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From Passion Fruit to Dragon Fruit: An Analysis of Agricultural Commodity Dynamics in Karo Regency Based on an Aggregate Approach

Utari Azrani[1,2)*], Zakki Muhtaram[1,2)], Putra Kurniawan[1)]

[1)]*Agribusiness Study Program, Faculty of Agriculture, Universitas Teuku Umar Alue Peunyareng, Ujong Tanoh Darat, Meureubo District, Aceh Barat Regency, Aceh*
[2)]*Human Development and Entrepreneurship Centre - HDEC UTU Universitas Teuku Umar, Aceh Barat Regency, Aceh*
*Corresponding author email: utariazrani@utu.ac.id

Abstract

This study examines the contrasting production trends of passion fruit and dragon fruit in Karo Regency, identifies plausible explanations, assesses agribusiness implications, and formulates policy directions. Secondary production data from *Karo Regency in Figures 2024* and 2025 and regional planning documents were combined with Manual Thematic Synthesis of purposively selected scholarly literature. Quantitative analysis covered annual commodity production, year-on-year production growth, cumulative production change, the production index, compound annual growth rate, the dragon-fruit-to-passion-fruit production ratio, commodity production shares, and production ranks. The synthesis used an Excel extraction matrix, manual coding, theme development, and comparison with regional statistics. Dragon fruit production increased from 6,012 quintals in 2021 to 93,930.63 quintals in 2024, with a production index of 1,562.39 and compound annual growth of approximately 150 percent. It ranked fourth in recorded perennial fruit and vegetable production in 2024, with a 3.55 percent share. Administrative records indicate declining passion fruit production, although recorded zeros do not establish the disappearance of cultivation. The literature suggests income prospects, production constraints, market access, technology, and social learning as plausible explanations. Agribusiness implications concern passion fruit supply and processing continuity and dragon fruit marketing, postharvest, and investment risks. Policy should combine passion fruit revitalization with market-oriented dragon fruit development. These aggregate and literature-based findings do not establish direct crop substitution or causal household income effects.

Keywords: commodity change, dragon fruit, horticulture, passion fruit, secondary data.

INTRODUCTION

Karo Regency is an important horticultural region in North Sumatra. Its highland agroclimatic conditions, traditions of fruit and vegetable cultivation, and connections to regional markets shape the character of local agribusiness. Passion fruit has long been associated with Karo as one of its distinctive local fruits. In recent years, however, dragon fruit has emerged as an alternative commodity with greater visibility in official production statistics. This study therefore seeks to identify literature-supported explanations for the contrasting trends of these two commodities, assess their implications for the respective agribusinesses, and formulate policy directions for their development in Karo Regency.

Commodity change is both a technical and a socio-economic phenomenon. From an agricultural socio-economic perspective, commodity choices are related to income, production risks, market access, capital requirements, information, and farmers' social networks. Studies of farm enterprise transitions show that farmers tend to adjust land use when a new commodity is perceived as more profitable or better suited to available resources (Zulkarnain et al., 2023; Zulkarnain & Sukmayanto, 2019). The agricultural adoption literature also indicates that these decisions are influenced by behavioral, social, and cognitive factors that shape

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farmers' perceptions of the risks and benefits of innovation (Dessart et al., 2019). These perspectives provide a framework for interpreting the contrasting aggregate trajectories of passion fruit and dragon fruit through economic incentives, production risks, and social learning; they do not establish that individual farmers replaced one crop with the other.

Statistical data provide a strong indication of the growing prominence of dragon fruit in Karo Regency. Dragon fruit production was recorded at 6,012 quintals in 2021, rising to 26,444 quintals in 2022, 86,894 quintals in 2023, and 93,930.63 quintals in 2024 (Badan Pusat Statistik Kabupaten Karo, 2024, 2025). This increase places dragon fruit among the perennial fruit commodities gaining importance in Karo's horticultural production structure. Meanwhile, administrative data from regional planning documents show that passion fruit production declined from 782 tonnes in 2019 to 190 tonnes in 2021 and was recorded as zero in 2022–2023 (Pemerintah Kabupaten Karo, 2024). The use of different data sources raises an important methodological issue because BPS does not consistently report passion fruit as a separate category in recent perennial fruit production tables.

