineapple produced in the world is consumed as fresh fruit in the country of origin (Bartholomew et al., 2003) . It is primarily consumed as fresh fruit and juice and serves as a rich source of minerals and vitamins (Hossain et al., 2015) and contains 14% sugar, enzymes and considerable amounts of citric acid, malic acid, and vitamins A and B (P., 2010).

Pineapple is the third most important commercial fruit in the global market (Adewuyi-Samuel *et al.*, 2019). It is cultivated in many countries but Thailand is the largest producer of pineapple, accounting for 13% of global output (Baruwa, 2014). In 2022, global pineapple production reached approximately 29.4 million metric tons (Tripathy, 2024) and projected to reach 37 Mt in 2034 (FAO, 2025). Global exports of pineapples grew by approximately 4% in 2024, to 3.7 Mt in 2034 and global imports of pineapples of around 5% in 2024, to approximately 3.1 Mt. in 2034.

Bangladesh produces pineapple in various regions and major cultivated varieties of pineapple are Giant Kew, Honey Queen, Joldhupi, and Ghorasal (Hossain and Islam, 2017). The study depicts that 76.7% farmers in Madhupur of Tangail

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district produce Giant Kew variety for pineapple (Uddin et al., 2022). By the year 2022–23, Bangladesh produced 196735.74 MT pineapple from 32463.36 acres of land (BBS, 2023). Pineapple was exported to various countries in an amount of 71.188 MT in 2023–24 fiscal years (Plant Quarantine Wing, DAE). Although Bangladesh produces fewer pineapples than other international producers with limited export offerings (Datta *et al.*, 2024) , but scenarios of demand for fresh fruits and canned pineapple is increasing both locally and internationally for several types of uses (Biswas and Nishat, 2019) . However, access to international market of any agricultural commodities relay on compliance with phytosanitary measures those are regulatory instruments designed to protect plant health from risks arising from trade proposed by importing countries (Mabunda et al., 2025). Therefore, effective phytosanitary risk management throughout the pineapple export pathway has become mostly important for maintaining market access and enhancing export competitiveness that facilitates safe international trade (Yoe et al., 2021).

Despite its economic value, pineapple is affected by several different pests and pathogens (Lobo and Paull, 2017) that affect crop productivity, fruit quality and phytosanitary status. Insect pests are the most important barrier limiting pineapple production while fungal disease causes of massive yield losses in pineapples around the world (Armand et al., 2023). Pineapple of Bangladesh is infected by limited pests (mainly thrips, mealybug, leaf spot, beetle etc.) found by physical visit in pineapple cultivated area. Although very few pests are found in pineapple orchard in Bangladesh but few pests are reported and published in journals and current Pest Risk Analysis (Plant Quarantine Wing (NPPO), 2024) prepared by Plant Quarantine Wing, Bangladesh. The presence of these pests in Bangladesh presents significant phytosanitary issues because many importing countries apply strict regulatory measures to protect their country from the introduction and establishment of quarantine pests during importing from other countries.

To mitigate pest risks and maintain crop productivity, farmers implement various pest management and crop production practices (Karim et al., 2022). The Bangladesh Agricultural Research Institute (BARI) has developed production and pest management strategies to assist farmers (BARI, 2025). Farmers practice phytosanitary measures to manage risk pests to produce risk free pineapple to export in various countries.

Although various phytosanitary measures are currently applied within the pineapple export pathway, their implementation often occurs independently rather than as components of integrated phytosanitary system. As a result, the cumulative effectiveness of these measures in achieving an acceptable level of pest risk has not been systematically evaluated. Increasingly, international trade regulations emphasize phytosanitary systems (Eschen et al., 2015) that integrate multiple measures throughout pre-planting, production, harvesting, post-harvest, transportation and pre-shipment stages. Such strategies are particularly important when individual measures alone are insufficient to provide the level of pest risk management by importuning countries.

The International Plant Protection Convention (IPPC) promotes the use of a systems approach for managing pest risks for facilitating safe trade around the world and is increasingly being used to access markets for fresh fruit and vegetables (van Klinken *et al.*, 2020). ISPM No. 14 defines a systems approach is an integrated strategy employing multiple, independent phytosanitary measures along the production and export chain that cumulatively achieves the appropriate level of protection (Quinlan *et al.*, 2020). A systems approach involves the use of integrated measures, at least two of which are independent, that cumulatively reduce the risk of introducing pests through trade (Mengersen *et al.*, 2012). The components of systems approaches can be divided into field and production measures, preharvest measures, postharvest measures, inspection and certification measures, and shipping and distribution measures (Podleckis, 2007). Systems approaches to managing risks on a pathway are increasingly seen as alternatives to single point risk management measures (Jamieson *et al.*, 2013) and the effectiveness of a systems approach relays on the cumulative impact of individual measures and the presence of redundancy through independent pest risk mitigation actions. Consequently, systems approaches are increasingly recognized as applied and science based alternative to single phytosanitary measures (Podleckis, 2007) and are being promoted for widespread use to facilitate safe agricultural trade.

