

From Green Calyces to Market Value: A Qualitative Analysis in Butterfly-Pea Supply Chain among Thai Small and Medium Enterprises

Nuatip Sumkaew¹ Chuenjid Kongkaew^{2*} Keatrawee Maneesawet³

Abstract

This qualitative multi-case study examines how Thai entrepreneurs working with *Clitoria ternatea* (butterfly pea) convert agronomic quality into market value. We utilize value chain to explain raw-material standards (e.g., “green calyces,” fully opened purple petals), processing choices (hot-water extraction versus powdering), and channel strategies (OTOP fairs, social media) across community enterprises and Original Equipment Manufacturers (OEMs). In-depth interviews was conducted with seven focal entrepreneurs spanning upstream growers/collectors, community processors, and OEM extractors. The corpus comprised seven cases, including two legal entities and five community enterprises. Across both groups, acceptable extract quality was consistently defined in terms of safety, absence of mold, and low moisture. Community enterprises were more likely to emphasize low-cost production, whereas legal entities were more strongly associated with quality-sensitive market requirements and growing interest in food, beverages, and dietary-supplement applications. Thematic analysis followed Braun and Clarke’s six-phase protocol. We triangulated codes and mapped a sector-specific value chain. Four cross-cutting themes emerged: (1) specification-driven sourcing (morning harvests, green calyces, moisture control, 10:1 fresh-to-dry ratio) to mitigate color loss; (2) processing know-how and quality-assurance routines emphasizing batch color/odor checks and periodic anthocyanin assays; (3) cost–quality trade-offs between “organic/no preservatives” positioning and shelf-life/phase stability; and (4) hybrid channels in which repeat buyers via fairs and Facebook dominate while paid digital advertising remains limited. A value-chain map and a coding tree visualize mechanisms. The study distills actionable standards (acceptance criteria, storage guidance) and low-cost QA/packaging tactics to reduce rework and claims while protecting the blue hue. Policy implications include targeted digital-selling training for rural SMEs and simple lab partnerships for color standardization. The findings link plant-chemistry insights on polyacylated anthocyanins (ternatins) to micro-level decisions by Thai SMEs, showing how upstream quality and midstream QA shape margins and channel performance.

Keywords: Butterfly pea, Entrepreneur, Value chain, Small and medium enterprises, Thailand

1. Introduction

Clitoria ternatea (butterfly pea) is a culturally embedded Southeast Asian herb whose polyacylated anthocyanins (“ternatins”) yield a vivid blue hue and functional properties valued across food, beverage, and personal-care markets. Contemporary plant-science syntheses show

¹ Lecturer, Faculty of Business, Economics and Communications, Naresuan University, Thailand

² Associate Professor, Faculty of Pharmaceutical Sciences, Naresuan University, Thailand

³ Student, Faculty of Pharmaceutical Sciences, Naresuan University, Thailand

* Corresponding Author e-mail: chuenjidl@nu.ac.th

that hot-water extraction under mildly acidic conditions can recover stable color, whereas photodegradation remains a primary risk; acylation improves thermal and storage stability (Fu et al., 2021; Jeyaraj, Lim, & Choo, 2022; Bani et al., 2024). For Thailand's rural producers and OEM extractors, these molecular properties operate as design constraints which must be translated into operational standards – harvest timing and petal maturity, post-harvest dehydration with moisture/a_w control, and light-safe packaging – to preserve the blue hue and limit downstream failure costs in small-batches (Fu et al., 2021; Vidana Gamage et al., 2021).