Previous studies on passion fruit show that the sustainability of this commodity is closely linked to farmers' economic rationality. (Azrani et al., 2023) found that income and landholding size were associated with farmers' decisions to continue passion fruit cultivation in Karo Regency. (Budiarta et al., 2021) emphasized the importance of social capital in empowering passion fruit farmers, while (Marpaung et al., 2016) evaluated hybrid passion fruit characteristics and consumer preferences, providing agronomic context for varietal and product-quality development. This literature suggests that sustaining passion fruit requires attention to both economic viability and product quality alongside its local identity.

In contrast, the dragon fruit literature highlights its economic and technological appeal. (Rahmat et al., 2024) reported financial feasibility for farming with supplemental lighting in a case study in Cilangkap Village, Tasikmalaya. (Saediman et al., 2021) described perceived profitability, ease of cultivation, and learning from other farmers as relevant to dragon fruit adoption in South Konawe. These findings provide possible explanations for consideration in Karo, without establishing equivalent returns or adoption conditions. Other studies emphasize institutional arrangements, marketing channels, sustainability, and agribusiness strategies (Asmara et al., 2022; Bachtiar et al., 2020; Hartiana et al., 2021).

Research directly linking the decline of passion fruit with the growth of dragon fruit in Karo Regency remains limited. Some studies examine the two commodities separately, whereas statistical data reveal only regional patterns. Combining statistical trends, regional planning documents, and the literature addresses three objectives: (1) identify plausible economic, production, market, and institutional explanations for the contrasting trends; (2) assess the implications for production, marketing, processing, and risk management in both agribusinesses; and (3) formulate policy directions for their development in Karo Regency. The aggregate approach evaluates potential mechanisms and implications; it does not estimate causal effects or verify individual farmers' crop-switching decisions.

RESEARCH METHODS

This study combined descriptive quantitative analysis of secondary production data with Manual Thematic Synthesis of the relevant literature. The study area was Karo Regency, North Sumatra. Data processing and manuscript

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preparation were undertaken in May 2026. The main quantitative data were obtained from *Karo Regency in Figures 2024* and *Karo Regency in Figures 2025*, particularly the tables reporting perennial fruit and vegetable production by crop type. Dragon fruit production data were available in quintals and converted to tonnes at a ratio of 1 tonne to 10 quintals. Passion fruit data were obtained from the Karo Regency Government Work Plan for 2025 (RKPD), enacted through Karo Regent Regulation No. 14 of 2024. This document includes Table 2.90 on perennial fruit production in Karo Regency during 2019–2023, sourced from the Karo Regency Agriculture Office in 2024. These figures were treated as administrative comparison data, separately from BPS statistics.

The unit of quantitative analysis was the commodity-year within Karo Regency's perennial fruit and vegetable production statistics. Observed variables were annual passion fruit production, annual dragon fruit production, and the production volumes of the other commodities reported in the 2024 BPS table. Derived indicators comprised year-on-year dragon fruit production growth, cumulative production change over 2021–2024, the dragon fruit production index with 2021 = 100, the compound annual growth rate (CAGR) over three annual intervals, the dragon-fruit-to-passion-fruit production ratio, commodity shares of total recorded production in 2024, and production ranks. Both focal commodities were expressed in tonnes for comparisons. Push factors, pull factors, agribusiness risks, and policy implications were examined qualitatively through the literature synthesis. Inference was restricted to regional aggregates and the literature because no farm household survey was conducted.

The qualitative interpretation drew on purposively selected scholarly journal articles and conference proceedings concerning passion fruit, dragon fruit, commodity adoption, farm enterprise transitions, marketing, institutional arrangements, agricultural information, resilience, and agribusiness sustainability. Selection considered relevance to the two commodities or to smallholder commodity change, the availability of reported findings, and the contribution to explaining agribusiness mechanisms. Socio-economic and agribusiness findings formed the main interpretive evidence. Agronomic research directly relevant to varietal quality and processing, such as (Marpaung et al., 2016), provided contextual support and was not treated as evidence of farmer-level economic behavior. News articles, opinion pieces, duplicates, and technical papers without a relevant agribusiness connection were excluded. Methodological references provided procedural guidance separately from substantive evidence. The selection was purposive and was not presented as an exhaustive systematic review.