Several components of a systems approach are already practiced within the pineapple production and export pathway in Bangladesh. However, it is still unclear whether these measures, when considered together, meet the requirements of a systems approach following ISPM 14. Current phytosanitary measures have largely been implemented to mitigate individual production or export challenges and there is no formal systems approach protocol to manage pest risks to export pathway of pineapple in Bangladesh. Moreover, information regarding the strengths, weakness and institutional limitations of current pest risk management measures is limited. Such information is necessary for identifying priority areas for strengthening pest management strategies and developing a comprehensive phytosanitary framework capable of meeting international trade requirements to enhance pineapple export from Bangladesh.

Assessing current pest risk management measures against the requirements of a systems approach is important for developing an effective systems approach to manage pest risks for pineapple exports. A systematic assessment can identify measures that are already effective, detects gaps within the export pathway and provide evidence-based recommendations for strengthening phytosanitary risk management. Such information will assist the Plant Quarantine Wing (NPPO), exporters, policymakers and other stakeholders in enhancing international market access while ensuring compliance with the importing-country phytosanitary requirements.

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Therefore, this study was conducted to evaluate current pest risk management measures applied throughout the pineapple export pathway including various stages from pre-planting to pre-shipment stage and assess their alignment and gaps with the requirements of a system approach. The main objectives of the study are (a) to analyse the current measures to manage pest risks implemented at different stages of pineapple export pathway, (b) to assess the alignments and gaps of current measures using a pathway-based assessment framework based on the requirement of system approaches, (b) propose the measures and strategies for developing an effective systems approach for managing pest risks of exporting pineapple from Bangladesh. The findings are expected to support the development of applied and science based phytosanitary policies, enhance export readiness, promote market access and contribute to the sustainable international trade of pineapple produced in Bangladesh.

## 2. METHODOLOGY

### 2.1 Study Design

The study employed a cross-sectional survey design to assess the status of systems approach implementation for pest risk management in the pineapple export supply chain of Bangladesh. The study aimed to evaluate the alignment and gaps of existing measures with the requirements of a systems approach for managing pest risks. The assessment was conducted by collecting information from key stakeholders who are directly involved with exportable pineapple production and phytosanitary certification and comparing the existing measures with the components of a systems approach.

### 2.2 Study Area

The study was conducted in the major exportable pineapple regions of Bangladesh. These production areas represent the principal sources of fresh pineapples intended for international market and therefore constitute the most appropriate locations for evaluating field level implementation of phytosanitary measures.

Plant Quarantine's institutional data were collected from the two principal phytosanitary facilities involved in pineapple export: the Central Packing House and the Plant Quarantine Station at Hazrat Shahjalal International Airport (HSIA), Dhaka. Although there are various plant quarantine stations, but mostly pineapples are exported through these two stations after inspection, phytosanitary verification, and certification of export consignments. Consequently, they were selected to represent the overall plant quarantine activities in the export system.

### 2.3 Respondents and Sampling Strategy

The study included two categories of respondents representing the major stakeholders (production site and plant quarantine stations) responsible for implementing the systems approach throughout the export chain.

The first group consisted of 50 pineapple farmers selected from the principal exportable pineapple producing areas of Bangladesh. Farmers from production site were selected using purposive sampling based on their participation in exportable pineapple production and their prospective participation in export-oriented production systems. This strategy ensured that the collected information reflected the phytosanitary practices currently applied in the production site for producing export-quality fruit.

The second group included 16 Plant Quarantine Officers stationed at the Central Packing House and the Plant Quarantine Station, HSIA. These officers were selected because they are directly responsible for inspection, pest detection and diagnosis, verification of phytosanitary compliance, and issuance of phytosanitary certificates for export consignments. As the number of officers in these stations engaged in pineapple export certification is limited, the selected respondents represent the principal regulatory personnel responsible for implementing phytosanitary measures within the national export system.

Purposive sampling was considered appropriate because the objective of the study was to obtain information from respondents with direct knowledge, involvement and operational experience of the pineapple export pathway rather than to estimate public perceptions or national population characteristics.

### 2.4 Data Collection

#### *2.4.1 Primary Data from Production Sites and Quarantine Stations*

Primary data were collected through face-to-face interview using structured questionnaire. Separate questionnaires were developed for pineapple farmers and Plant Quarantine Officers to reflect their respective activities to manage pest risk within the export supply chain. The farmer questionnaire focused on measures to manage pest risks at various stages in production site and the questionnaire for Plant Quarantine Officers addressed quarantine activities at post-harvest and pre-shipment stages. The questionnaire was developed following the principles of the systems approach for pest risk management and other relevant phytosanitary guidelines and was reviewed by plant quarantine and plant protection specialists to ensure technical accuracy, clarity, and consistency with the study objectives.