From a supply-chain standpoint, agri-ingredient industries are effectively viewed as interdependent upstream, midstream, and downstream segments in which value is captured when technical constraints, governance, and market access are co-managed (Cai & Lo, 2020). In the butterfly-pea context, the upstream segment includes domestic farmer groups/co-ops and regional imports; the midstream comprises community entrepreneurs and OEMs that transform flowers/leaves into extracts or finished goods; and the downstream spans wholesalers, retailers, service outlets, and export channels. For lower-middle-income (LMI) farmers and micro-entrepreneurs, the central challenge is value capture rather than volume, i.e., translating quality into price premia, repeat purchase, and reliable cash flow through upgrading (process, product, functional, and channel) under appropriate governance and partner capability (Galdos-Urbizu et al., 2024; Cai & Lo, 2020). Consequently, the challenge for SME producers is not merely producing butterfly pea, but converting raw-material quality into price premiums, repeat purchase, and more stable cash flow under resource constraints. This issue becomes especially relevant in natural-product chains, where quality claims must be translated into operational standards and credible market signals.

Relevant literature offers useful but still fragmented insights. Studies on butterfly pea have primarily examined extraction methods, color stability, and antioxidant properties, including the effects of pH, temperature, and storage conditions on anthocyanin preservation (Fu et al., 2021; Vidana Gamage et al., 2021; Bani et al., 2024). In parallel, supply chain and SME studies have highlighted the roles of upgrading, contract-based coordination, channel integration, and traceability in improving firm performance and market access (Ton et al., 2017; Cai & Lo, 2020; Ahmed & MacCarthy, 2023). However, these strands of literature are rarely integrated to explain how SMEs translate chemistry-based constraints into sourcing standards, quality assurance routines, cost–quality decisions, and channel strategies in real operating contexts.

This gap is particularly important in the context of Thai SMEs. Existing studies tend to focus either on product chemistry or on generalized supply-chain models, while limited empirical attention has been given to how small and medium enterprises in emerging economies operationalize these issues across different business forms, such as community enterprises and OEM-oriented firms. As a result, there remains an insufficient understanding of how quality is created, maintained, and monetized in small-batch, natural-product supply chains, and how such mechanisms differ across SME types, market positions, and channel configurations.

Against this backdrop, the present study examines how Thai entrepreneurs along the butterfly-pea supply chain convert upstream raw-material quality into downstream market value. Using a qualitative multi-case design, we follow actors ranging from growers who specify green calyces and morning harvests to community processors producing preservative-light products as well as an OEM extractor who powderizes anthocyanin extracts and implements lot-level QA. We contribute: (i) a sector-specific value-chain map for a non-timber herbal product; (ii) an integrated

explanation of cost–quality trade-offs and QA routines relevant to Lower-Middle-Income cash-flow constraints; and (iii) actionable guidance on governance/traceability and capability-appropriate omni-channel strategies for monetizing verifiable quality (Fu et al., 2021; Vidana Gamage et al., 2021; Cai & Lo, 2020; Liu et al., 2021; Ahmed & MacCarthy, 2023).

2. Literature Review

A supply chain is a network of inter-firm relationships that channels products and services from sources to end consumers through structurally distinct yet interdependent upstream, midstream, and downstream segments. This tripartite lens, common in process industries, has proven especially useful in agri-food and natural-ingredient sectors because it links technical constraints, governance arrangements, and market access across the full conversion pathway (Trienekens, 2011). In this study, the upstream spans domestic farmer groups and cooperatives cultivating butterfly pea alongside regional imports (China, India, Laos, Vietnam); the midstream covers community entrepreneurs and OEMs in herbal pharmaceuticals, cosmetics, food and beverage, and dietary supplements that transform flowers/leaves into extracts or finished goods; the downstream comprises wholesalers, retailers, service outlets, and export channels where customer experience and compliance claims are monetized.

For lower-middle-income (LMI) entrepreneurs, income growth hinges on value capture rather than volume alone. Contemporary value chain scholarship in developing-country agriculture emphasizes upgrading—process, product, functional, and channel—as the principal routes to higher margins and resilience, moderated by governance and partner capabilities (Trienekens, 2011). In practice, process/product upgrading reduces waste and raises quality, while functional/channel upgrading moves SMEs toward higher-value B2B niches or closer to end markets. Recent syntheses caution that inclusion without verifiable quality or reliable channels rarely delivers durable income gains, underscoring the need to design quality, inclusion, and scale jointly (Ton et al., 2017).