Manual Thematic Synthesis was used, defined here as a manually coded application of thematic synthesis using a Microsoft Excel extraction matrix. Excel was selected because the units of analysis were articles and secondary documents, and the number of documents remained manageable through manual coding. The analysis followed the coding, descriptive-theme, and analytical-theme stages of Thomas and Harden (2008), with guidance on trustworthiness and literature review design (Nowell et al., 2017; Snyder, 2019). The analytical stages comprised: (1) reading all articles and documents in full; (2) extracting information on authors, year, location, commodity, objectives, methods, variables, key findings, and relevance to commodity change; (3) openly coding meaning units such as income, landholding size, production risks, plant diseases, prices, markets, lighting technology, capital, institutional arrangements, value chains, social diffusion,

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resilience, and sustainability; (4) grouping codes into descriptive themes and developing analytical themes covering push factors associated with passion fruit, pull factors associated with dragon fruit, barriers to or risks of change, and agribusiness policy implications; and (5) comparing the literature-derived themes with production trends and regional planning documents.

Coding consistency was maintained through two rounds of analysis. The first round generated initial codes inductively from each article's findings, while the second reorganized the codes into the push–pull and agribusiness risk framework used in the discussion. The extraction matrix served as an audit trail, allowing the source of each theme to be traced back to the original article. The frequency with which a theme appeared was not treated as a statistical measure but as an indication of recurring issues in the literature. Interpretive trustworthiness was maintained through source triangulation, repeated reading, and the search for negative cases, particularly studies identifying the risks or limitations of dragon fruit as an alternative commodity.

Quantitative analysis used the observed production volumes to calculate growth, cumulative change, indices, CAGR, ratios, shares, and ranks. Equations (1)-(4) define year-on-year growth, the production index, CAGR, and the production share, respectively.

$$\text{Growth (\%)} = \frac{X_t - X_{t-1}}{X_{t-1}} \times 100 \quad (1)$$

$$\text{Index} = \frac{X_t}{X_{2021}} \times 100 \quad (2)$$

$$\text{CAGR (\%)} = \left[\left(\frac{X_t}{X_0}\right)^{\frac{1}{n}} - 1\right] \times 100 \quad (3)$$

$$\text{Contribution (\%)} = \frac{\text{commodity production}}{\text{total perennial fruit and vegetable production}} \times 100 \quad (4)$$

In these equations, X_t denotes production in the current year or at the end of the period, X_{t-1} denotes production in the previous year, X_{2021} denotes production in the 2021 base year, and X_0 denotes production at the beginning of the period. The variable n is the number of yearly intervals between the beginning and end of the period.

The denominator in Equation (4) is 2,645,692.18 quintals, the combined production of the 16 commodities with numerical values in the 2024 column of Table 5.1.14 in *Karo Regency in Figures 2025* (Badan Pusat Statistik Kabupaten Karo, 2025). This coverage follows the source table, including jengkol and petai; it therefore represents neither fruit production alone nor the combined production of the six commodities displayed. The denominator is the sum of the 16 numerical entries in that source column; no unavailable observation was imputed. Table 3 presents the six highest-producing commodities, the aggregate for other commodities, and the denominator total. Percentages are rounded to two decimal places.

Cumulative production change was calculated as the percentage difference between the 2024 and 2021 dragon fruit production values. For the production ratio, dragon fruit production was divided by passion fruit production in the same year using tonnes for both; a ratio was calculated only when both observations were available and passion fruit production was positive. Production ranks were obtained by ordering 2024 commodity volumes from highest to lowest. Reported

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administrative zeros were retained as reported values and were distinguished from unavailable observations.