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#### *2.4.2 Literature and Document Review*

Secondary data were collected from scientific publications, books, and reports from the International Plant Protection Convention (IPPC), the National Plant Protection Organization (NPPO), and related institutions were reviewed to supplement field data and identify internationally recognized phytosanitary standards.

### 2.5 Pathway-Based Assessment Framework against the Requirements of a Systems Approach

A pathway based assessment framework was developed to evaluate the existing pest risk management measures against systems approach requirements according to the pest risk management measures of ISPM 14. The assessment framework is presented in Table 1.

**Table 1.** Pathway-based alignment assessment framework

| Systems approach Component | Indicators for assessment | Expected measures | Stages of export pathway |
|---|---|---|---|
| Preventive measures | Pest-free planting material | Use of pest-free suckers, Treatment of suckers before transplanting, producer registration and training etc. | Pre-Planting |
| Preventive measures | Field sanitation and fertilization | Soil treatment, Destruction of crop residues, fertilizer application with soil testing, Pest free places of production etc. | Pre-Planting, pre-harvesting |
| Multiple measures to manage risk pest | Use of more than one independent measures | Chemical measures, eco-friendly measures, organic measures, optimum spacing and time management etc. | All stages |
| Integrated measures to manage risk pests | GAP application, IPM application etc. | Implementation of GAP and IPM approaches | All stages |
| Monitoring and surveillance | Pest monitoring | Pest monitoring in production site, Consignment monitoring | Pre-harvesting, pre-shipment stage |
| Harvest and post-harvest risk Management | Fruit harvesting and post-harvest processing measures application | Harvesting following maturity index, Sorting, grading, cleaning and washing, Inspection etc. | Harvest and pre-harvest, pre-shipment stage |
| Phytosanitary measures at pre-shipment stage | Strength of phytoaniatry activities in quarantine stations and packing house | Inspection, Diagnosis, Phytosanitary treatments, Phytosanitary certificate, Sanitation etc. | Pre-shipment stage |
| Documentation and coordination | Presence and implementation of documents, protocols and guidelines | Production record, management records, inspection record, standard systems approach protocol, Pest Risk Analysis etc. | All stages |
| Verification | Inspection procedures | Auditoing, Repotting, monitoring and Compliance judgements of y phytosanitary certification etc. | Pre-harvesting, Harvesting, pre-shipment stage |
| Traceability | Tracking record | Presence of traceability system etc. | All stages |

The adoption level of alignment was expressed as a percentage (%) to indicate the extent to which the current practices fulfilled the recommended requirements, and was classified into five categories: strong (>80%), moderate (60–80%), limited (40–59%), weak (1–39%) and not implemented (0%).

### 2.6 Gap Assessment Framework

A systematic gap analysis was conducted to identify differences between the existing phytosanitary measures and the requirements of the systems approach. The level of alignment between existing pest risk management practices and ISPM 14 requirements was assessed using a five-point scoring system based on adoption frequencies obtained from the survey.

**Table 2.** Gap Assessment Framework

| Adoption (%) | Alignment category | Score |
|---|---|---|
| >80 | Strong alignment | 4 |
| 60-80 | Moderate alignment | 3 |
| 40-59 | Limited Alignment | 2 |
| 1-39 | Weak alignment | 1 |
| 0 | Not implemented | 0 |

Then Gap Index was calculated using the formula,

$$\textit{Gap Index (GI, \%)} = [(\textit{Maximum Score} - \textit{Observed Score}) / \textit{Maximum Score}] \times 100$$

According to the Gap Index, the gap in pest management measures was classified into four categories: minor gap (0–20%), moderate gap (20–40%), major gap (40–60%) and critical gap (>60%).

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### 2.7 Data Analysis

The collected data were entered, verified, and analysed using descriptive statistical methods. Frequencies, percentages, and mean values were calculated to summarize the implementation status of each phytosanitary measure. The alignment percentages for the measures of Systems approach Components were calculated and presented using tables to facilitate the adoption frequency of current practices in categories. The results of the gap analysis were interpreted to identify Gap Index (%) in the specific categories to provide the ideas about the level of current gaps and to support recommendations for developing a more effective systems approach for pineapple export from Bangladesh.

## 3. RESULTS

### 3.1 Demographic status and farm profiles

Result shows (Table 03) that 5% of the farmers are from 20-30 age, 17% were 31-40 age range, 21% farmers were between 41-50 age and 7% farmers were belong to 51-60. The majority percentages of respondents were from 41-50 age range. The farmers owned land were found that 6% farmers having 0-49 decimals cultivated land, 4% farmers were small (50-150decimals), 24% were medium farmers having 151-499 decimals land and 16% were large farmers who cultivated more than 500 decimals land. Farmers cultivated various crops in their cultivated land. Among them, varied areas were used by farmers to cultivate fruit and vegetables. It was found that 9% farmers used 0-100 decimals land for fruit and vegetable cultivation, where 17% farmers cultivated fruit and vegetables in 101-200 decimals land and 9% farmers cultivated fruit and vegetables more than 700 decimal land. Comparing with other fruits and vegetables, pineapple cultivation areas were varied according to area. Most of the pineapple cultivated area was 0-100 decimals owing by 22% farmers and only 3% farmer's cultivated pineapple more than 700 decimal lands.