Translating these ideas to butterfly pea yields four income-linked levers aligned with our themes. First, a chemistry-to-operations discipline is required because butterfly pea’s blue hue arises from polyacylated anthocyanins (ternatins) that are relatively photolabile despite good thermal/storage stability; therefore, harvesting standards (morning; fully opened purple petals), moisture/*aw* control, and light-safe packaging operate as revenue insurance by preventing color loss and downstream claims in small-batches (Vidana Gamage et al., 2021; Fu et al., 2021; Bani et al., 2024). Second, green governance and credible signaling matter: certification schemes (e.g., COSMOS, NATRUE, EU Ecolabel) and definitional standards (ISO 16128, amended 2022) reduce information asymmetry and discipline upstream sourcing, enabling SMEs to justify price premia and access channels where claims must be auditable (Battaglia et al., 2022; ISO, 2022). Third, Cost-of-Quality (CoQ) economics provide the business case for LMI contexts. Meta-evidence from green supply-chain management (GSCM) shows that targeted prevention/appraisal—tight receiving specifications, periodic potency/color checks, and light-protective packaging—reduces internal/external failure costs (rework, returns) and stabilizes gross margin without heavy capital expenditure, a critical condition for cash-constrained SMEs (Hariyani et al., 2024). Fourth, traceability offers a staged digital pathway to credibility: lot coding, ΔE /*aw* logs, and periodic assays can be implemented immediately, while higher-cost IoT sensors or blockchain-enabled ledgers can be phased in as partner capabilities mature, thereby

strengthening provenance and auditability in herbal chains that are otherwise fragmented (Liu et al., 2021; Ahmed & MacCarthy, 2023).

Finally, channel strategy is pivotal for monetization at the base of the market pyramid. Systematic reviews indicate that capability-appropriate omni-channel portfolios—for example, pairing offline fairs/OTOP with social/online presence—extend reach and resilience when firms establish basic digital routines (content cadence, response targets, simple analytics) (Cai & Lo, 2020). In beauty and personal care, evidence from emerging markets shows that eco-credibility and packaging shape attitudes, purchase intentions, and loyalty only when claims are verifiable, reinforcing the earlier point that QA/governance investments must be market-facing to translate into repeat purchase and cash-flow stability for LMI entrepreneurs (Suphasomboon & Vassanadumrongdee, 2022; Del Greco et al., 2024). This implies that QA and governance investments must remain market-facing if they are to translate into repeat purchase and cash-flow stability for LMI entrepreneurs.

The literature suggests that butterfly-pea SME decision-making is shaped by the intersection of three primary theoretical domains: (1) plant chemistry and operational constraints, (2) value-chain governance and cost-of-quality, and (3) traceability, omni channeling, and market access. Chemistry-defined constraints determine what constitutes acceptable raw material and feasible process control; governance and CoQ mechanisms translate these constraints into coordinated quality practices; and traceability together with channel strategy converts credible quality into customer trust, repeat purchases, and sustainable market access. In this sense, SME decision-making occurs under resource and capability constraints and involves continuous trade-offs between affordability, quality consistency, and commercial viability. Figure 1 presents the conceptual framework guiding the study. The framework explains how butterfly-pea SMEs translate chemistry-informed constraints into operational standards, quality-control routines, and market-facing strategies, which in turn shape value capture under resource-constrained conditions.

Domain 1: Plant chemistry and operations constraints Anthocyanin / ternatin stability Photolability and moisture sensitivity Harvesting, drying, and packaging standards	→	SME decision-making under resource and capability constraints Sourcing and acceptance criteria QA and documentation choices	→	Operational and market outcomes Quality consistency Channel credibility Repeat purchase and market access
Domain 2: Value-chain governance and cost-of-quality Governance, documentation, and signaling Prevention–appraisal–failure logic Quality coordination across actors	→	Cost–quality trade-offs Traceability depth and channel strategy	→	Value capture and commercial viability
Domain 3: Traceability, omni-channeling, and market access Lot coding and staged traceability Offline–online channel integration Buyer confidence and market access	→			

Figure 1 Conceptual framework for value creation in butterfly-pea SMEs

Figure 1 integrates three primary theoretical domains relevant to butterfly-pea SME decision-making: plant chemistry and operational constraints, value-chain governance and cost-of-quality (CoQ), and traceability/omnichanneling/market access. These domains intersect within the context of SME decision-making under resource and capability constraints. In this model, chemistry-defined constraints shape sourcing and processing standards; governance and CoQ mechanisms support quality control and coordination; and traceability and channel strategies convert verifiable quality into customer trust, repeat purchases, market access, and value capture.