The quantitative and thematic findings were integrated according to the three research objectives. Production indicators described the contrasting commodity trajectories; Manual Thematic Synthesis identified plausible explanations and potential agribusiness implications; and the combined evidence informed policy directions. Findings from studies outside Karo were treated as contextual support. Prices, planted area, farm costs, household income, and farmer-level crop transitions were not measured in the present analysis, so causal effects and realized welfare impacts could not be estimated.

RESULTS AND DISCUSSION

Data Availability, Statistical Visibility, and Production Changes

An important finding from the use of secondary data is the difference in statistical visibility between dragon fruit and passion fruit. Dragon fruit was explicitly recorded in BPS Karo Regency tables for 2021–2024, whereas passion fruit was not consistently presented as a separate category in recent perennial fruit production tables. Methodologically, the absence of passion fruit from BPS tables is insufficient to conclude that its cultivation has ceased. From a policy perspective, incomplete commodity statistics may hinder the identification of needs for extension, financing, market promotion, and value chain interventions. (Carletto et al., 2015) emphasized that the quality and coverage of agricultural data are directly related to the quality of policy formulation. For passion fruit in Karo, the available evidence therefore concerns declining administratively recorded production and incomplete representation in the selected statistical tables; it does not measure actual changes in institutional support.

The passion fruit data in this article refer to Table 2.90 of the Karo Regency RKPD for 2025 and are therefore used as administrative comparison data. When BPS data show growth in dragon fruit and administrative data indicate a decline in passion fruit, the two sources together suggest a change in the relative positions of the commodities at the aggregate level. Estimating the extent of direct substitution at the plot level requires primary data or plot-level panel data. Differences in statistical coverage should be resolved before comparing the commodities' access to development programs or financing; these outcomes were not measured in this study. Table 1 illustrates this pattern.

Table 1. Trends in Passion Fruit and Dragon Fruit Production in Karo Regency, 2019–2024.

Year	Passion fruit (tonnes)	Dragon fruit (quintals)	Dragon fruit (tonnes)	Dragon fruit growth (%)
2019	782.00	n.a.	n.a.	-
2020	311.00	n.a.	n.a.	-
2021	190.00	6,012.00	601.20	-
2022	0.00	26,444.00	2,644.40	339.85
2023	0.00	86,894.00	8,689.40	228.60
2024	n.a.	93,930.63	9,393.06	8.10

Source: *BPS Kabupaten Karo (2024, 2025) for dragon fruit; Pemerintah Kabupaten Karo (2024, Table 2.90) for passion fruit; processed by the authors. The value 0.00 for passion fruit follows the RKPD administrative records and does not verify that all cultivation ceased. n.a. = data unavailable in the sources used; "-" = growth not calculated.*

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Table 1 shows very rapid growth in recorded dragon fruit production after 2021. Production increased from 6,012 quintals to 93,930.63 quintals in 2024, reaching 15.62 times its 2021 level, equivalent to a cumulative increase of 1,462.39 percent. Growth was highest in 2022 and 2023 and slowed to 8.10 percent in 2024. The lower growth rate indicates slower recorded production expansion, but these data do not distinguish changes in planted area, yield, crop maturity, weather, or reporting. The larger production volume nevertheless makes market capacity, postharvest handling, and coordinated marketing relevant policy considerations.

Conversely, administrative data show a weakening trend for passion fruit. Recorded production declined from 782 tonnes in 2019 to 190 tonnes in 2021 and was recorded as zero for 2022–2023. These administrative entries require caution: (Azrani et al., 2023) surveyed passion fruit farmers in Karo in April–June 2022, so a recorded zero cannot establish that cultivation had ceased. Their finding that income and landholding size were associated with continued cultivation suggests an economic mechanism for investigation, but does not identify the cause of the administrative production trend. Table 2 presents the dragon fruit production index and the production ratio for the year in which a comparison is possible.

Table 2. Dragon Fruit Production Index and Production Ratio to Passion Fruit in Karo Regency.