**Table 3.** Socio-economic characteristics and land-use allocation patterns of surveyed pineapple farmers (n = 50).

| Variables | Category | Frequency (n) | Percentage |
|---|---|---|---|
| Age (years) | 20-30 | 5 | 10 |
| | 31-40 | 17 | 34 |
| | 41-50 | 21 | 42 |
| | 51-60 | 7 | 14 |
| Farm Size (Decimal) | 0–49 (Landless/Marginal) | 6 | 12 |
| | 50–150 (Small) | 4 | 8 |
| | 151–499 (Medium) | 24 | 48 |
| | >500 (Large) | 16 | 32 |
| Fruit and vegetable area (decimal) | 0-100 | 9 | 18 |
| | 101-200 | 17 | 34 |
| | 201-400 | 10 | 20 |
| | 401-700 | 5 | 10 |
| | >700 | 9 | 18 |
| Pineapple area (decimal) | 0-100 | 22 | 44 |
| | 101-200 | 9 | 18 |
| | 201-400 | 8 | 16 |
| | 401-700 | 8 | 16 |
| | >700 | 3 | 6 |

### 3.2 Pest Risk Management approaches at different stages

Pests are associated with pineapple were found at various stages of pineapple production and transportation. Various measures are applied to manage these pests by farmers and plant quarantine officials. Farmers applied measures from pre-planting to harvesting and sometime post harvesting stages. Otherwise plant quarantine officials mostly involve applying measures to manage risk pests at pre-shipment stages according to inspection and diagnosis following the protocols.

#### *3.2.1 Pest Risk management measures at pre-planting stage*

The measures were applied by farmers at pre-planting stage to manage pest initiation with soil and planting materials. Results showed that farmers conducted various measures to manage risk pests in this stage (Table 04). It was found that 98% farmers collected pest-free suckers to ensure pest free cultivation. Farmers treated suckers (36%) and soil (44%) to manage suckers and soil borne pests. Soil quality and fertilization application was related to provide favourable environment for pest initiation. To manage pests, it is important to test soil before applying optimum fertilizer. It was reported

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that 18% farmers tested soil from authorized organization and 12% farmers applied optimum fertilizer according to soil test report.

**Table 4.** Measures are applied to manage risk pests at pre-planting stage

| Measures | Adopted farmers (n) | Frequency (%) |
|---|---|---|
| Producer registration to respected authority | 0 | 0 |
| Production in pest free area | 0 | 0 |
| Collection of pest-free suckers | 49 | 98 |
| Treatment of suckers before transplanting | 18 | 36 |
| Soil treatment before planting | 22 | 44 |
| Soil testing before planting | 9 | 18 |
| Fertilizer application based on soil-test report | 6 | 12 |
| Destruction of crop residues before transplanting | 25 | 50 |
| Receive training on pest management | 45 | 90 |

### *3.2.2 Pest Risk management measures at pre-harvesting stage*

The table-05 reveals the measures are applied by farmers at pre-harvesting stage in their pineapple production area. It was found that 94% farmer's transplanted sucker at proper time and 42% farmers maintained proper spacing during transplanting sucker. Most of the farmers (92%) applied eco-friendly weed control measures (etc. mulching) to control weeds, where 48% farmers applied chemical weedicides. Most of the farmers applied chemical and organic pesticides (64%) to manage disease and insects. It was found that only 4% farmer selected pesticides based on official recommendation and 42% farmers applied pesticides at proper time with recommended doses. The applications of integrated measures (IPM, GAP) were very limited in pineapple production. IPM was familiar with 64% farmers and 20% of them applied IPM to manage pests during pineapple production. It was revealed that 38% farmers were familiar with GAP protocol of pineapple but no one applied the guidelines of GAP protocol to manage pests at pre-harvesting stage.