This integrated framing suggests that chemistry-defined constraints (e.g., photolability and moisture sensitivity) should materialize as receiving specifications, post-harvest protocols, and packaging choices; that green governance and traceability reduce information asymmetry and support premium price realization; that CoQ-oriented QA is economically consequential in small-batch production; and that omni-channel strategies calibrated to capability enable SMEs to convert quality credibility into revenue. This conceptual framing directly motivates the multi-case thematic analysis undertaken in the present study, which examines how Thai entrepreneurs transform upstream raw-material quality into downstream market value through specification-driven sourcing, QA routines, cost–quality trade-offs, hybrid channels, and governance mechanisms.

3. Methodology

3.1 Research design and case selection

We adopted a qualitative multi-case design to explain mechanisms linking raw-material quality, QA routines, and channel outcomes across heterogeneous entrepreneurial contexts. Multi-case designs are well-suited to building context-sensitive explanations in operations and supply-chain research, particularly where governance and capability interact with technical constraints. We used purposive, maximum-variation sampling until saturation explanation to capture upstream growers/collectors, community-scale processors/brands, and OEM extractors, thereby enabling theoretical replication across roles and capabilities. The final corpus comprised seven cases spanning the supply chain (upstream ≈ 1 ; community-scale midstream ≈ 4 ; OEM midstream ≈ 2), anonymized as Cases A–G.

3.2 Data collection

Population and sample

The target population comprised entrepreneurs in Thailand who use butterfly pea (*Clitoria ternatea*) extract and/or flowers as inputs for pharmaceutical, dietary-supplement, food/beverage, or cosmetic products. The study sample consisted of establishment representatives with decision-making authority (e.g., owners, senior managers, heads of procurement).

Inclusion criteria

Participants were eligible if they: (1) were a senior executive or head of procurement at the establishment; (2) operated in Thailand and used *C. ternatea* extract and/or flowers as raw materials; (3) were aged ≥ 20 years; and (4) provided voluntary, written informed consent.

Sampling approach

We employed non-probability sampling, combining purposive selection—to ensure coverage across roles and supply-chain positions—with snowball sampling to identify additional eligible establishments. The final sample size was guided by thematic saturation; interviewing

continued until no substantively new codes or themes emerged, ensuring adequate coverage of sourcing criteria, QA routines, and channel practices.

Procedures

Data were collected in Thai through in-person or online semi-structured interviews, depending on participant availability. Each interview lasted 20–60 minutes and was supported by field notes and, where available, artifact/photo elicitation. The interview guide covered: sourcing standards (e.g., harvest timing, “green calyx,” moisture/a_w), processing choices (extraction, drying, powdering), QA routines (batch color/odor checks, ΔE logging, potency assays, certificates of analysis [COAs], retention samples), channel strategy (OTOP fairs, social media), and governance/documentation (MOUs, lot cards). Semi-structured protocols provided depth while preserving comparability across cases (Kallio et al., 2016). All interviews were audio-recorded, transcribed verbatim, and anonymized; role descriptors were retained (e.g., grower–collector, community shampoo maker, OEM extractor). To enhance credibility, we triangulated interview data with supporting documents (specification sheets, COAs, lot records) and photographs when provided (Nowell et al., 2017).