Year	Dragon fruit (tonnes)	Production index (2021 = 100)	Passion fruit (tonnes)	Dragon fruit/ passion fruit ratio
2019	n.a.	n.a.	782.00	n.a.
2020	n.a.	n.a.	311.00	n.a.
2021	601.20	100.00	190.00	3.16
2022	2,644.40	439.85	0.00	n.a.
2023	8,689.40	1,445.34	0.00	n.a.
2024	9,393.06	1,562.39	n.a.	n.a.

Source: *BPS Kabupaten Karo (2024, 2025) and Pemerintah Kabupaten Karo (2024, Table 2.90); processed by the authors. The ratio is calculated only when data for both commodities are available and passion fruit production is greater than zero. n.a. = data unavailable or the ratio cannot be calculated.*

Table 2 shows that the dragon fruit production index reached 1,562.39 in 2024 relative to 2021 = 100. The CAGR over the three annual intervals was 149.99 percent. This summarizes rapid production expansion and supports considering whether markets and postharvest systems can absorb the additional supply. In 2021, the only overlapping year with a positive recorded passion fruit value, dragon fruit production was 3.16 times administratively recorded passion fruit production after unit conversion. This cross-source ratio describes relative production levels for one year, not a changing ratio over time or the extent of crop substitution.

This interpretation is important because farming systems have the capacity to withstand pressures, adapt, and transform. The farming system resilience framework emphasizes that responses to economic and environmental pressures can take the form of robustness, adaptation, or transformation (Meuwissen et al., 2019). This framework provides a basis for considering managed dragon fruit development and passion fruit revitalization as complementary options for Karo's commodity portfolio; the production series alone does not establish farm-level adaptation or transformation.

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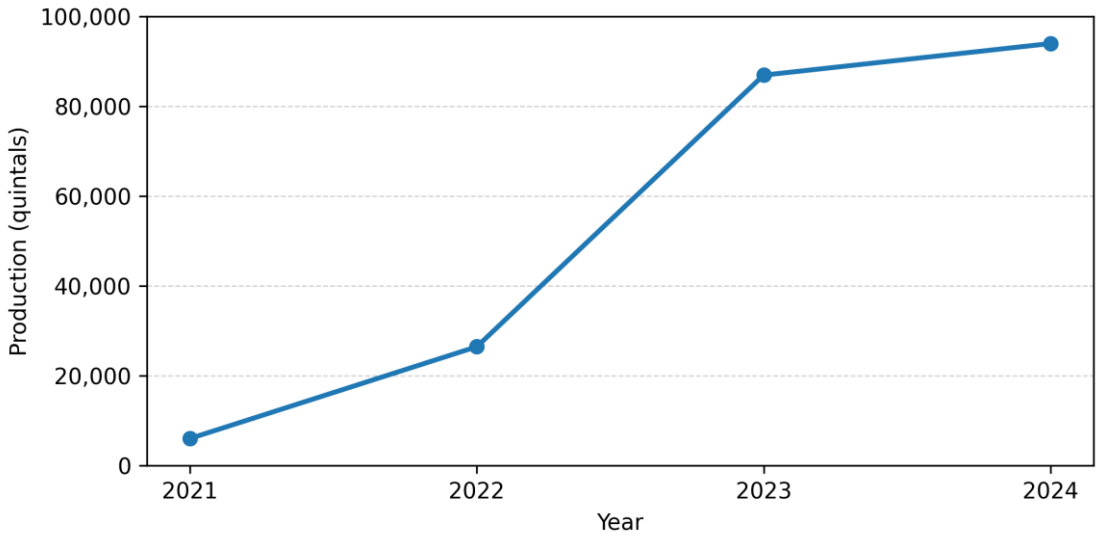


Figure 1. Dragon Fruit Production Trend in Karo Regency, 2021–2024.

The Position of Dragon Fruit in the Horticultural Production Structure

Dragon fruit has not displaced the dominance of Karo's major commodities, such as citrus, snake fruit, and bananas. Nevertheless, the 2024 data show that dragon fruit has attained a notable position in the production statistics. Table 3 ranks dragon fruit fourth among the commodities covered by the BPS table, contributing 3.55 percent of total recorded perennial fruit and vegetable production. This percentage uses a denominator of 2,645,692.18 quintals, not the combined production of the six fruit types displayed.