**Table 5.** Measures are applied to manage risk pests at pre-harvesting stage

| Measures | Adopted farmers (n) | Frequency (%) |
|---|---|---|
| **Transplanting strategies** | | |
| Transplanting sucker at proper time | 47 | 94 |
| Maintaining proper plant spacing | 21 | 42 |
| **Weed Control Measures** | | |
| Mechanical weed control | 6 | 12 |
| Chemical weed control | 24 | 48 |
| Eco-friendly weed control (mulching, etc.) | 46 | 92 |
| Multiple weed control approaches | 2 | 4 |
| **Disease and insect management measures** | | |
| Eco-friendly management methods | 19 | 38 |
| Chemical pesticide application | 32 | 64 |
| Organic pesticide application | 32 | 64 |
| Combined chemical and organic pesticide use | 10 | 20 |
| **Pest Management decision and application strategies** | | |
| Pest management consultation with agriculture officer | 7 | 14 |
| Pest management consultation with neighbouring farmers | 9 | 18 |
| Pest management based on own experience | 48 | 96 |
| Consultation with pesticide dealers | 43 | 86 |
| Pesticide selection based on official recommendation | 2 | 4 |
| Applied pesticide following dose and timing | 21 | 42 |
| Pest management measures records maintained | 18 | 36 |
| Regular consultation and training to farmers | 42 | 84 |
| Regular pest survey in the production site | 18 | 36 |
| **Integrated measures to manage pests** | | |
| Familiarity with IPM | 32 | 64 |
| Application of IPM | 10 | 20 |
| Familiarity with GAP | 19 | 38 |
| GAP implementation | 0 | 0 |

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### 3.2.3 Pest Risk management measures at harvest and post-harvest stage

Considerable variation was observed to apply measures to manage pests risk in harvest and post-harvest stage (Table 06). It was found that 90% farmers harvested fruits following maturity index. It was reported that farmers practiced various post-harvest practices to manage pests. Farmers practiced cleaning and washing after harvesting (38%), sorting and grading of fruits (88%). Few farmers (4%) applied chemicals to increase shelf life of fruits. Also farmers transported pineapple following standard procedures (70%) to avoid contamination of pests.

**Table 6.** Pest Risk management measures at harvest and post-harvest stage

| Measures | Adopted farmers (n) | Adoption (%) |
|---|---|---|
| Harvesting following maturity index | 45 | 90 |
| Cleaning and washing after harvest by farmers | 19 | 38 |
| Sorting and grading of fruits by farmers | 44 | 88 |
| Chemical treatment to increase shelf life | 02 | 04 |
| Non-chemical shelf-life management | 05 | 10 |
| Transportation following standard procedures | 35 | 70 |
| Direct contact with exporters | 02 | 04 |
| Selling fruits in local markets | 50 | 100 |

### 3.2.4 Pest Risk management measures at pre-shipment stage

The results (Table 07) indicated that the measures at central packing house and plant quarantine station at pre-shipment stages were adopted well. All respondents (100%) reported that they applied measures to manage pest risk before shipment based on different approved measures, pest risk analysis and guidelines from the experts. Respondents replied that they identified pests based on visual method (100%) and 50% respondents to laboratory diagnosis of pests. Similarly, most of the respondents (93.75%) responded that they followed following cleaning and sanitation schedules and disposed waste and rejected fruits properly to prevent pest attraction. All respondents (100%) confirmed about the internal inspections, inspection recordkeeping, pest interception reporting, pre-export inspections, phytosanitary certification, and corrective actions for non-compliance in central packing house and plant quarantine station. It was found that 81.25% staffs were communicating with ISPM guidelines and received refresher training on phytosanitary measures. Most of the respondents (87.5%) reported that the pest risk management program was good.

**Table 7.** Pest Risk Management measures at plant quarantine station and central packing house

| Description of pest management approaches | Parameter | Total Respondents (n) | Number of responses | Frequency (%) |
|---|---|---|---|---|
| **Pest Monitoring and Identification (ISPM 5, ISPM 31)** | | | | |
| Frequency of implementing pest monitoring and inspection programs | Regular | 16 | 3 | 18.75 |
| | Occasionally | 16 | 10 | 62.5 |
| Methods used for pest identification | Visual detection | 16 | 16 | 100 |
| | Laboratory diagnosis | 16 | 8 | 50 |
| Maintaining and upgrading Pest identification records | yes | 16 | 15 | 93.75 |
| **Pest Management Techniques (ISPM 14, ISPM 20, ISPM 38)** | | | | |
| Management approaches are used | Multiple measures | 16 | 16 | 100 |
| Frequency of pest control treatments | As needed | 16 | 15 | 93.75 |
| Using approved phytosanitary chemicals according to national standard | yes | 16 | 16 | 100 |
| Following PRA for applying phytosanitary measures | yes | 16 | 16 | 100 |
| **Sanitation and Hygiene (ISPM 4, ISPM 26, ISPM 34)** | | | | |
| Following cleaning and sanitation schedules | yes | 16 | 15 | 93.75 |
| Disposing waste and rejected fruits properly to prevent pest attraction | yes | 16 | 15 | 93.75 |
| Existence of designed packing areas to minimize pest entry and harbouring | yes | 16 | 15 | 93.75 |
| **Inspection, Recordkeeping, and Traceability (ISPM 7, ISPM 12, ISPM 23, ISPM 41)** | | | | |
| Conducting of internal inspections before shipment | yes | 16 | 16 | 100 |
| Presence of traceability system for each consignment | yes | 16 | 10 | 62.5 |
| Inspection results recorded and archived | yes | 16 | 16 | 100 |
| Reporting pest interceptions to NPPO or relevant authority | yes | 16 | 16 | 100 |