3.3 Data analysis

We followed reflexive thematic analysis in line with Braun and Clarke’s six-phase protocol (familiarization; coding; theme generation; review; definition/naming; reporting) (Braun & Clarke, 2006). ATLAS.ti free trial software was employed. Two researchers independently coded the full corpus and then reconciled discrepancies through structured discussion, iteratively refining a codebook and maintaining an audit trail of decisions (Braun & Clarke, 2019, 2021; Nowell et al., 2017). Coding captured first-order indicators (e.g., “morning harvest,” “green calyx,” “ ΔE log,” “COA/retention,” “opaque/UV packaging,” “OTOP + Facebook,” “MOU/spec sheet”) which were then aggregated into cross-case themes consistent with the literature-specification-driven sourcing, processing know-how and QA routines, cost–quality trade-offs, hybrid channels and capability building, and governance and relational routines. To visualize mechanisms, we developed (i) a value-chain map for the sector and (ii) a coding tree linking molecular constraints (photolability, moisture) to operational standards and channel choices; we also prepared a cross-case indicator matrix (e.g., Morning harvest = Yes/No; ΔE logging = Yes/No; COA present = Yes/No) to support pattern matching across cases.

To strengthen trustworthiness, we used well-accepted criteria for credibility, dependability, confirmability, and transferability: independent coding and reconciliation; a maintained audit trail; verbatim quotations with case labels; and triangulation across roles and artifacts (Nowell et al., 2017; Guest et al., 2020). We treated saturation pragmatically as theme stability, which was observed around cases 6–7 for acceptance criteria and QA routines (Guest et al., 2020).

3.4 Ethics

The study received approval from the institutional ethics committee (Approval No. P1-0074/2566). All participants provided informed consent, were informed of their right to withdraw, and were assured of confidentiality via anonymized case labels (A–G).

4. Results

We analyzed seven cases across the butterfly-pea supply chain-upstream growers/collectors ($n \approx 1$), community-scale processors/brands ($n \approx 4$), and one OEM extractor ($n \approx 2$)-using Braun and Clarke's six-phase protocol. Groups converged on the same minimum quality requirement-safe, mold-free, and low-moisture extract-whereas community enterprises more explicitly emphasized low-cost production and domestic marketing support, and legal entities were more closely associated with foreign-market and quality-sensitive demand.

Five themes structure the findings: (1) specification-driven sourcing; (2) processing know-how and QA routines; (3) cost-quality trade-offs; (4) hybrid channels and capability building; and (5) governance and relational routines. We interpret patterns in light of plant-chemistry evidence on tannin stability/photolability, green supply-chain governance (including ISO 16128), Cost-of-Quality (CoQ) for small-batch herbal products, digital traceability, and capability-appropriate omni-channeling.

4.1 Specification-driven sourcing: chemistry-informed acceptance criteria

Across cases, entrepreneurs reported a convergent, practice-ready set of receiving standards that translate chemical principles into farm-gate operations. Core elements included: (i) morning harvests of fully opened purple petals; (ii) use of a green calyx as a field proxy for freshness; (iii) rapid post-harvest dehydration to a crisp state followed by active control of moisture and water activity (a_w) during storage; and (iv) an operational fresh-to-dry conversion factor of approximately 10:1 for procurement and volume planning. Batches exhibiting excess moisture, bleaching, off-odors, or mold were reworked or rejected. In several buyer-supplier dyads, memoranda of understanding (MOUs) formalized acceptance criteria and documentation (e.g., lot cards, intake logs). To mitigate pesticide risk and secure continuity of supply, several respondents preferred self-cultivation.

"We harvest in the morning and select fully opened flowers; the color must be vivid purple with a green calyx. If petals are moist or pale, they are culled and dried to a crisp before shipment." (Case C)

"Any lot with an abnormal odor or mold is returned immediately; a lot card accompanies every delivery." (Case E)

4.2 Processing know-how and QA routines: low-cost appraisal, industrial consistency

Community processors predominantly employed hot-water infusion (6/7 cases), while formal COA documentation was observed in only 2/7 cases. Several used pressure pots to maintain stable temperatures and occasionally collected hydrolates as by-products. The OEM partner converted liquid extracts into spray- or freeze-dried powders, implemented lot-level color and odor checkpoints, conducted periodic anthocyanin assays, and issued Certificates of Analysis (COAs). Retention samples, basic CIELAB (ΔE) color logs, and moisture/ a_w checks were observed across seven cases, albeit with varying rigor.