Table 3. Position of Major Fruit Commodities in Perennial Fruit and Vegetable Production in Karo Regency, 2024.

Rank	Commodity	Production (quintals)	Contribution (%)
1	Siam oranges/tangerines	1,990,963.65	75.25
2	Snake fruit (salak)	247,740.25	9.36
3	Banana	159,968.15	6.05
4	Dragon fruit	93,930.63	3.55
5	Avocado	79,668.00	3.01
6	Mango	27,581.75	1.04
-	Other commodities	45,839.75	1.73
Total: 16 commodities		**2,645,692.18**	**100.00**

Source: *BPS Kabupaten Karo (2025, Table 5.1.14, p. 180), processed by the authors; the source table reports preliminary figures. Other commodities comprise durian, water apple, jengkol, mangosteen, pineapple, papaya, petai, rambutan, sapodilla, and soursop. Contributions use a total of 2,645,692.18 quintals as the denominator. Component percentages may not sum to 100 percent because of rounding.*

The 2024 statistics indicate a substantial recorded dragon fruit production volume of 9,393.06 tonnes. Its contribution remains far below that of citrus, showing that the two focal commodities represent only part of Karo's horticultural production structure. In this study, the phrase "from passion fruit to dragon fruit" refers to their contrasting aggregate production trajectories and statistical visibility. It does not imply that the same farmers or plots moved between the two commodities, or that dragon fruit replaced Karo's wider horticultural system.

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Clearly defining the limits of interpretation is necessary to prevent overgeneralization. Differences in statistical visibility may affect how commodities are represented in planning, but the present study does not measure resulting differences in support or financing. For passion fruit, lower recorded production raises a potential concern about continuity of raw material supply for processors; for dragon fruit, a larger recorded volume increases the relevance of market coordination and postharvest capacity. These are agribusiness implications to investigate rather than measured changes in processing output, prices, or household welfare.

Push Factors Associated with Passion Fruit and Pull Factors Associated with Dragon Fruit

The literature synthesis identifies plausible economic, production, and institutional explanations for the contrasting trajectories. (Azrani et al., 2023) found that income and landholding size were associated with decisions to retain passion fruit in Karo. This supports examining economic incentives, but does not demonstrate that declining income caused the recorded production decline. (Marpaung et al., 2016) provide agronomic evidence on hybrid fruit characteristics and consumer preferences, supporting attention to varietal and processing quality. (Budiarta et al., 2021) emphasize social capital in empowering passion fruit farmers. Together, these findings suggest potential connections among economic viability, product quality, and collective action; they do not establish the relative causal importance of these factors in the regional time series.

The literature identifies income potential, technology, markets, and farmer-to-farmer information as possible attractions of dragon fruit. (Rahmat et al., 2024) reported financial feasibility for supplemental-lighting cultivation in a case study of one farmer in Tasikmalaya, while (Djogolang et al., 2022) reported favorable returns in another regional setting. (Saediman et al., 2021) identified perceived profitability, ease of cultivation, and learning from fellow farmers among growers in South Konawe. Behavioral influences on adoption (Dessart et al., 2019) and the quality and sources of agricultural information (Wale & Mkuna, 2023) provide further interpretive context. These findings identify mechanisms for investigation in Karo; the present data do not measure local lighting adoption, investment returns, or the contribution of each mechanism to production growth.

The appeal of dragon fruit must nevertheless be considered alongside its constraints. In their study in Banuroja Village, Pohuwato Regency,(Hasanah et al., 2021) identified limited capital and threats from pests and diseases, and emphasized training or extension services to address competition. These findings provide a point of comparison for Karo rather than direct evidence of farmers' conditions in the study area.

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Table 4. Literature-Based Framework of Potential Push and Pull Factors in Commodity Change.

