

## Agronomic, environmental and institutional determinants of mango production in developing countries: a systematic literature review

Khairun Nisaa<sup>1</sup> Mohd Nor<sup>1,2</sup>, Abdul Rahman Saili<sup>3</sup>, Narzullo Naimovich Oblomuradov<sup>4</sup>, Achilov Mashrab Ulugbekovich<sup>4</sup>, Karieva Gulnora Abdullaevna<sup>4</sup>, Sri Fatimah<sup>5</sup> and Fazleen Abdul Fatah<sup>2\*</sup>

<sup>1</sup>Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA Perlis Branch, Arau Campus, Perlis, Malaysia

<sup>2</sup>Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Melaka Branch, Jasin Campus, 77300 Merlimau, Melaka

<sup>3</sup>Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Sarawak Branch, Kota Samarahan Campus, 94300 Kota Samarahan, Sarawak

<sup>4</sup>Agrobusiness Management and Logistics, Tashkent State Agrarian University, Tashkent, 100128, Uzbekistan

<sup>5</sup>Department of Agricultural Socio-Economics, Faculty of Agriculture, Padjadjaran University, Indonesia

### ARTICLE HISTORY

Received : 8 January 2026

Accepted : 24 February 2026

Online : 30 September 2026

### KEYWORDS

agronomy  
environment  
mango  
efficiency  
review

### ✉ \*CORRESPONDING AUTHOR

Dr. Fazleen Abdul Fatah  
Faculty of Plantation and  
Agrotechnology, Universiti Teknologi  
MARA, Melaka Branch, Jasin  
Campus, 77300 Merlimau, Melaka  
Email: [fazleen5201@uitm.edu.my](mailto:fazleen5201@uitm.edu.my)

### ABSTRACT

Mango (*Mangifera indica* L.) is one of the tropical fruits that is commonly grown to enhance livelihoods, farmers' income, and generate export earnings for most of the developing nations. However, its productivity levels vary substantially depending on soil characteristics, climatic conditions, and economic and management practices. To address this shortcoming, the study aims to provide comprehensive insights into the determinants of mango production and to highlight key knowledge gaps by synthesizing the main themes and critical theories found in existing literature. This study conducted a systematic review of 38 peer-reviewed publications from 2000 to 2025 that identify the agronomic and environmental factors shaping mango production in developing economies, and it uses the PRISMA method to examine the critical factors influencing mango production. By systematically categorizing studies by themes, this study provides a comprehensive synthesis of production determinants and policy implications to guide future research. Overall, the findings found key determinants including fertiliser management, labour skill, planting density, and pest-control practices are the most significant agronomic factors, while the rainfall variability, temperature extremes, soil fertility, and drought frequency show measurable influence in the environmental dimension. The review highlights actionable guidance for cross-regional benchmarking and stakeholders to achieve sustainable and more resilient mango production systems in developing countries.

© 2026 UMK Publisher. All rights reserved.

## 1. INTRODUCTION

Mango (*Mangifera indica* L.) is considered one of the most important tropical fruits due to its value for nutritional characteristics and health-promoting properties in reducing risk factors associated with obesity, diabetes, and cardiovascular disease (Elhadi *et al.* 2023). In addition, it is a rich source of vitamins, minerals, and antioxidants, and a great source of magnesium and potassium, both of which are connected to lower blood pressure and immune health (Burton-Freeman *et al.* 2025).

Mango is one of the world's most traded fruit crops, valued for its nutritional attributes, export potential, and source of income and employment for rural livelihoods (FAO 2023; Bura *et al.* 2023). Global mango production exceeds 50 million tonnes annually, with developing countries in Asia and Africa being among the largest exporting regions (FAO 2023). The crop supports the livelihoods of millions of smallholder farmers

and plantation workers through various value chain activities, including on-farm employment, harvesting, processing, and marketing.

Despite the strong nutritional value and high demand for mangoes, production varies widely across different farming systems and regions. There are significant differences in resource use, yield stability, output levels, and profit margins, even when farms use similar technologies. Studies in Ghana, Malaysia, and Myanmar have consistently shown major performance gaps among mango growers. These gaps are often linked to differences in environmental challenges, access to inputs, and management practices (Sein *et al.* 2013; Mensah & Brummer 2016; Nor *et al.* 2024). These variations highlight the complex relationships between support systems, physical limitations, and farming decisions that influence agricultural success (Dominic *et al.* 2024).

A considerable body of research has explored the factors affecting mango farming. This often focuses on

specific farming practices, such as managing labor, distributing fertilizer, applying irrigation, shaping the canopy, and controlling pests. Field trials have tested techniques like Integrated Nutrient Management (INM), pruning, and irrigation strategies (Prasad *et al.* 2019; Rehman *et al.* 2015; Ofori *et al.* 2023). In addition, other studies have pointed out how climate and environmental factors- like soil health, extreme temperatures, rainfall patterns, and drought frequency- pose significant challenges to productivity (FAO 2023; Raushan *et al.* 2025; Dominic *et al.* 2024). These findings come from diagnostic and survey-based research that looks at the adoption of modern methods, socio-economic factors, and soil-plant interactions (Ahmed *et al.* 2020; Muhammad Naveed *et al.* 2022; Bibi *et al.* 2023). Additionally, institutional aspects such as cooperatives, access to credit, extension programs, digital advisory services, and market access have proven essential for helping farmers adopt better practices and deal with environmental difficulties (Haryanto *et al.* 2023; Xie *et al.* 2024; World Bank 2023).

In agricultural economics, frontier-based methods have been used to assess farm success by separating external random shocks from management-related inefficiencies (Farrell 1957; Battese & Coelli 1995). Recent advancements in methodology, including deep learning and meta-frontier analysis, have highlighted technological gaps across different farming environments (Mensah & Brummer, 2016; O'Donnell 2018; Nor *et al.* 2024; Afsar *et al.* 2024; Trinh *et al.* 2025). While these methods provide useful insights into measuring farm performance, the current study does not directly compute technical efficiency values. Instead, it uses a framework that focuses on the factors affecting mango production in developing countries. By emphasizing the drivers of production rather than only efficiency scores, this research offers a broader analysis of how management choices interact with environmental and institutional factors.

This paper adopted a systematic literature review approach to synthesize agronomic, environmental and institutional determinants of mango production across developing countries. Following the PRISMA approach, the review is to make sure the process was transparent, organised, and easy to follow (Page *et al.* 2021). The review aimed to consolidate findings from empirical studies, agronomic field experiments, and environmental assessments that directly influence production in mango production systems.

## 2. MATERIALS AND METHODS

### 2.1. Literature identification and search strategy

The literature included in this review was identified from peer-reviewed journal articles, institutional reports, and working papers cited within the manuscript. These comprised studies on agronomic management (e.g., fertiliser use, labour

allocation, pest control), environmental determinants (e.g., temperature, rainfall, soil quality), and integrated efficiency modelling frameworks used in mango production systems. Key literature forming the evidence base included studies from Asia, Africa, and Latin America, such as Barwal *et al.* (2022), Ofori *et al.* (2023), Nor *et al.* (2024), Lei *et al.* (2025), Raushan *et al.* (2025), Dominic *et al.* (2024), Sein *et al.* (2013), and Mensah & Brummer (2016).

**Table 1:** Search string for literatures

| Database / Source                                              | Search string (Title / Abstract / Keywords)                                                                                                                                                                                                                                                |
|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Scopus                                                         | ("mango production" OR "mango farming" OR "mango cultivation") AND ("technical efficiency" OR "production" OR "resource use efficiency" OR "productivity") AND ("agronomic factors" OR "nutrient management" OR "irrigation" OR "pest management" OR "climate" OR "environmental factors") |
| Google Scholar                                                 | ("mango" AND "technical efficiency") OR ("mango production" AND "efficiency") OR ("mango farming" AND "productivity") AND ("agronomic" OR "environmental" OR "climate")                                                                                                                    |
| Grey literature<br>(FAO, World Bank,<br>institutional reports) | ("mango production" AND "efficiency") OR ("horticulture efficiency" AND "mango")                                                                                                                                                                                                           |

A comprehensive literature search was conducted using Scopus, Google Scholar, and selected grey literature sources (Table 1). The search strings combined keywords related to mango production, technical efficiency, agronomic practices, and environmental factors. The search was restricted to studies published between 2000 and 2025. In total, 2,551 records were identified before screening and eligibility assessment following the PRISMA framework (refer to Figure 1).

The PRISMA 2020 framework, which was proposed by Page *et al.* (2021), offers a systematic and transparent methodology for executing and documenting systematic reviews, aiming to enhance reproducibility, mitigate selection bias, and strengthen the credibility of systematic reviews, particularly in multidisciplinary and policy-relevant research domains. The process was underpinned by a methodical search approach, organised data extraction, and appropriate quality evaluation. The procedure is structured into four primary phases: identification, screening, eligibility, and inclusion. During identification, systematic and predetermined search strategies are employed across various databases to encompass all possibly pertinent studies. Next, the screening phase entails the systematic elimination of duplicate entries, followed by an evaluation of titles and abstracts to discard irrelevant or unrelated studies. During the eligibility phase, full-text papers are assessed according to specific inclusion and exclusion criteria, while methodological quality and risk-of-bias evaluations are conducted to ensure the evidence's robustness.

Finally, the inclusion stage preserves merely that

research which fulfils the established criteria for synthesis. The search followed a thematic approach, aligning with the conceptual framing as described by Braun and Clarke (2006). Because the SLR is a mixed-method (quantitative and qualitative), qualitative synthesis is the most appropriate analysis (Flemming *et al.* 2021). Inductive thematic analysis is one of the qualitative techniques we used to analyze the extracted data, concentrating on collating relevant or similar data into potential themes and gathering all data pertinent to each possible theme that will finally produce a thematic map or analysis.