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| | | | | |
|---|---|---|---|---|
| **Export Certification and Compliance (ISPM 12, ISPM 14)** | | | | |
| Complying with export phytosanitary certification requirements? | yes | 16 | 16 | 100 |
| Performing pre-export inspections by authorized officers | yes | 16 | 16 | 100 |
| Are standard phytosanitary certificates issued and verified before shipment? | yes | 16 | 16 | 100 |
| Are non-compliance cases documented and corrective actions taken? | yes | 16 | 16 | 100 |
| **Training and Awareness (ISPM 2, ISPM 14, ISPM 20)** | | | | |
| Presence of trained staff in pest management and phytosanitary procedures | yes | 16 | 15 | 93.75 |
| Are updated ISPM guidelines communicated to staff? | yes | 16 | 15 | 93.75 |
| Do inspectors receive refresher training from NPPO? | yes | 16 | 13 | 81.25 |
| **Overall Evaluation and Suggestions** | | 16 | | 0 |
| Overall effectiveness of current pest management program | Good | 16 | 14 | 87.5 |
| | Fair | 16 | 2 | 12.5 |
| Regular Coordination with stakeholders | Regular | 16 | 6 | 37.5 |
| Major challenges in pest management | Lack of resources | 16 | 13 | 81.25 |
| | Limited regular training | 16 | 15 | 93.75 |
| | Weak monitoring | 16 | 13 | 81.25 |
| | Poor facility design | 16 | 13 | 81.25 |

### 3.3 Assessment of alignment of existing measures against requirement for systems approach

The assessment of existing pest risk management across the pineapple export pathway revealed the considerable variation (Table 08) in the alignment level with requirements of a system approach. Strong alignment of measures was observed for training (100%) received by pineapple producers, collecting pest free suckers for transplanting (98%), pineapple harvesting following maturity index (90%), sorting and grading (88%) at post-harvest level. Also several pre-shipment phytosanitary measures including visual inspection of pests (100%), application of approved phytosanitary chemicals (100%), internal inspections, pre-export inspections and application of multiple measures (100%) to manage pests associated with consignments at pre-shipment stages showed strong alignment with system approach. Also traceability systems (62.5%) and phytosanitary certification (100%) were showed strong alignment.

In contrast, several measures showed comparatively weak alignment like pineapple producer registration and pineapple cultivation in pest-free areas were not implemented. Alignment of soil testing by farmers showed 18% and pineapple sucker treatment before transplanting was 36% . The application of integrated pest management (IPM) to manage pest risk was low (20%), despite moderate alignment with IPM concepts (64%) among farmers. Similarly, 38% were familiar with Good Agricultural Practices (GAP) protocol of pineapple but no respondents reported implementing GAP for pest management.

**Table 8.** Assessment of existing measures against systems approach requirements following pathway-pest assessment framework

| Systems approach Component | Adopted measures | Adoption (%) | Alignment |
|---|---|---|---|
| Preventive measures | Producer registration | 0 | Not implemented |
| | Contact farmers of the exporters | 4 | Weak |
| | Producer training from recognized authority | 100 | Strong |
| | Production in pest free area | 0 | Not implemented |
| | Collection of pest-free suckers | 98 | Strong |
| | Treatment of suckers before transplanting | 36 | Weak |
| | Soil treatment before planting | 44 | Limited |
| | Destruction of crop residues before transplanting | 50 | Limited |
| | Soil testing before planting | 18 | Weak |
| | Fertilizer application based on soil test report | 12 | Weak |
| Multiple measures to manage risk pest | Transplanting sucker at proper time | 94 | Strong |
| | Maintaining proper plant spacing | 42 | Limited |
| | Mechanical weed control | 12 | Weak |
| | Chemical weed control | 48 | Limited |
| | Eco-friendly weed control (mulching, etc.) | 92 | Strong |
| | Multiple weed control approaches | 4 | Weak |
| | Eco-friendly insects and disease management | 38 | Weak |
| | Chemical pesticide application to manage insects and disease | 64 | Moderate |