Dimension	Passion fruit: push factors	Dragon fruit: pull factors	Implications for Karo
Economic	Income and landholding size are associated with decisions to continue cultivation.	Financial feasibility and new income opportunities.	Cost–benefit analysis for smallholders is needed.
Production	Varietal and fruit-quality findings provide a basis for assessing revitalization options.	Supplemental lighting offers production opportunities in an external case study.	Technical extension and energy efficiency are important.
Market	Distinctive local commodities are vulnerable when value chains are weak.	Market opportunities reported elsewhere; potential market saturation risk.	Price information, cooperatives, and market diversification are needed.
Social	Social capital among passion fruit farmers needs to be mobilized.	Adoption can spread through the example of successful farmers.	Farmer groups should provide a space for shared learning.
Sustainability	Local identity weakens when the commodity is not economically viable.	Rapid expansion may create price risks; lighting costs apply where adopted.	Policy should be based on a commodity portfolio.

Source: *Synthesis of (Abdul-Rahaman & Abdulai, 2018), (Azrani et al., 2023; Birthal & Hazrana, 2019; Budiarta et al., 2021; Dessart et al., 2019; Marpaung et al., 2016; Meuwissen et al., 2019; Rahmat et al., 2024; Saediman et al., 2021; Wale & Mkuna, 2023), and related articles; processed by the authors. Factors represent literature-supported explanations and potential risks, not estimated determinants in Karo.*

Dragon Fruit Expansion and Emerging Agribusiness Risks

Dragon fruit expansion has two sides: opportunities to increase income and exposure to market risks. Rapid production growth can increase farmers' income during the initial phase but may create downward price pressure if markets cannot absorb the supply. Fruit commodities also face challenges related to freshness, sorting, grading, packaging, transportation, and marketing timing. Accordingly, the success of dragon fruit cannot be measured solely by production growth, but also by the agribusiness system's capacity to develop markets, reduce postharvest losses, and maintain farmers' bargaining power.

In a study in Purwoharjo District, Banyuwangi Regency, (Widjayanti, 2023) showed that dragon fruit farming profits differed across marketing channels, while the most efficient channel varied by fruit quality grade. These findings support the importance of organizing marketing channels and managing product quality in dragon fruit development in Karo, without assuming equivalent profit levels across regions. The agricultural commercialization literature indicates that market linkages, contracts, and partnerships can increase smallholder income, although the benefits are not automatically distributed evenly. (Ton et al., 2018) found that contract farming can raise income in various cases, but its effectiveness depends on the service package, farmer organization, and the design of contractual

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relationships. (Meemken & Bellemare, 2020) likewise emphasized that contract farming is a potentially beneficial instrument that can also exclude smallholders when quality, volume, or capital requirements are too demanding. Dragon fruit development in Karo therefore requires market governance that protects smallholders rather than merely expanding production.

Using farm household data from Kenya, (Ogutu et al., 2020) showed that commercialization can improve income, food security, and several indicators of dietary quality through increased food purchases. These findings offer a conceptual comparison for assessing agribusiness benefits beyond production volume; they do not constitute evidence of welfare impacts on dragon fruit farming households in Karo.

Institutionally, farmer groups can serve as an important channel for reducing transaction costs, strengthening access to inputs, improving information quality, and undertaking collective marketing. (Abdul-Rahaman & Abdulai, 2018) showed that participation in farmer groups is associated with higher yields and greater technical efficiency, while (Wale & Mkuna, 2023) emphasized the importance of up-to-date agricultural information tailored to farmers' needs. The lesson for Karo is that dragon fruit expansion should be accompanied by stronger farmer groups, technical extension services, price information, and access to financing so that its benefits are not confined to well-capitalized farmers.

In a study of community-based dragon fruit farming in Cilacap Regency, (Subhan et al., 2020) found that the ecological dimension was classified as highly sustainable, whereas the social and economic dimensions were classified as moderately sustainable. This difference supports a multidimensional assessment of sustainability, indicating that production growth alone is insufficient to assess the success of dragon fruit expansion in Karo.