## 2.2. Screening criteria

Studies were included if they met the following criteria: a) Focused on mango production within developing-country contexts; b) Reported agronomic, environmental, institutional, or climatic determinants affecting productivity or efficiency; c) Employed an empirical, quantitative, or observational approach relevant to yield, productivity or agronomic modelling and were explicitly cited in this manuscript, as described in Table 2.

reference list were retained.

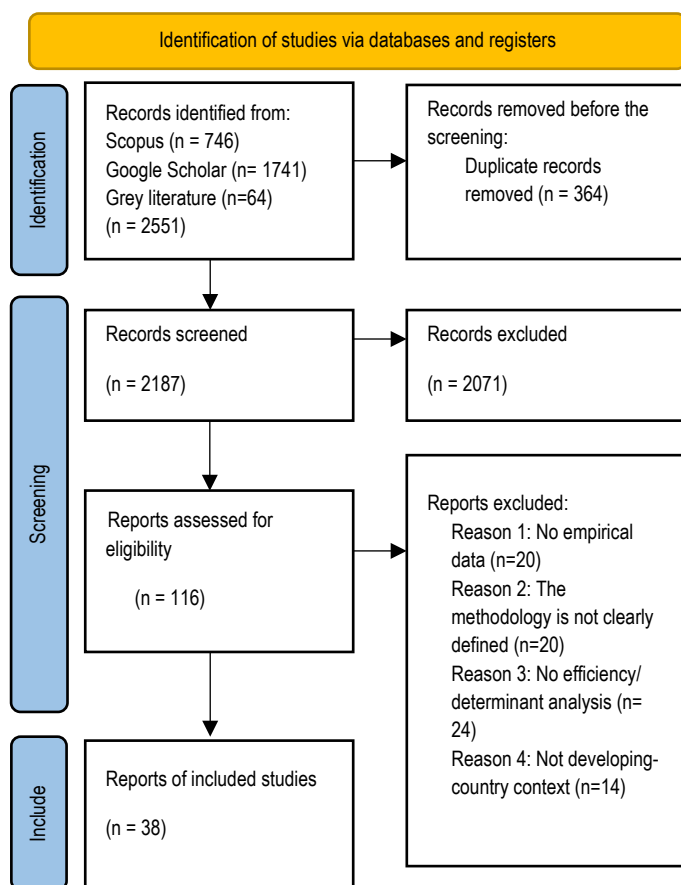
Following the PRISMA 2020 model, the initial search in Scopus and Google Scholar, as described in Figure 1, yielded 2,551 various types of articles. After the title and abstract screening and removal of duplicates and irrelevant papers, 116 articles were considered eligible for full-text evaluation. Subsequently, 38 articles were included in the analysis (refer to Figure 1).

**Table 2:** The inclusion and exclusion criteria

| Criteria category     | Inclusion criteria                                                                                                                                 | Exclusion criteria                                                                                        |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Study focus           | Studies that examine mango ( <i>Mangifera indica</i> ) production, productivity, or yield                                                          | Studies focusing on crops other than mango or non-agricultural sectors                                    |
| Determinants examined | Studies addressing agronomic factors, environmental factors, their interactions, and/or policy or institutional implications                       | Studies focusing solely on biological, genetic, or laboratory-based outcomes without efficiency relevance |
| Study design          | Empirical studies using quantitative methods (e.g. econometric models, field experiments, spatial analysis, review analysis) or qualitative method | Conceptual papers, opinion pieces, editorials, commentaries, or narrative essays                          |
| Geographical context  | Studies conducted in developing and emerging economies, including country-specific, multi-country, or global analyses                              | Studies conducted exclusively in high-income countries without relevance to developing-country contexts   |
| Publication type      | Peer-reviewed journal articles and relevant grey literature (e.g. FAO, World Bank reports)                                                         | Conference abstracts only, unpublished theses, non-reviewed sources                                       |
| Language              | Studies published in English                                                                                                                       | Studies published in languages other than English                                                         |
| Data availability     | Studies with clear methodology and extractable empirical results                                                                                   | Studies with unclear methods, insufficient data, or inaccessible full texts                               |

## 2.3. Data extraction and eligibility

A thematic synthesis was conducted, grouping evidence into agronomic determinants, environmental determinants, and institutional determinants. Quantitative insights from quantitative or qualitative studies were interpreted in relation to environmental conditions using frameworks described by Lei *et al.* (2025) and Zheng *et al.* (2025). Institutional dimensions—such as extension, credit access, and digital advisory tools—were incorporated using evidence from Haryanto *et al.* (2023) and Xie *et al.* (2024). This method ensured a comprehensive integration of agronomic, environmental, and institutional insights solely from sources included in the manuscript.



**Figure 1:** The Flow diagram of PRISMA

Studies were excluded if they did not contain extractable empirical information, did not analyse mango production (e.g., purely conceptual horticulture papers), or lacked relevance to efficiency, agronomic determinants, or climate influences. Only sources present in the manuscript's

**Table 3:** Scoring criteria for the Mixed-Method Appraisal Tool (MMAT).

| No. | Study                         | Design suitability | Method transparency | Data/ sample adequacy | Analysis robustness | Findings–conclusions alignment | Overall rating |
|-----|-------------------------------|--------------------|---------------------|-----------------------|---------------------|--------------------------------|----------------|
| 1   | Ahmed et al. (2020)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 2   | Afsar et al. (2024)           | Yes                | Yes                 | CD                    | Yes                 | Yes                            | 4/5            |
| 3   | Beatrice et al. (2025)        | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 4   | Baltazari et al. (2020)       | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 5   | Bibi et al. (2023)            | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 6   | Barwal et al. (2022)          | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 7   | Asadu et al. (2024)           | Yes                | Yes                 | CD                    | Yes                 | Yes                            | 4/5            |
| 8   | Dutta et al. (2016)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 9   | Edward et al. (2021)          | Yes                | Yes                 | CD                    | Yes                 | Yes                            | 4/5            |
| 10  | FAO (2023)                    | Yes                | CD                  | CD                    | Yes                 | Yes                            | 3/5            |
| 11  | Ruzhani & Mushunje (2025)     | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 12  | Rehman et al. (2015)          | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 13  | Guvvali et al. (2020)         | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 14  | Haryanto et al. (2023)        | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 15  | Hasan et al. (2013)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 16  | Khan & Ahmed (2021)           | Yes                | CD                  | CD                    | Yes                 | Yes                            | 3/5            |
| 17  | Dominic et al. (2024)         | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 18  | Lu et al. (2025)              | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 19  | Lima et al. (2021)            | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 20  | Mensah & Brummer (2016)       | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 21  | Mitra et al. (2023)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 22  | Momin et al. (2021)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 23  | Mukherjee (2016)              | Yes                | CD                  | CD                    | Yes                 | Yes                            | 3/5            |
| 24  | Mulungu et al. (2023)         | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 25  | Muhammad Naveed et al. (2022) | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 26  | Muriithi et al. (2016)        | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 27  | Nor et al. (2024)             | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 28  | O'Donnell (2018)              | Yes                | Yes                 | CD                    | Yes                 | Yes                            | 4/5            |
| 29  | Ofori et al. (2023)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 30  | Prasad et al. (2019)          | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 31  | Raushan et al. (2025)         | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 32  | Sein et al. (2013)            | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 33  | Singh et al. (2010)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 34  | Susanto et al. (2020)         | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 35  | Trinh et al. (2025)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 36  | Xie et al. (2024)             | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 37  | Zheng et al. (2025)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |
| 38  | Patel et al. (2022)           | Yes                | Yes                 | Yes                   | Yes                 | Yes                            | 5/5            |

\*CD= Cannot determine

#### 2.4. Quality appraisal

To ensure the review was established based on credible evidence, each article included underwent a quality or risk-of-bias assessment utilising the Mixed-Method Appraisal Tool (MMAT), which has already been employed in earlier systematic review studies (Okoli, 2015; Shaffril *et al.* 2020). The evaluation concentrated on various elements, such as the clarity of the research design description, the transparency of the sampling techniques, the robustness of the statistical analysis, and the credibility of the conclusions drawn from the data presented. Articles exhibiting inadequate or ambiguous methodological transparency were previously excluded during the eligibility phase. The MMAT was selected due to its efficacy across several study designs, including qualitative, quantitative, and mixed-methods approaches. Each study was assessed according to five primary criteria:

- Suitability of the study design to the research question;
- Transparency and reliability of methodologies;
- Sufficiency of data and representativeness of the

sample;

- Robustness of analysis and interpretation;
- Alignment between findings and conclusions.

A three-option scoring system was employed (Yes / No / Cannot Determine). Studies that satisfied a minimum of three out of five criteria were retained for synthesis.

The methodological quality assessment using the Mixed Methods Appraisal Tool (MMAT) in Table 3 shows that the overall quality of the included studies is high. All 38 studies met the minimum inclusion threshold of  $\geq 3/5$ . Out of the 38 studies evaluated, 31 studies achieved the maximum score of 5/5, indicating strong methodological rigor across all MMAT criteria, including suitability of study design, transparency of methodology, adequacy of data, robustness of analysis, and alignment between findings and conclusions.

In addition, 4 studies obtained a rating of 4/5, suggesting generally strong methodological quality but with minor limitations related to data representativeness or incomplete reporting of methodological procedures. Meanwhile, 3 studies received a rating of 3/5, primarily due to unclear systematic selection procedures or insufficient

information regarding data sources and sampling representativeness particularly in deep learning models (e.g., Afsar *et al.* 2024), broad scoping reviews (e.g., Edward *et al.* 2021), and policy reports (e.g., FAO 2023). For example, some review-based or modelling studies lacked sufficient information regarding dataset representativeness or systematic inclusion criteria. While this reduced their MMAT score in terms of methodological transparency, these works still provide important theoretical and contextual contributions to the understanding of mango production systems and agricultural productivity analysis. Their conceptual perspectives complement the empirical findings of higher-rated studies and help broaden the interpretative scope of the review.