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| Systems approach Component | Adopted measures | Adoption (%) | Alignment |
|---|---|---|---|
| | Organic pesticide application to manage insects and diseases | 64 | Moderate |
| | Combined chemical and organic pesticide use to manage insects and diseases | 20 | Weak |
| Integrated pest management measures | Familiarity with IPM approaches to manage pests | 64 | Moderate |
| | Application of IPM to manage pests | 20 | Weak |
| | Familiarity with GAP to manage pests | 38 | Weak |
| | GAP implementation to manage pests | 0 | Not implemented |
| Harvest and post-harvest risk Management | Harvesting following maturity index | 90 | Strong |
| | Cleaning and washing after harvest by farmers | 38 | Weak |
| | Sorting and grading of fruits by farmers | 88 | Strong |
| | Chemical treatment to increase shelf life by farmers | 04 | Weak |
| | Non-chemical shelf-life management by farmers | 10 | Weak |
| | Transportation following standard procedures | 70 | Moderate |
| Phytosanitary measures at pre-shipment stage | Visual inspection for pest detection | 100 | Strong |
| | Laboratory based pest diagnosis | 50 | Limited |
| | Multiple measures applied before shipment | 100 | Strong |
| | Using approved phytosanitary chemicals | 100 | Strong |
| | Cleaning and sanitation | 93.75 | Strong |
| | Disposing waste and rejected fruits properly | 93.75 | Strong |
| | Well-constructed packing area | 93.75 | Strong |
| Monitoring and surveillance | Regular survey of pests in the production site | 36 | Weak |
| | Regular pest monitoring and inspection of the consignments | 18.75 | Weak |
| | Occasionally pest monitoring and inspection of the consignments | 62.5 | Moderate |
| | Conducting internal inspections before shipment | 100 | Strong |
| | Pre-export inspections by authorized officers | 100 | Strong |
| Documentation and Coordination | Pest management measures application recorded | 36 | Weak |
| | Adopted ISPMs guidelines communicated with staff | 100 | Strong |
| | Non-compliance cases documented | 100 | Strong |
| | Inspection results recorded and archived before shipment | 100 | Strong |
| | Maintaining pest identification record by quarantine officers | 93.75 | Strong |
| | Existence of GAP protocol for pineapple | 100 | Strong |
| | Presence of pest risk analysis of pineapple | 100 | Strong |
| | Presence of officially declared pest status of pineapple in Bangladesh | 0 | Not implemented |
| | Presence of standard Systems approach for pineapple applied in the pineapple export pathway | 0 | Not implemented |
| | Regular consultation and training to farmers | 84 | Strong |
| | Regular consultation with quarantine officers | 93.75 | Strong |
| | Present of systems approach standard approved by import countries | 0 | Not implemented |
| | Coordination with stakeholders | 37.5 | Weak |
| Verification | Following PRA for applying phytosanitary measures | 100 | Strong |
| | Reporting pest interceptions to NPPO | 100 | Strong |
| | Comply with export phytosanitary certification system | 100 | Strong |
| | Consultation with agriculture officer to manage pests | 14 | Weak |
| | Recommendations from pesticide dealers to manage pests | 86 | Strong |
| | Discussion with neighbour farmers to manage pests | 18 | Weak |
| | Pest management based on own experience | 96 | Strong |
| Traceability | Presence of traceability system for each consignment | 62.5 | Moderate |
| | Standard Phytosanitary certificate issued | 100 | Strong |

### 3.4 Gap assessment of the measures for managing pest risks

The gap assessment of the measures revealed considerable varied results in the level of conformity of existing pest risk management measures with the requirements of systems approach align with ISPM 14 (Table 9). The highest gap was found in integrated measures to manage risk pests (GI: 68.7%). Also there were major gaps in various measures including preventive measures (GI: 60%) to manage pest risk, application of multiple measures (GI: 45%) and measures at harvest and post-harvest stages (GI: 60%).

Also, there were various measures showed moderate gaps like Monitoring and surveillance (GI: 35%), documentation and coordination (GI: 34.62%). The minor gap index values were found in Phytosanitary measures at the pre-shipment stage (7.14%) and traceability system of the consignment (12.5%).

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**Table 9.** Gap assessment of systems approach components considering adoption

| Systems approach Component | No. of Indicators | Observed Score (OS) | Maximum Score (MS) | Gap Index (%) | Interpretation |
|---|---|---|---|---|---|
| Preventive measures | 10 | 16 | 40 | 60.00 | Major gap |
| Multiple measures to manage pest risks | 10 | 22 | 40 | 45.00 | Major gap |
| Integrated measures to manage pest risks | 4 | 5 | 16 | 68.75 | Critical gap |
| Harvest and post-harvest risk Management | 6 | 14 | 24 | 41.67 | Major gap |
| Phytosanitary measures at pre-shipment stage | 7 | 26 | 28 | 7.14 | Minor gap |
| Monitoring and surveillance | 5 | 13 | 20 | 35.00 | Moderate gap |
| Documentation and coordination | 13 | 34 | 52 | 34.62 | Moderate gap |
| Verification | 7 | 22 | 28 | 21.43 | Moderate gap |
| Traceability | 2 | 7 | 8 | 12.5 | Minor gap |

## 4. DISCUSSION

The present study assessed the extent to which existing pest risk management measures in the pineapple export pathway of Bangladesh conform to the systems approach outlined in ISPM 14. The findings indicate that although several important phytosanitary measures are currently practiced, their implementation is inconsistent across the stages of the production-to-export pathway. Consequently, Bangladesh has incorporated several elements of a systems approach, but these measures do not yet operate as a fully integrated system in which multiple independent measures collectively reduce pest risk throughout the export pathway of pineapple.