Diversification, Commodity Identity, and Agribusiness Policy Directions

This article proposes agribusiness diversification as a policy response to contrasting production trends; it does not demonstrate diversification or substitution on individual farms. Diversification can reduce dependence on a single commodity, but its suitability depends on farm resources and market conditions. (Birthal & Hazrana, 2019) link diversification to resilience against climatic shocks, while (Michler & Josephson, 2017) examine its relationship with poverty dynamics. These findings support considering a regional portfolio in which passion fruit is strengthened through product quality, value addition, and local identity, while dragon fruit development is linked to production efficiency and market capacity.

The value of passion fruit extends beyond production volume. This commodity serves as a symbol of Karo's agroecology and economic identity and is linked to local processing industries. Its declining recorded production and incomplete statistical coverage raise concerns about commodity diversity and the continuity of processing inputs, although processing volumes and raw material shortages were not measured here. Passion fruit revitalization should therefore focus on strengthening product differentiation, processing, geographical branding, and value chains based on local identity.

Dragon fruit expansion, meanwhile, requires careful management because food and agribusiness systems are complex. (Conti et al., 2024) emphasized that agri-food system interventions need to account for complexity, trade-offs, and local context. For Karo, the analysis suggests attention to potential price risks and unequal access to capital alongside income opportunities. Where supplemental

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lighting is adopted, its energy costs and investment requirements should also be assessed. Policy therefore needs to move beyond seedling assistance or expansion of planted area to encompass market information, marketing institutions, energy efficiency, inclusive financing, and processed product development.

Table 5 summarizes the agribusiness policy directions that can be derived from the analysis. The matrix emphasizes that the main concerns include increasing production, strengthening institutions, protecting smallholders, and managing market risks during horticultural commodity change.

Table 5. Matrix of Horticultural Agribusiness Policy Implications for Karo Regency.

Key issue	Potential socio-economic risk	Direction of agribusiness intervention
Statistical visibility of passion fruit	Limited commodity visibility in planning and programs	Harmonization of BPS and Agriculture Office data, commodity data collection, and annual production monitoring
Passion fruit revitalization	Loss of commodity identity and raw materials for processing	Varietal improvement, disease control, processing, branding, and market promotion
Dragon fruit expansion	Market saturation and price fluctuations	Price information, market diversification, sorting, grading, postharvest handling, and processing
Lighting technology where adopted	Energy costs and unequal access to capital	Energy efficiency, investment credit, technical training, and cost–benefit analysis
Farmer institutions	Low bargaining power and high transaction costs	Cooperatives/farmer groups, collective marketing, transparent partnerships, and fair contracts
Smallholder inclusion	Risk that expansion benefits favor well-capitalized farmers	Inclusive financing, group-based assistance, and support for farmers with small landholdings

Source: *Literature synthesis and authors' analysis.*

The matrix supports a complementary policy approach for consideration, rather than an empirically tested ranking of policy alternatives. The first track is to revitalize passion fruit as a commodity associated with local identity through improvements in data, plant quality, processing, and branding. The second is to manage dragon fruit expansion so that production growth is accompanied by stronger markets, technological efficiency, and smallholder protection. This approach is consistent with the logic of an agribusiness system that treats production, value addition, market risks, and the distribution of benefits as interconnected elements.

CONCLUSIONS AND RECOMMENDATIONS

At the regional aggregate level, dragon fruit production reached 15.62 times its 2021 level in 2024, while administrative records indicate declining passion fruit production. The literature identifies income prospects, production constraints, market access, technology, and social learning as plausible explanations for these contrasting trajectories; the present data do not establish their causal effects in Karo.

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For passion fruit, the agribusiness implications concern maintaining a viable production and processing base and improving statistical visibility. For dragon fruit, the larger production volume creates marketing and value-addition opportunities but also potential price, postharvest, and investment risks, including energy costs where lighting is adopted. Household income effects and direct crop substitution were not measured.

Policy should combine targeted passion fruit revitalization through better data, suitable varieties, plant health support, processing, and branding with managed dragon fruit development through market diversification, farmer organizations, investment appraisal, energy efficiency, and inclusive finance. Farm- and plot-level research is needed to test the proposed mechanisms and assess realized effects.

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