Overall, these results indicate that the majority of the reviewed literature demonstrates high methodological robustness, with more than 80% of the studies meeting all MMAT quality criteria. The relatively small proportion of lower-rated studies suggests that potential risks of bias within the evidence base are limited and are mainly associated with data insufficiency or conceptual analyses rather than empirical investigations.

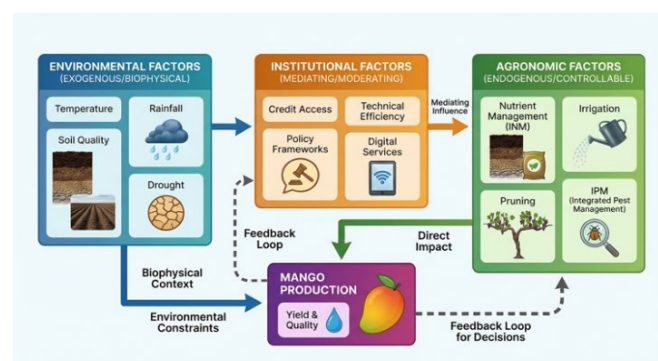
## 2.5. Conceptual framework

The determinants of mango production can be understood through a multi-layered conceptual framework that distinguishes between endogenous actions and exogenous constraints, mediated by institutional support (Figure 2). The framework highlights that environmental factors represent the biophysical context for mango cultivation. These factors include temperature, rainfall, soil quality, and drought conditions, which shape the natural environment for production and impose key limits on crop growth and productivity. These conditions are mainly exogenous which are outside the farmers' control but greatly affect how agricultural systems perform.

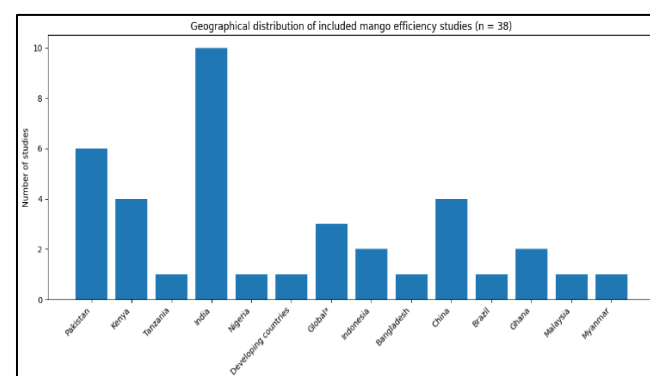
Institutional factors act as mediating or moderating mechanisms that affect farmers' ability to react or respond to environmental conditions and adopt suitable production strategies. Factors like access to credit, foreign direct interaction between Environmental Factors (Exogenous), Institutional Factors (Mediating), and Agronomic Factors (Endogenous) in mango production.

Agronomic factors are management practices that farmers can control on their farms which are known as endogenous. These practices include integrated nutrient management (INM), irrigation, pruning, integrated pest management (IPM), and harvesting methods. These technical interventions directly impact mango production outcomes by improving plant health, optimizing resource use, and increasing both yield and fruit quality. Feedback

loops ensure that positive production results can lead to greater institutional recognition and improved agronomic strategies.



**Figure 2:** Conceptual Framework illustrating the environmental, agronomic and institutional factors that influence mango production.



**Figure 3:** Geographical distribution of studies based on region or country.

## 3. RESULT AND DISCUSSION

### 3.1 Background of the selected article

Following final data extraction, a total of 38 studies were included in the synthesis. These comprised country-specific, multi-country, and global-level analyses, which explains the broader geographical distribution presented in Figure 3. The concentration of studies in South Asia suggests a strong research focus on mango efficiency in traditional production hubs, while relatively fewer studies from Southeast Asia and Africa indicate potential gaps for future empirical investigation.

### 3.2 The themes and sub-themes

Table 4 synthesises evidence from 38 empirical studies on mango production across developing economies that showed pertinent factors determine the productivity of mango across the developing countries. As described by the conceptual framework, three major themes appeared: (1) agronomic factors, (2) environmental factors, and (3) institutional factors.

These themes discuss empirical evidence on agronomic determinants—factors largely within farmers'

control. It also examines environmental determinants that define biophysical limits and explores their interactions as well as evaluates institutional intervention strategies, methodological innovations, and policy implications. Collectively, these sections operationalise the dual three-perspective introduced here: that mango-production efficiency is co-determined by management, agronomic quality, and environmental suitability, and institutional or policy implications, all of which must be addressed to achieve sustainable productivity gains. Most studies focus on agronomic determinants, including nutrient management, labour use, pest control, irrigation, canopy management, and post-harvest practices, which consistently explain variation in technical efficiency. Fewer studies examine environmental factors, such as climate variability and drought stress, or the interaction between agronomic and environmental conditions. Several studies also highlight policy and institutional roles, especially extension services and digital advisory support, in addressing persistent efficiency gaps.

### 3.3 Agronomic factors

Agronomic determinants represent the controllable management factors that influence the conversion of inputs into outputs. In mango cultivation, these include fertiliser and nutrient management, labour and managerial skill, pest and agrochemical control, planting density and canopy design, and post-harvest practices (Prasad *et al.* 2019). Empirical research across developing countries confirms that such factors collectively explain most within-country variation in technical efficiency (TE) scores (Nor *et al.* 2024; Barwal *et al.* 2022; Ofori *et al.* 2023; Beatrice *et al.* 2025).

While the relative magnitude of each determinant differs by region and production system, the consistent finding is that managerial and agronomic practices, rather than technology itself, drive much of the inefficiency observed in mango production.

Across the literature, five major agronomic determinants consistently emerge as key levers of efficiency as defined in Table 5:

- i. Fertiliser management – optimising type, timing, and quantity through INM and soil testing;
- ii. Labour and management expertise - developing human resources through training and expansion;
- iii. Pest and disease control - embracing IPM and lessening chemical addiction;
- iv. Canopy design- keeping the structure sound in terms of yield and resource efficiency;
- v. Practices in the post-harvest - minimization of losses and enhanced access to the market.

**Table 4:** Summary of thematic contributions based on country or region

| No | Authors                       | Year | Country                             | Theme                                                    |
|----|-------------------------------|------|-------------------------------------|----------------------------------------------------------|
| 1  | Ahmed <i>et al.</i>           | 2020 | Pakistan                            | Agronomic factors                                        |
| 2  | Afsar <i>et al.</i>           | 2024 | Pakistan                            | Agronomic factors                                        |
| 3  | Beatrice <i>et al.</i>        | 2025 | Kenya                               | Agronomic factors                                        |
| 4  | Baltazari <i>et al.</i>       | 2020 | Tanzania                            | Agronomic factors                                        |
| 5  | Bibi <i>et al.</i>            | 2023 | Pakistan                            | Agronomic factors                                        |
| 6  | Barwal <i>et al.</i>          | 2022 | India                               | Agronomic factors                                        |
| 7  | Asadu <i>et al.</i>           | 2024 | Nigeria                             | Agronomic factors                                        |
| 8  | Dutta <i>et al.</i>           | 2016 | India                               | Agronomic factors                                        |
| 9  | Edward <i>et al.</i>          | 2021 | Developing countries (Global South) | Environmental factors                                    |
| 10 | FAO                           | 2023 | Global*                             | Policy and institutional implications                    |
| 11 | Ruzhani & Mushunje            | 2025 | Global*                             | Policy and institutional implications                    |
| 12 | Rehman <i>et al.</i>          | 2015 | Pakistan                            | Agronomic factors                                        |
| 13 | Guvvali <i>et al.</i>         | 2020 | India                               | Interactions between agronomic and environmental factors |
| 14 | Haryanto <i>et al.</i>        | 2023 | Indonesia                           | Policy and institutional implications                    |
| 15 | Hasan <i>et al.</i>           | 2013 | Bangladesh                          | Agronomic factors                                        |
| 16 | Khan & Ahmed                  | 2021 | Pakistan                            | Agronomic factors                                        |
| 17 | Dominic <i>et al.</i>         | 2024 | Kenya                               | Environmental factors                                    |
| 18 | Lu <i>et al.</i>              | 2025 | China                               | Interactions between agronomic and environmental factors |
| 19 | Lima <i>et al.</i>            | 2021 | Brazil                              | Environmental factors                                    |
| 20 | Mensah & Brummer              | 2016 | Ghana                               | Policy and institutional implications                    |
| 21 | Mitra <i>et al.</i>           | 2023 | India                               | Environmental factors                                    |
| 22 | Momin <i>et al.</i>           | 2021 | India                               | Policy and institutional implications                    |
| 23 | Mukherjee                     | 2016 | India                               | Agronomic factors                                        |
| 24 | Mulungu <i>et al.</i>         | 2023 | Kenya                               | Policy and institutional implications                    |
| 25 | Muhammad Naveed <i>et al.</i> | 2022 | Pakistan                            | Interactions between agronomic and environmental factors |
| 26 | Muriithi <i>et al.</i>        | 2016 | Kenya                               | Agronomic factors                                        |
| 27 | Nor <i>et al.</i>             | 2024 | Malaysia                            | Policy and institutional implications                    |
| 28 | O'Donnell                     | 2018 | Global* (TE definition)             | Policy and institutional implications                    |
| 29 | Ofori <i>et al.</i>           | 2023 | Ghana                               | Policy and institutional implications                    |
| 30 | Prasad <i>et al.</i>          | 2019 | India                               | Agronomic factors                                        |
| 31 | Raushan <i>et al.</i>         | 2025 | India                               | Agronomic factors                                        |
| 32 | Sein <i>et al.</i>            | 2013 | Myanmar                             | Policy and institutional implications                    |
| 33 | Singh <i>et al.</i>           | 2010 | India                               | Agronomic factors                                        |
| 34 | Susanto <i>et al.</i>         | 2020 | Indonesia                           | Agronomic factors                                        |
| 35 | Trinh <i>et al.</i>           | 2025 | China                               | Interactions between agronomic and environmental factors |
| 36 | Xie <i>et al.</i>             | 2024 | China                               | Policy and institutional implications                    |
| 37 | Zheng <i>et al.</i>           | 2025 | China                               | Policy and institutional implications                    |
| 38 | Patel <i>et al.</i>           | 2022 | India                               | Agronomic factors                                        |

\*includes developing and developed countries

A combination of these determinants accounts for much of the difference in technical efficiency that is found between the regions (Nor *et al.* 2024; Barwal *et al.* 2022; Lu *et al.* 2025). Notably, their impacts are not autonomous: e.g., the responsiveness to fertiliser is regulated by soil moisture, and pest occurrence is affected by canopy microclimate. This interdependence has a direct association with the environmental determinants as discussed in

Section 3.2.3. These findings have direct policy implications. Both knowledge dissemination interventions: soil-testing services, farmer field schools, and IPM training, provide high efficiency at low cost. The use of post-harvest losses and the increase in use of resources can also be strengthened by strengthening farmer organisations to manage common infrastructure like cold storage. Finally, sustainable mango intensification under new climatic and market conditions is based on agronomic efficiency improvements.