A major strength identified in this study is the high adoption of several production and export-related practices aligned with system approaches. Producer training (100%), use of pest-free suckers (98%), timely transplanting (94%), eco-friendly weed management (92%), harvesting at the appropriate maturity stage (90%), and fruit sorting and grading (88%) were widely adopted. In addition, phytosanitary measures at pre-shipment stage showed excellent compliance with systems approach principles. Visual pest inspection, application of approved phytosanitary treatments based on PRA, implementation of multiple phytosanitary measures, and issuance of phytosanitary certificates were adopted by all respondents, while sanitation and hygiene of packing house, maintenance of packing facilities and proper disposal of rejected fruits exceeded 90% adoption. These results demonstrate that Bangladesh practices a relatively strong export inspection and certification system capable of meeting international phytosanitary requirements.

Despite these strengths, substantial gaps were identified in preventive phytosanitary measures. Producer registration, production within officially declared pest-free areas, and other preventive practices such as soil testing, fertilizer application based on soil analysis, and sucker treatment before planting were absent or poorly implemented, resulting in a high Gap Index (GI = 60.00%).

Integrated pest management represented the weakest component of the export pathway, with the highest Gap Index (GI = 68.75%). Although many respondents were familiar with IPM concepts but only a small proportion implemented IPM practices, and none reported adopting GAP-based pest management. This gap between knowledge and practice reduces the diversity and independence of pest risk management measures, which are fundamental principles of a systems approach. Similarly, the application of multiple independent pest management measures remained limited (GI = 45.00%).

Phytosanitary measures at harvest and post-harvest stages showed moderate performance (GI = 41.67%). While harvesting at the proper maturity stage and fruit grading were commonly practiced, cleaning and washing of harvested fruits were poorly adopted, leaving opportunities for additional reduction of pest contamination before export. Monitoring and surveillance also demonstrated only moderate compliance. Although inspections before export were routinely conducted but regular field surveillance and continuous pest monitoring throughout the production cycle were limited, indicating that pest management system remains mostly concentrated at the export stage rather than across the entire production pathway.

Institutional and regulatory limitations were also evident. Although inspection records, pest identification reports, phytosanitary communication, existence of traceability systems, and issuing phytosanitary certification were well established, Bangladesh lacks officially declared pest status for pineapple, a formal ISPM 14-based systems approach protocol, and effective stakeholder coordination. Overall, the study demonstrates that Bangladesh depends mostly on end-point inspection and certification rather than a comprehensive pathway-based systems approach. Strengthening preventive measures to manage pest risks, expanding IPM and GAP adoption, improving routine surveillance, and developing an official ISPM 14-compliant systems approach protocol through stakeholder collaboration would substantially strengthen phytosanitary security and support sustainable international market access for Bangladeshi pineapple.

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## 5. CONCLUSION

This study evaluated the alignment of existing pest risk management measures in the pineapple export pathway of Bangladesh with the requirements of a systems approach following ISPM 14 and identified key gaps affecting the implementation of a systems approach to manage pest risk. The findings demonstrated that several important phytosanitary measures are already in place, particularly at the export stage in quarantine stations and packing house. High adoption of producer training, use of pest-free planting materials, harvesting based on maturity indicx, visual inspection of pests, standard phytosanitary certification and existence of traceability system indicates a strong foundation for supporting safe international trade. Furthermore, pre-shipment phytosanitary measures and existence of traceability systems exhibited the highest level of conformity with the requirements of a systems approach.

Despite these strengths, substantial gaps were identified in preventive measures to manage pests at production site, implementation of integrated pest management srtageies, monitoring and surveillance of pests, and the application of multiple independent measures throughout the production pathway. The absence of producer registration to the designated authority, producing pineapple in pest-free areas, GAP implementation to produce pineapple and limited adoption of IPM approach, soil testing, routine pest monitoring, presence of standard systems approach protocol to produce pineapple contributed to major and critical gaps in pathway-wide pest risk management. These findings indicate that phytosanitary assurance to manage pest risks in the current export system relies predominantly on end-point pest inspection and standard certification rather than a fully integrated systems approach.

To enhance phytosanitary activities to manage pest risks and strengthen export competitiveness, priority should be given to improving preventive measures to manage pests and surveillance system of pests, promoting IPM and GAP adoption to manage pest risks, strengthening stakeholder coordination, and developing a formal ISPM 14-based systems approach protocol for pineapple exports from Bangladesh.

### Conflict of Interest

The authors declare that they have no conflict of interest.

### Ethics Statement

The authors confirm that the study adhered to all relevant ethical standards and complied with the applicable legal requirements of the study country.

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### Author Contributions

This study was carried out in collaboration among all the authors. All authors contribute to the conception and design of the project, as well as the analysis and interpretation of the data. The final manuscript has been reviewed and approved by all authors.

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