**Table 5:** Summary of major agronomic determinants of mango production and representative evidence.

| Determinant                      | Mechanism influencing efficiency                                                                                          | Representative evidence                                                    | Key references                                                                         |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Fertiliser & nutrient management | Balanced fertilisation improves nutrient uptake and soil health; over-application raises cost and lowers marginal returns | Site-specific management improves yield stability and reduces inefficiency | Barwal <i>et al.</i> (2022); Lei <i>et al.</i> (2025); Asadu <i>et al.</i> (2024)      |
| Labour & managerial skill        | Skilled labour improves pruning, irrigation, and pest control; training reduces inefficiency                              | Managerial ability significant in efficiency variation                     | Ofori <i>et al.</i> (2023); Nor <i>et al.</i> (2024)                                   |
| Pest & disease management        | IPM lowers pesticide costs and environmental risk; maintains yield                                                        | IPM adoption associated with higher TE                                     | Muriithi <i>et al.</i> (2016); Dodd <i>et al.</i> (1991); Dominic <i>et al.</i> (2024) |
| Planting density & canopy design | Optimal spacing improves light and air flow; reduces disease incidence                                                    | Moderate densities and regular pruning enhance efficiency                  | Prasad <i>et al.</i> (2019); Hasan <i>et al.</i> (2013)                                |
| Post-harvest handling            | Improved storage and logistics increase marketable yield                                                                  | Cooperative storage and grading raise returns                              | Prasad <i>et al.</i> (2019); Minh <i>et al.</i> (2024); Barwal <i>et al.</i> (2022)    |

#### a. Fertiliser and nutrient management

The use of fertilisers is a source of productivity that is very strong, but is also a tendency towards inefficiency in its management (Khan & Ahmed, 2021). As the research in India and Bangladesh indicates, the use of unbalanced nutrients, especially more nitrogen than phosphorus or potassium, increases the cost of production but does not give a commensurate growth in yield (Singh *et al.* 2010; Barwal *et al.* 2022; Govindasamy *et al.*, 2025). Nor *et al.*

(2024) in the Harumanis orchards of Malaysia found that fertiliser was a major factor that determined output, but over-application decreased the marginal productivity.

The Chinese analyses affirm the same trends. In a study by Lei *et al.* (2025), the authors applied the energy-life-cycle framework to analyse the use of mango systems in the Hainan Province and found that the inputs of fertilisers constituted most energy use, which is inefficient when used in excess of recommended levels. These findings reflect larger evidence on tropical fruit systems that precision of nutrient management, such as soil tests or calibrated fertigation, increases technical and environmental efficiency (Dutta *et al.* 2016; Asadu *et al.*, 2024).

The use of integrated nutrient management (INM) as a combination of organic compost, bio-fertilisers, and mineral compounds is progressively known as a viable method of maintaining soil fertility and improving the fruit quality of mango over the long-term in Pakistan (Hasan *et al.* 2013; Patel *et al.* 2022). Additionally, they further noted that the outcome of INM on tropical orchards was a higher nutrient-use efficiency and fruit quality because soil organic matter and nutrient balance were maintained. Smallholders have not yet adopted such practices in large numbers, largely because of the price, the absence of training, and even because of extension services. However, a general agreement amongst the literature is that rather than intensive, nutrient optimisation is the most important in reducing the efficiency gaps.

#### b. Labour, management skill and experience.

The mango fruit is a labour-intensive crop, especially when pruning, controlling pests, and harvesting. The efficiency is, however, dictated by the way in which the labour is organised and applied as opposed to the amount of labour. Ofori *et al.* (2023) have shown that the extent of productivity differences between Ghanaian fruit farms was explained by managerial ability in large proportions. On the same note, Nor *et al.* (2024) indicated that the more skilled or higher-trained workers scored higher on TE in Malaysia, meaning that the quality of human-capital is a notable explanatory variable.

Labour productivity is also enhanced when the farms have easy access to simple mechanisation such as motorised sprayers, pruning lifts, or portable harvest aids, which increase timeliness and alleviate fatigue. Experienced farmers in East Africa demonstrate that partial mechanisation increased efficiency, primarily by eliminating bottlenecks of labour when doing main tasks in the orchard (Dominic *et al.* 2024). Training and extension thus have a very indirect, yet important, effect in which it informed

farmers to utilize the inputs more efficiently, and less labour is assigned to inefficient allocation, and hence the performance constraints are lower (Sein *et al.*, 2013).

### **c. Agrochemical application and pest-management.**

The pest and disease control significantly affects the mango's production and yield. Specifically harmful in tropical climates are fruit fly (*Bactrocera dorsalis*), mango hopper (*Idioscopus* spp.), or anthracnose (*Colletotrichum gloeosporioides*), which are detrimental (Susanto *et al.* 2020). Traditional management imposes a lot on chemical pesticides, which nevertheless become more expensive and riskier to the environment and development of resistance.

According to recent studies, when farms adopt integrated pest management (IPM), farms become increasingly profitable (Mulungu *et al.* 2023). Alam *et al.* (2016) determined that in Bangladesh, the IPM practices are an effective strategy for obtaining higher yields. Similarly, pest scouting and trap use training in Kenya decreased the usage of pesticides and improved the quality of fruits in those farmers (Dominic *et al.* 2024). Dodd *et al.* (1991) noted that biological control with the help of entomopathogenic fungi and parasitoids is one of the sustainable alternatives to IPM that does not lead to the unnecessary use of chemical pesticides but ensures yields.

These findings suggest that both agronomic and environmental factors can be enhanced with the transition to the model of managing pests based on knowledge, as opposed to regular prophylactic spraying. Adoption barriers, however, comprise poor availability of biological agents, poor advisory systems, and the perceived risk of loss of yields by the farmers. To improve uptake, policies in support of community-based IPM training and demonstration plots have thus been suggested (FAO 2023).

### **d. Planting density, canopy design, and orchard layout**

The density of planting and canopy architecture have an impact on light interception, nutrient uptake, and the regulation of microclimate. High tree densities, which are too dense, cause competition for water and nutrients, and the disease, since the air does not circulate adequately, and overly sparse plantations do not make proper use of the land resources. In hilly terrain, contour planting and terracing are used to prevent erosion and preserve the moisture of the soil.

Studies in South Asia and Southeast Asia indicate that moderate densities that are adapted to the cultivar and

the environment between yield per unit area and labour input are optimal (Hasan *et al.* 2013). Pruning is therefore one of the most important management practices for the mango tree (Rehman *et al.* 2015; Mukherjee, 2016). Prasad *et al.* (2019) demonstrated that the systematic pruning that ensured open canopies enhanced the penetration and efficiency of light and photosynthesis, leading to trees of better health and more stable yields. This structural management also lowers the humidity of the canopy, curbing the risk of fungal diseases. Pruning, mulching, and intercropping enhance input-output through the regulation of microclimate (e.g., humidity in the canopy, soil temperature, and moisture preservation) and facilitate nutrient uptake more efficiently (Guvvali *et al.* 2020; Raushan *et al.* 2025; Edward *et al.* 2021; Prasad *et al.* 2019).

### **e. Post-harvest handling and value-chain management**

Post-harvest activities such as cold-storage have a strong impact on the realised output and profitability (Baltazari *et al.* 2020; Momin *et al.* 2021). The losses incurred during harvesting, grading, transportation, and storage can be over ten percent in most of the tropical systems, which simply reduce apparent farm productivity (FAO 2023; World Bank 2023).

In Thailand and Vietnam, it has been demonstrated that better handling and packaging minimize physical losses and preserve the quality of the fruits, which can then be sold with greater profit without extra use of inputs (Minh *et al.* 2024). Further production is introduced through cooperative marketing and shared cold-storage facilities, which distribute the fixed costs, and the prices are kept stable.

In Malaysia, farmers' cooperatives that participate in the Harumanis mango sale performed better in terms of net returns with the coordination of the collection, grading, and branding processes (Nor *et al.* 2024). Spoilage is also minimized by training on harvest maturity indices and post-harvest hygiene. All these interventions show that productivity gains are not limited to the field, but they are also applicable to the whole value chain.

## **3.4 Environmental Factors**

Environmental determinants determine the biophysical boundaries in which the production of mango takes place. Potential yield and the effectiveness of conversion of farm inputs to output are largely dependent on temperature, rainfall, soil fertility, and the occurrence of extreme events. As opposed to agronomic factors, which are normally under the control of a farmer, the environmental variables are exogenous but have a high

interaction with the management practices. An effectively operated orchard under poor conditions might thus not seem efficient as long as these factors are not directly included in productivity studies (FAO, 2023; Lei *et al.* 2025).

#### **a. Rainfall and irrigation management.**

The amount and distribution of the rainfall have a direct effect on the yield and efficacy of the mango, especially in rain-based systems. Unpredictable precipitation interferes with flowering and raises the chances of dropping fruits, and too much humidity caused by monsoon conditions enhances the prevalence of anthracnose and powdery mildew (FAO, 2023).

Empirical studies have always shown that productivity can be improved through access to reliable irrigation to stabilize yield during changeable seasons. Farmers in South Asia who used drip or micro-sprinkler irrigation were more water-use-efficient than surface irrigation-based farms (Raushan *et al.* 2025). In the Mekong Delta, scheduled irrigation programs enhanced the fruit setting and decreased water usage with no yield loss (Minh *et al.* 2024). According to Malaysian research as well, the frequency and timing of irrigation are positively, but not always significantly, correlated with productivity (Nor *et al.* 2024).

The productivity benefits do not significantly contribute to the yield increase compared to climatic risk reduction. Irrigation moves the farms to the achievable frontier by smoothing out the variability of rainfall. Therefore, water-management enhancements are also a principal climate-adaptation intervention (Trinh *et al.* 2025).

#### **b. Soil fertility, structure and topography**

Nutrient availability, water retention, and root growth in soils are influenced by soil properties, which in turn affect production (Ahmed *et al.* 2020). Poor or infertile soils lower the efficiency of the fertiliser investment and result in large dispersion of efficiency in the same area (Asadu *et al.*, 2024). The authors of the study by Keshyagol *et al.* (2026) discovered that the higher the levels of organic carbon in the soil and its structure, the higher the resource-use efficiency of tropical fruit systems.

The farmers in the semi-arid regions of mangoes in Kenya identified soil infertility and hardening as some of the primary causes of yield stagnation (Dominic *et al.* 2024). The same has been observed in Asia, where low soil organic matter has been associated with reduced responsiveness to fertiliser, indicating that agronomic efficiency depends on soil health. The addition of soil indicators to stochastic-

frontier models can thus enhance the power of the explanation to eliminate the possibility of attributing environmental constraints on the inefficiency of management (Lei *et al.* 2025).

Topography also alters the results of efficiency. Poor drainage and erosion in sloping terrains reduce the availability of nutrients and are an obstacle to mechanised work. Contour planting and terracing lower the run-off rate, preserve the soil moisture, and indirectly raise the yield (Hasan *et al.* 2013).

#### **c. Extreme events and climate abnormalities**

Extreme weather episodes- droughts, cyclones, and floods are on the rise in the tropical areas, and their impact on mango production can be measured. Droughts lower flowering and fruit set, floods and high-speed winds lead to mechanical loss of fruits and damage to the canopy (FAO 2023). Such shocks affect annual output estimates through a sudden reduction of production in at least well-managed farms.

A new body of literature on climate-adjusted efficiency modelling seeks to isolate weather effects (which are temporary) and inefficiency that is enduring. A more recent survey of tropical fruit crop production sensitivity to climate has provided importance in the addition of rainfall deviation and temperature aberration variables in stochastic-frontier frameworks (Raushan *et al.* 2025). By including these types of indices, analysts can estimate the extent of perceived inefficiency by climatic variation and not by management failure.

The adaptation practices, such as mulching, rainwater collection, drip irrigation, and drought-tolerant rootstocks, are also being embraced as two-fold solutions that maintain the yield and efficiency (Wei *et al.* 2017; Raushan *et al.* 2025). These practices can be incorporated in national fruit-development programmes to minimise vulnerability to extreme events, with the productive frontier being retained.

In addition to biophysical interactions, institutional and social dynamics are the mediators of farmers responding to environmental bottlenecks. Availability of irrigation facilities, soil testing facilities, and extension facilities is what will dictate the possibility of management to be adapted to local conditions (World Bank 2023). As an example, the digital agro-advisory systems in China have allowed adjusting the fertilising and irrigation cycles according to the real-time weather conditions to enhance their efficiency and adaptation to the climate (Xie *et al.* 2024). Equally, Malaysian and Thai farmer cooperatives help to distribute inputs and technical expertise to

collectively adapt to climate stress (Nor *et al.* 2024).

In the absence of such institutional encouragement, farmers will easily adopt homogeneous management regimes that do not suit environmental site-specific conditions and continue to perpetuate inefficiency. Such an observation is consistent with the argument of production being a systemic characteristic that is not only influenced by agronomic precision but also the capacity of institutions to transform environmental knowledge into practice.

### 3.5 Interactions between agronomic and environmental factors

Environmental conditions and the agronomic management interact dynamically in determining the production of the mango. Even though agronomic factors are mostly under the control of farmers, temperature, rainfall, soil structure, and microclimatic factors exert a strong effect on their marginal productivity, and it is necessary to distinguish between managerial inefficiency and actual environmental disadvantage (FAO 2023; O'Donnell 2018). Performance of fertilisers, such as moisture and temperature of the soil, soil moisture, and soil temperature, are among the factors that reduce the effect of added fertiliser under degraded or water-scarce soils, although the technique of using fertilisers might be appropriate (Lei *et al.* 2025). Environmental context also determines the success of pest and disease management: the presence of high humidity favors fungal pathogens, including *Colletotrichum gloeosporioides*, whereas warm, dry climates stimulate the growth of fruit flies, which underscores the ecological sensitivity of input use (Dodd *et al.* 1991).

The region-specific efficiency outcomes are found in these interactions, as seen in Malaysia, where the cooler and wetter Mata Ayer zone was more responsive to fertiliser use than the hotter and drier Chuping area, despite being under the same management regime, which supports the necessity of including environmental controls in efficiency estimation (Nor *et al.* 2024). The agronomic effectiveness is also mediated by climate variability because the effects of temperature and rainfall dictate the irrigation need, optimum fertiliser application, and when to carry out orchard activities. Delayed rainfall in semi-arid systems reduces the period of vegetation and reduces nutrient availability to the system, but precision irrigation systems include drip and fertigation irrigation methods, which synchronise the delivery of water and nutrients to the vegetation, minimizing inefficiency (Raushan *et al.* 2025). On the other hand, when the rainfall is too heavy, the labour mobility may limit the applicability of pesticides and lower their efficiency due to

higher levels of inputs, as witnessed in India and Bangladesh (Barwal *et al.* 2022). The structure of soils, the percentage of organic matter, and topography also affect the efficiency of the conversion of inputs to output; soils with elevated organic carbon concentrations are more responsive to fertilizers and contain more nutrients, whereas compacted or eroded soils have low yield despite high input (Keshyagol *et al.* 2026).

### 3.6 Institutional Factors

#### a. Climate-smart agronomic practices

Climate-smart agriculture (CSA) incorporates productivity, adaptation, and mitigation objectives (FAO, 2023). CSA strategies within the mango systems are aimed at water conservation, restoration of soil health, and regulation of microclimate.

The cheap interventions, such as mulching and cover cropping, would save on moisture, lower the soil temperature, and help with weed control, which would help to increase the efficiency of input usage (Muhammad Naveed *et al.* 2022; Raushan *et al.* 2025). Canopy management, such as pruning and height control, improves the level of light interception and airflow, which in turn decreases the occurrence of diseases and improves fruit quality (Prasad *et al.* 2019).

Scheduling of irrigation and fertilisation is also climate responsive, which can enhance efficiency. Phenological stage matching with irrigation intervals in Malaysia and India minimized water consumption and maximized fruit set (Nor *et al.* 2024; Barwal *et al.* 2022). Compost and biochar are examples of soil organic amendments that enhance the fertility and retention of water in soil that buffer orchards against drought stress (Asadu *et al.* 2024).

One of the ways through which policymakers can hasten the process is by incorporating the principles of CSA within the national fruit-development programmes and through training under the extension services. Furthermore, local adaptation trials, which prove an increase in yield and efficiency in the field, are a way to develop farmer confidence in the practices.

#### b. Integrated pest and disease management (IPM)

The presence of pest and disease pressures are very significant contributors of yield loss or inefficiency. Excessive use of chemicals has augmented the cost of production and ecological hazards. The integrated pest management (IPM) presents a moderate solution; a mixture of cultural, biological, and chemical control for mango production (Muriithi *et al.* 2016).

The field research in Vietnam and Kenya shows that IPM implementation can create cost savings in pesticide use and yield similar or increased yields (Muriithi *et al.* 2016; Dominic *et al.* 2024). The parasitoid approach and entomopathogenic fungi are effective in the biological control of the mango hoppers and fruit flies (Dodd *et al.* 1991). Additional methods, e.g., field sanitation, pheromone trap use, and selective pruning, also reduce populations of pests.

In order to magnify the benefits, extension systems need to focus more on farmer-field schools and demonstration orchards. India and Thailand Governments funded programmes have been able to spread IPM knowledge using participatory learning, resulting in reduced dependency on pesticides in the long term (Singh *et al.* 2010). Safe biological agents should also be registered and made available by regulatory frameworks to promote wider utilization.

According to several studies, site-specific management and balanced use of nutrients lead to higher yield with the increase in costs, which is not proportional (Barwal *et al.* 2022; Asadu *et al.* 2024). Special programmes encouraging soil testing and integrated nutrient management (INM) have proved rather effective. As an example, the farms with INM practices in South and Southeast Asia had more consistent productivity, fewer nutrient losses, and better soil structure in comparison with the conventional systems (Hasan *et al.* 2013).

Simultaneously, the optimisation of water-use is still important in varying rainfall patterns. New technologies such as drip irrigation and fertigation have also enhanced efficiency in water usage and have made it possible to deliver fertilisers with great accuracy (Raushan *et al.* 2025). Farmers who have implemented these technologies have been recording increased consistency in their yields, particularly in semi-arid and drought-prone zones. Small-scale irrigation facilities, such as subsidies, access to credit, or group ownership, can be more easily adopted through the policy support of these facilities.

Optimisation of agrochemical use should also be done. Safe handling, appropriate dosage, and pest threshold evaluation training may help decrease the unnecessary use, which will reduce the cost of production and eliminate the threat to the climate (Alam *et al.* 2016). However, blanket prescriptions on pesticide use are still prevalent in most developing nations; this needs to be changed to adopt evidence-based and integrated strategies.

#### **c. Institutional and market support**

The institutional extension, cooperatives, credit, and access to markets have a strong impact on the efficiency of the farm level. In most developing nations, the technology adoption by farmers is limited by the fact that they have low access to financial services and information (World Bank 2023). Enhancing these institutions is thus important, just like enhancing agronomic practices.

Farmer cooperatives and producer organisations allow the setting up of a large-scale purchasing of inputs, common usage of post-harvest facilities, and enhanced bargaining power on the market (Prasad *et al.* 2019). The indirectly advantageous effect of cooperative marketing of mangoes in Malaysia and Thailand has improved technical efficiency because of the increment in the farmgate prices and the cost reduction in transactions (Nor *et al.* 2024). On the same note, the productivity of smallholders has enhanced in India and Pakistan through the contract-farming approaches that offer secure markets and extension services (Barwal *et al.* 2022).

There are complementary roles of credit and access to insurance. When farmers have more access to credit, they are able to invest in inputs that increase their efficiency, like irrigation or pruning tools (Haryanto *et al.* 2023). Meanwhile, crop-insurance schemes alleviate risk aversion, and this will encourage the use of better technologies despite uncertain climatic conditions. The policy actions aimed at increasing financial inclusion (e.g., group lending or micro-insurance) can hence hasten the efficiency benefits in the sector.

The extension and advisory services are still centralized. Participatory approaches are slowly replacing traditional top-down models and creating a farmer's capacity to solve problems and enhance feedback between research and practice (FAO, 2023). The extension training, which needs to be financed by means of digital and local demonstration plots, is essential in scaling up good practices within the heterogeneous farming communities.

#### **d. Digital innovations and knowledge-based systems**

Digitalisation provides new possibilities to enhance technical and environmental efficiency. Mobile-based decision-support systems, weather forecasts, and remote-sensing applications are among the tools that enable farmers to maximise the utilisation of inputs and can predict the variability of the climate.

Digital agro-technology services in China have also enhanced the technical-performance variation of smallholder mango farmers because they can make informed irrigation and pest-management decisions. Other

tools of the same type are being piloted in India and the Philippines, where mobile platforms provide site-based fertiliser advice and alerts about pests. These advantages are most amplified as the digital solutions are incorporated in larger extension models that guarantee access and understanding among the smallholders.

Governments and research organizations ought to encourage open-data systems, which enable meteorological, soil, and market data to be linked to advisory services. Collaboration with agri-tech companies that are privately owned can help in accelerating the innovations as long as the privacy of the data is maintained and it is affordable.

Meanwhile, the digital divide, such as limited connectivity, literacy, and trust, is a factor in the rural regions. Combining both digital technology and face-to-face training will provide inclusive adoption. Digitalisation is therefore not to be seen as an alternative to extension but rather as a facilitating complement that is more accurate and covers a larger audience with knowledge.

#### **e. Data gaps and measurement challenges**

The unstable farm-level data are also an issue that mango-efficiency studies continue to face. Record keeping is not common in smallholder farms, and therefore, it is challenging to get accurate measures of input and output. Most of the research works use recall surveys, which create measurement error and bias (Mensah & Brummer 2016).

To overcome this, digitisation of data collection through mobile applications and geographic information systems (GIS) should be encouraged in work in the future. Farm surveys can be supplemented by remote sensing, which is able to give objective information on the density of trees, canopy cover, and crop vigour (Afsar *et al.* 2024). The combination of geospatial data with the frontier analysis would enhance the accuracy of the spatial efficiency patterns and environmental gradients (Zheng *et al.* 2025).

Unifying data collection procedures between countries and research facilities would also streamline meta-analysis and comparative studies, which would give a more coherent overview of the world with regard to mango production. Technical efficiency is based on the efficiency with which inputs are utilised, i.e., fertiliser, water, and agrochemicals. A number of studies show that site-specific management and equal distribution of nutrients enhance the yield without an increase in costs (Barwal *et al.* 2022; Asadu *et al.* 2024). In particular, programmes on soil testing and integrated nutrient management (INM) have been effective. As an example, the farms with INM systems in South and Southeast Asia demonstrated greater stable productivity,

lower losses of nutrients, and better soil structure in comparison to the conventional systems (Hasan *et al.* 2013; Bibi *et al.* 2023; Raushan *et al.* 2025).

Meanwhile, the use of water is still a critical issue in varying rainfall patterns. Drip irrigation and fertigation systems have also led to a higher level of water-use efficiency and have facilitated the accurate application of fertiliser (Raushan *et al.* 2025). Farmers who have embraced these technologies have been known to record increased consistency in their yields, particularly in semi-programmed areas and drought-prone regions. Subsidies, credit access, or group ownership policy support small-scale irrigation infrastructure, which can be promoted more broadly.

#### **4. REGIONAL PATTERN COMPARISON**

Although the review of this manuscript focuses only on South Asia, there are prominent differences in the factors affecting mango production in various continents, namely Africa, South Asia, and Southeast Asia. The differences are associated with irrigation systems, climate, farming practices, and institutional growth. Moreover, the relevance of this review is enhanced through a comparative approach by proving that production performance is influenced by structural and environmental contexts and farming techniques.

Studies in South Asia, namely, Bangladesh, Pakistan, and India, are inclined towards investigating the factors affecting production performance. Their focus is primarily on highlighting nutrient management, fertilizer use, pest control, labor distribution, and orchard design as the contributor towards yield production (see Barwal *et al.* 2022; Hasan *et al.* 2013; Raushan *et al.* 2025; Khan & Ahmed, 2021). Furthermore, the farming systems in this region are partially- or semi-irrigated perennial orchards, which are known for established farming practices and higher input usage. The adaptation of these farming systems is due to the environmental challenges (e.g., unpredictable monsoons, temperature changes during flowering, and ongoing soil nutrient depletion), which affect their practices (Mitra *et al.* 2023; FAO, 2023). However, the production differences in the South Asia region are often associated with how inputs are used and variations in management quality, instead of strict environmental limits (Nor *et al.* 2024). Thus, to boost management efficiency, the policy in this region often emphasizes climate-smart orchard techniques, precise nutrient management, enhancing extension services, and pest management education.

However, researchers from the African continent, namely Kenya, Ghana, and Tanzania, have shown that

environmental and institutional challenges significantly affect mango production in their countries (Mensah & Brummer 2016; Dominic *et al.* 2024; Ofori *et al.* 2023). Many farming systems in the countries utilise conventional methods such as relying heavily on rain, face limited irrigation access, and substantially use fewer inputs. Moreover, factors associated with the environment, such as unpredictable rainfall, drought, and soil degradation, significantly affect output production (FAO, 2023; Dominic *et al.* 2024). Additionally, farmers in this region also faced institutional barriers, namely, limited extension services, lack of credit access, inadequate post-harvest facilities, and bad marketing systems, which hinder the adoption of efficient farming practices (World Bank 2023; Haryanto *et al.* 2023). Furthermore, instead of being planted in a specialized orchard, mango trees are often planted as part of mixed crop and livestock farming systems in some African countries. This method often affects the production performance due to the household-level decisions about resource allocation, reducing the focus on orchard management. The priority of policy in this region often transcends enhancing farming practices to involve building irrigation infrastructure, developing cooperatives, soil restoration projects, and managing climate risks.

The perennial orchard systems in Southeast Asia are mixed, leading to better market connections and institutional support. Studies in the region, particularly in Indonesia, Malaysia, Vietnam, and Thailand, show that production performance is shaped by environmental factors and farming practices, which are related to high humidity and monsoon rain patterns (Nor *et al.* 2024; Susanto *et al.* 2020). Moreover, pest and disease pressures are significant in humid tropical climates, leading to the important role of pest management and control of canopy conditions on farm performance (Mulungu *et al.* 2023; Susanto *et al.* 2020). The Southeast Asia farmers have better ability to adjust their management based on market signals and weather changes compared to their counterparts in the African regions due to modern cooperative marketing systems and digital advisory services (Xie *et al.* 2024). Therefore, the policies in this region emphasizes on post-harvest quality control, irrigation planning, digital extension tools, and export standards.

This review also highlights structural differences in how production works by comparing the rain-fed and the irrigated systems. The rain-fed systems, which are commonly used by many farmers in the African region and semi-arid regions of South Asia, are susceptible to drought and changes in rainfall (FAO, 2023; Raushan *et al.* 2025). The outcome of these systems is commonly affected by the

environmental limits, in which any improvements in farming practices alone may not be able to lessen climatic risks. On the other hand, the irrigated systems are more common in many parts of Southeast and South Asia, in which these systems are able to produce greater yield stability and are more responsive to pest and nutrient management works (Trinh *et al.* 2025; Nor *et al.* 2024). The irrigation systems lessen the effect of rainfall fluctuations and increase the productivity of other inputs. This allows management decisions to have a greater consequence on production performance. The two different systems point to the fact that investing in infrastructure can lead to bigger performance improvements, especially in rain-dependent regions, whereas the precise management of inputs could enable higher returns in irrigated systems.

In parts of Southeast Asia and South Asia, mango is often planted in one-of-a-kind orchards that emphasize long-term planning and organized canopy management (Hasan *et al.* 2013; Barwal *et al.* 2022). In this region, production performance is determined by soil health, orchard layout, and how efficiently inputs are managed. However, in many African regions, mango trees are part of varied smallholder systems. Therefore, resources like labour, land, and financial support are shared among various farming (Mensah & Brummer 2016; Ofori *et al.* 2023). As a result, yield and productivity stability are affected because of the spreading of resources on orchard management. From a policy perspective, new technology adoption and export market connections can benefit specialized orchards. However, a mixed system orchard requires broader rural development strategies that focus on access to extension services, credit, and reducing risks from diversification strategies.

This review has highlighted that by comparing the patterns of mango production performance across regions, one can identify the factors that can influence its output, namely, agronomic management, institutional capacity, and environmental challenges, though the importance of each factor varies by region. Moreover, the South Asia region indicates more variation driven by management under partly controlled irrigation, whereas in the African region, environmental risks and institutional barriers play a crucial role. The review also highlights that Southeast Asia achieves a balance between institutional responsiveness and environmental pressures. These differences push for policies that are suitable for specific regions instead of having a one-size-fits-all method. Finally, to improve mango production in any developing country, the concerned entity must consider farming system types, irrigation access, climate exposure, and the level of institutional development.

## 5. CONCLUSION AND RECOMMENDATIONS

This review synthesizes empirical findings of past studies on the factors affecting mango production in the African, South Asia, and Southeast Asia regions. A total of 38 peer-reviewed studies from 2000-2025 were reviewed using the PRISMA framework. The findings indicate that mango production in these regions is influenced by a mix of agronomic practices, institutional support, and environmental conditions. Several key insights and theoretical contributions arise from this review.

Firstly, this review highlights that the production of perennial crops like mango is mediated by environmental factors. Unlike annual crops, perennial orchard systems accumulate the impacts of soil conditions, climate differences, and management resolutions over multiple seasons. The responsiveness of agronomic inputs and yield potential is influenced by variables such as rainfall variability, soil fertility, temperature differences, and extreme weather. This points to the notion that production performance in perennial systems must be recognized as structurally rooted within the environmental context rather than solely on management-driven.

Secondly, farmers' responses to environmental constraints are shaped by institutional variables that serve as moderating mechanisms. Moreover, farmers' access to extension services, credit facilities, cooperatives, digital advisory systems, and market infrastructures shapes their improved practices and ability to adapt to climate differences. In the absence of institutional support, environmental constraints create a stronger limiting effect on farm production performance. On the other hand, in the region where institutional supports are strong, farmers tend to demonstrate better adaptive ability. Thus, this indicates the need for conceptualising production performance as institutionally rooted rather than solely agronomically set.

Thirdly, agronomic precision stands as a key factor for enhancing production performance, whilst reducing environmental impact. The yield stability and resource productivity are influenced by balanced nutrient management, climate-responsive irrigation scheduling, integrated pest management, and canopy regulation. Notably, these practices lessen the risks of nutrient runoff, overuse of pesticide, and soil degradation which eventually lead to enhanced output. Therefore, this suggests that performance improvement and environmental sustainability are not mutually the whole objectives in perennial horticulture systems.

Fourthly, this review highlights that structural variations in irrigation access, farming system integration, and institutional ability can influence the importance of

agronomic versus environmental factors. The irrigation systems in these regions indicate several variations; the South Asian systems show stronger management-driven variation under partially irrigated conditions, while African systems exhibit greater environmental and institutional constraints under rain-fed structures, whilst Southeast Asian systems employ hybrid patterns that combine climatic exposure with stronger market integration. These variations signal a region-specific approach rather than a one-size-fits-all strategy.

The review also identifies several research gaps. Firstly, most past research focused on a cross-sectional study design, lacking longitudinal or panel data to track changes over time. The results of longitudinal or panel data may suggest a stronger finding because management and environmental factors build up season after season, in which this type of data is beneficial for separating structural challenges from temporary shocks. Thus, future research can benefit from longitudinal data that can illustrate the effect over time during periods of climate variability.

Furthermore, this review has shown that African production systems are underrepresented compared to South Asia. Empirical studies are scarce in the region, even though environmental challenges are more severe in Africa. Thus, to enhance knowledge of rain-fed perennial systems, soil recovery methods, and institutional adaptations to climate pressures in the region, more research is needed.

Finally, it is noteworthy that better connections are required between economic performance analyses and agronomic experiments. Many economic studies are lacking in detailed environmental data, while most agronomic studies assess yield responses without looking at institutional feasibility. Thus, bridging these gaps may enhance the reliability of future productivity measurements.

To conclude, mango production in the regions under review results from the intricate interaction of environmental limitations, agronomic practices, and institutional support. To improve farm performance, tailored strategies that integrate infrastructure investment, climate-smart agriculture, localized advice, and institutional support are required. Thus, to develop sustainable practices in perennial cropping systems amid growing climatic uncertainty, it is vital for future research to employ longitudinal data that covers a wider geographic area and use climate-adjusted models.

## ACKNOWLEDGEMENTS

The authors express their gratitude to Universiti Teknologi MARA, Malaysia for facilitating this research process.

## REFERENCES

- Ahmed, N., Umer, A., Ali, M. A., Iqbal, J., Mubashir, M., Grewal, A. G., Butt, B., Rasheed, M. K., Chaudhry, U. K. (2020). Micronutrients status of mango (*Mangifera indica*) orchards in Multan region, Punjab, Pakistan, and relationship with soil properties. *Open Agriculture*, 5(1), 271–279. <https://doi.org/10.1515/opag-2020-0033>
- Afsar, M. M., Bakhshi, A. D., Iqbal, M. S., Hussain, E., Iqbal, J. (2024). High-precision mango orchard mapping using a deep learning pipeline leveraging object detection and segmentation. *Remote Sensing*, 16(17), 3207. <https://doi.org/10.3390/rs16173207>
- Alam, M. Z., Haque, M. M., Islam, M. S., Hossain, E., Hasan, S. B., Hasan, S. B., Hossain, M. S. (2016). Comparative study of integrated pest management and farmers practices on sustainable environment in the rice ecosystem. *International Journal of Zoology*, 7286040. <https://doi.org/10.1155/2016/7286040>
- Asadu, C. O., Ezema, C. A., Ekwueme, B. N., Onu, C. E., Onoh, I. M., Adejoh, T., et al. (2024). Enhanced efficiency fertilizers: Overview of production methods, materials used, nutrients release mechanisms, benefits and considerations. *Environmental Pollution and Management*, 1, 32–48. <https://doi.org/10.1016/j.epm.2024.07.002>
- Baltazari, A., Mtui, H., Chove, L., Msogoya, T., Kudra, A., Tryphone, G., Mwatawala, M. (2020). Evaluation of post-harvest losses and shelf life of fresh mango (*Mangifera indica* L.) in eastern zone of Tanzania. *International Journal of Fruit Science*, 20(4), 855–870. <https://doi.org/10.1080/15538362.2019.1697411>
- Battese, G. E., Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2), 325–332. <https://doi.org/10.1007/BF01205442>
- Beatrice, O. P. A., Rewe, T., Ogalo, L. (2025). Mango (*Mangifera indica*) farming as influenced by agronomic and marketing channels in Siaya County, Kenya. *Asian Journal of Agricultural and Horticultural Research*, 12(3), 54–64. <https://doi.org/10.9734/ajahr/2025/v12i3393>
- Bibi, F., Hameed, A., Muhammad, N., Shahzad, K., Ahmad, I., Shah, T. A., Gaafar, A.-R. Z., Hodhod, M. S., Bourhia, M., Nafidi, H.-A. (2023). Potential of integrated nutrient management to rehabilitate the dieback-affected mango cultivar Sammer Bahisht Chaunsa. *Sustainability*, 15(14), 11118. <https://doi.org/10.3390/su151411118>
- Bura, S., Jasrotia, A., Sharma, S., Sharma, A., Tutlani, A. (2023). Recent advances in breeding of mango (*Mangifera indica*): A review. *International Journal of Environment and Climate Change*, 13(11), 521–538. <https://doi.org/10.9734/ijecc/2023/v13i113196>
- Burton-Freeman, B. M., Sandhu, A. K., Edirisinghe, I. (2025). Health benefits of the mango fruit: Recent review of literature. *Food & Function*, 16(22), 8680–8694. <https://doi.org/10.1039/d5fo00902b>
- Barwal, P., Sharma, S., Bali, D., Laishram, C., Kashyap, P. (2022). Resource use efficiency and constraint analysis of mango cultivation in Kangra District of Himachal Pradesh. *Indian Journal of Ecology*, 49(5), 1736–1742. <https://doi.org/10.55362/IJE/2022/3727>
- Braun, V., Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
- Dodd, J. C., Estrada, A. B., Matcham, J., Jeffries, P., Jeger, M. J. (1991). The effect of climatic factors on *Colletotrichum gloeosporioides*, causal agent of mango anthracnose, in the Philippines. *Plant Pathology*, 40, 568–575. <https://doi.org/10.1111/j.1365-3059.1991.tb02421.x>
- Dominic, K., Okeyo, B., Timamy, M. K. (2024). Socio-economic and physical factors affecting mango performance and productivity in Makueni County, Kenya. *International Journal of Research and Innovation in Social Science*, 8(12), 4456–4468. <https://doi.org/10.47772/IJRISS.2024.8.120374>
- Dutta, P., Das, K., Patel, A. (2016). Influence of organics, inorganic and biofertilizers on growth, fruit quality, and soil characters of Himsagar mango grown in new alluvial zone of West Bengal, India. *Advances in Horticultural Science*, 30(2), 81–85. <https://doi.org/10.13128/ahs-19133>
- Edward, W. A., Ankomah-Appiah, E., Mustapha, A., Jacob, O. S. (2021). Climate change, health and safety of workers in developing economies: A scoping review. *The Journal of Climate Change and Health*, 3, 100034. <https://doi.org/10.1016/j.joclim.2021.100034>
- Elhadi, M., Yahia, J. J. O.-P., Brecht, J. K., Garcia-Solis, P., Maldonado Celis, M. E. (2023). The contribution of mango fruit (*Mangifera indica* L.) to human nutrition and health. *Arabian Journal of Chemistry*, 16, 104860. <https://doi.org/10.1016/j.arabj.2023.104860>
- FAO. (2023). Climate-smart horticulture for tropical fruit production. Food and Agriculture Organization of the United Nations.
- Flemming, K., Noyes, J. (2021). Qualitative evidence synthesis: Where are we at? *International Journal of Qualitative Methods*, 20, 1609406921993276.
- Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General)*, 120, 253–281. <https://doi.org/10.2307/2343100>
- Govindasamy, R., Mohana Priya, K., Kaleeswari, G. (2025). Economic assessment of fertilizer use efficiency in India. *EPRA International Journal of Economic and Business Review*, 13(5).
- Guvvali, T., Bhagwan, A., Kiran Kumar, A., Avil Kumar, K., Vijay, D. (2020). Response of irrigation and mulching on yield, water use efficiency, nutrient use efficiency and economy of mango cv. Banganpalli in semiarid region, Southern Telangana region. *International Research Journal of Pure & Applied Chemistry*, 21(23), 215–224. <https://doi.org/10.9734/IRJPAC/2020/v21i2330320>
- Haryanto, T., Wardana, W. W., Jamil, I. R., Brintanti, A. R. D., Ibrahim, K. H. (2023). Impact of credit access on farm performance: Does source of credit matter? *Heliyon*, 9, e19720. <https://doi.org/10.1016/j.heliyon.2023.e19720>
- Hasan, M. A., Manna, M., Dutta, P., Bhattacharaya, K., Mandal, S., Banerjee, H., Ray, S. K., Jha, S. (2013). Integrated nutrient management in improving fruit quality of mango ‘Himsagar’. *Acta Horticulturae*, 992, 167–172. <https://doi.org/10.17660/ActaHortic.2013.992.20>
- Khan, M., Ahmed, N. (2021). Sustainable management of mango nutrition for better yield and quality. *Cercetări Agronomice în Moldova*, 53(4), 473–501. <https://doi.org/10.46909/cerce-2020-040>
- Keshyagol, K., Vanarotti, M., Madiwal, S., et al. (2026). Sustainable farming systems integrating soil health water use efficiency and crop productivity for climate resilience. *Discover Sustainability*, 7, 481. <https://doi.org/10.1007/s43621-026-02855-0>
- Lei, Y., Zhou, X., Cheng, H. (2025). Assessment of energy, environmental and economic sustainability of the mango orchard production system in Hainan, China. *Sustainability*, 17(15), 7030. <https://doi.org/10.3390/su17157030>
- Lima, M. A. C. de, et al. (2021). Mango physiological responses to drought. *Scientia Horticulturae*, 277, 109815. <https://doi.org/10.1016/j.scienta.2020.109815>
- Lu, D., Zhang, X., Yang, D., Zhang, S. (2025). What affects agricultural green total factor productivity in China? A configurational perspective based on dynamic fuzzy-set qualitative comparative analysis. *Agriculture*, 15(2), 136. <https://doi.org/10.3390/agriculture15020136>
- Mensah, A., Brummer, B. (2016). Drivers of technical efficiency and technology gaps in Ghana's mango production sector: A stochastic metafrontier approach. *African Association of Agricultural Economists (AAAE) Fifth International Conference Proceedings*, 246269. <https://doi.org/10.22004/ag.econ.246269>
- Minh, H. V. T., Nam, N. D. G., Ngan, N. V. C., et al. (2024). Is Vietnam's Mekong Delta facing wet season droughts? *Earth Systems and Environment*, 8, 963–995. <https://doi.org/10.1007/s41748-024-00472-3>
- Mitra, S. K., et al. (2023). Temperature & rainfall influence on mango. *Scientia Horticulturae*, 311, 111763. <https://doi.org/10.1016/j.scienta.2022.111763>
- Momin, M. A., et al. (2021). Profitability of mango farming. *Agricultural Research*, 10(4), 614–623. <https://doi.org/10.1007/s40003-021-00548-2>
- Mukherjee, S. K. (2016). Mango cultivation and agronomic practices. *Scientia Horticulturae*, 207, 154–162. <https://doi.org/10.1016/j.scienta.2016.05.013>
- Mulungu, K., Muriithi, B. W., Kassie, M., Khamis, F. M. (2023). Economic performance of mango integrated pest management practices at different scales of production. *Frontiers in Insect Science*, 3, 1180568. <https://doi.org/10.3389/finsc.2023.1180568>
- Muhammad Naveed Akhtar, Hussain, A., Nawaz, M., Fareed, A., Ullah, S., Ahmad, S. (2022). Effect of mulching and drip irrigation on water use efficiency and vegetative growth of mango under small tree system. *Plant Bulletin*, 1(2), 101–120. <https://doi.org/10.55627/pbulletin.001.02.0250>
- Muriithi, B., Affognon, H., Diro, G., Kingori, S., Tanga, C., Nderitu, P., Mohamed, S., Ekesi, S. (2016). Impact assessment of integrated pest management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya. *Crop Protection*, 81, 20–29. <https://doi.org/10.1016/j.cropro.2015.11.014>

- Nor, K. N. M., Abdul Fatah, F., O'Donnell, C. J. (2024). Determinants of technical efficiency of Harumanis mango production in Perlis, Malaysia. *Research on World Agricultural Economy*, 5(4), 367–386. <https://doi.org/10.36956/rwae.2023043>
- Ofori, I. K., Gbolonyo, E. Y., Ojong, N. (2023). Foreign direct investment and inclusive green growth in Africa: Energy efficiency contingencies and thresholds. *Energy Economics*, 117, 106414.
- Okoli, C. (2015). A guide to conducting a standalone systematic literature review. *Communications of the Association for Information Systems*, 37, Article 43. <https://doi.org/10.17705/1CAIS.03743>
- O'Donnell, C. J. (2018). *Productivity and efficiency analysis*. Springer Singapore.
- Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., McKenzie, J. E. (2021). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *BMJ*, 372, n160. <https://doi.org/10.1136/bmj.n160>
- Raushan, K., Ravindra, K., Supriya, Amresh Chaudhary. (2025). Optimizing fruit yield and quality in mango cv. Langra through integrated nutrient management techniques. *Indian Journal of Horticulture*, 82(1), 55–60. <https://doi.org/10.58993/ijh/2025.82.1.10>
- Rehman, A., Malik, A. U., Ali, H., Alam, M. W., Sarfraz, B. (2015). Preharvest factors influencing the postharvest disease development and mango fruit quality. *Journal of Environmental & Agricultural Sciences*, 3, 42–47.
- Prasad, K., Sharma, R. R., Sethi, S., Srivastav, M. (2019). Influence of harvesting method on postharvest loss, shelf-life and quality of mango (*Mangifera indica*) fruits. *Indian Journal of Agricultural Sciences*, 89(3), 445–449. <https://doi.org/10.56093/ijas.v89i3.87587>
- Ruzhani, F., Mushunje, A. (2025). Technical efficiency in agriculture: A decade-long meta-analysis of global research. *Journal of Agriculture and Food Research*, 19, 101667. <https://doi.org/10.1016/j.jafr.2025.101667>
- Sein, M., Mitsuyasu, Y., Kazuo, O. (2013). Technical efficiency analysis of mango production in central Myanmar. *J. ISSAAS*, 19(1), 49–62. <https://www.cabidigitallibrary.org/doi/pdf/10.5555/20133303444>
- Shaffril, H. A., Ahmad, N., Samsuddin, S. F., Samah, A. A., Hamdan, M. E. (2020). Systematic literature review on adaptation towards climate change impacts among indigenous people in the Asia Pacific regions. *Journal of Cleaner Production*, 258, 120595. <https://doi.org/10.1016/j.jclepro.2020.120595>
- Singh, K. V., Singh, G. P., Priyadarshi, A. (2010). Extent of adoption of improved practices of mango production by mango growers in Muzaffarnagar district of Uttar Pradesh. *Indian Research Journal of Extension Education*, 10, 107–113. <https://api.seea.org.in/uploads/pdf/v10320.pdf>
- Susanto, A., Sudarjat, Yulia, E., Permana, A. D., Gunawan, A., Yulistira, D. H. (2020). Effectiveness of modified traps for protection against fruit flies in mango. *Jurnal Biodjati*, 5(1), 99–106. <https://journal.uinsgd.ac.id/index.php/biodjati/article/view/7926/4105>
- Trinh, T. V. H., Zhou, W. (2025). Investigating the technical efficiency and balanced development of climate-smart agriculture in Northeast China. *Land*, 14(3), 547. <https://doi.org/10.3390/land14030547>
- Xie, C., Gao, Y., Zhong, Y., Zhao, Z. (2024). Impact of digital agro-technology services on technical efficiency and income of small-scale farmers: Empirical study from mango production in China. *Agriculture*, 14(12), 2143. <https://doi.org/10.3390/agriculture14122143>
- Zheng, M., Ma, Y., Zheng, X., Wang, X., Li, L., Xu, F., Zhang, X., Gan, F., Wang, J., Zhu, Z. (2025). Evaluating territorial space use efficiency: A geographic data envelopment model considering geospatial effects. *Land*, 14(3), 635. <https://doi.org/10.3390/land14030635>
- Patel, Z. K., Tank, R. V., Patel, N. B., Tandel, B. M. (2022). Effect of integrated nutrient management on yield, soil nutrient status and economics of mango cv. Kesar. *The Pharma Innovation Journal*, 11(12), 2062–2067. <https://www.thepharmajournal.com/archives/2022/vol11issue12/PartZ/11-12-261-136.pdf>
- Wei, J., Liu, G., Liu, D., Chen, Y. (2017). Influence of irrigation during the growth stage on yield and quality in mango (*Mangifera indica* L.). *PLOS ONE*, 12(4), e0174498. <https://doi.org/10.1371/journal.pone.0174498>
- World Bank. (2023). *Building resilient agricultural value chains*. World Bank Publications.