"We boil and filter in small-batches, record color and odor every time, and keep retention samples." (Case B)

"Our OEM supplies a powder; every lot undergoes QC with a COA, and anthocyanins are assayed on a routine schedule." (Case A)

A clear distinction emerged between community enterprises and OEM actors. Community cases relied on low-cost, manual QA routines (e.g., batch-level color and odor checks), whereas OEM actors implemented formalized systems, including COAs and periodic anthocyanin assays, reflecting differences in scale, compliance requirements, and target markets.

However, several operational challenges were observed. Variability in drying conditions and manual processing led to inconsistencies in color intensity and moisture levels across batches, increasing the risk of quality variation and product rejection. In addition, limited documentation in most community cases constrained traceability and reduced the credibility of quality claims. These findings highlight a cost–quality trade-off, whereby low-cost QA practices support affordability but may not ensure consistent quality or verifiability at commercial scale.

4.3 Cost–quality trade-offs: natural positioning versus shelf-life and phase stability

A persistent managerial tension involved “organic/no-preservative” positioning versus shelf-life and phase stability. Approximately 80% (4/5) community enterprises reported shorter shelf-life (~3 months) when avoiding synthetic preservatives and occasional phase separation, which prompted smaller batch sizes, opaque/UV-blocking containers, tight headspace management, and on-label guidance (e.g., “shake before use”). By contrast, the OEM’s powdering and controlled storage extended stability windows but required capital investment, process know-how, and formal QA documentation.

“We use no preservatives; customers prefer it, but the shelf-life is short. With opaque packaging and careful storage, the color lasts longer.” (Case D)

“Once we moved to powder, quality control became easier, but we had to invest in equipment and complete the QC paperwork.” (Case A)

These trade-offs were more pronounced among community enterprises, which prioritized “natural/no preservative” positioning, whereas OEM actors were better able to balance stability and quality through capital-intensive processing technologies. While the avoidance of synthetic preservatives supported a “natural” product image, it also resulted in shorter shelf-life and a higher risk of spoilage, thereby creating tension between perceived quality and economic viability. This suggests that cost–quality trade-offs are not uniform across SME types but are shaped by differences in scale, technological capability, and market orientation.

4.4 Hybrid channels and capability building: transitional equilibria

All community cases (5/5) blended offline fairs with Facebook-based direct sales, while none reported sustained use of paid digital advertising. Repeat purchasers dominated volumes; paid digital advertising/marketplaces remained nascent owing to capability and budget constraints. Where teams instituted a basic content cadence, response-time norms, and simple analytics, monthly sales stabilized and cash-flow predictability improved.

“We mainly sell at OTOP fairs; most volume comes from repeat customers. We take direct orders via Facebook but have not run paid ads.” (Case F)

“Once we posted regularly and replied promptly, sales stabilized.” (Case E)

Differences were also observed across channel strategies. Community enterprises relied primarily on hybrid offline–social channels, while OEM actors operated predominantly in B2B markets with limited direct consumer engagement. Some community enterprises reported limited

effectiveness of online channels due to low engagement, lack of content consistency, and difficulty in reaching new customers without paid promotion.

4.5 Governance and relational routines: MOUs, shared QC vocabularies, and reduced uncertainty

Beyond day-to-day operations, governance mechanisms lowered uncertainty and reduced intake disputes: MOU-style contracts between growers and downstream buyers; shared QC vocabularies (ΔE tolerances, moisture/a_w thresholds); and documentation routines (batch logs, COAs, retention samples). Formal MOUs were observed in 3/7 cases, primarily among upstream–midstream relationships.

“We have agreed specifications for raw materials with our suppliers; if a lot fails the criteria, it is returned as agreed.” (Case G)

“We use the same terminology for ΔE and moisture, and a COA accompanies every lot.” (Case A)

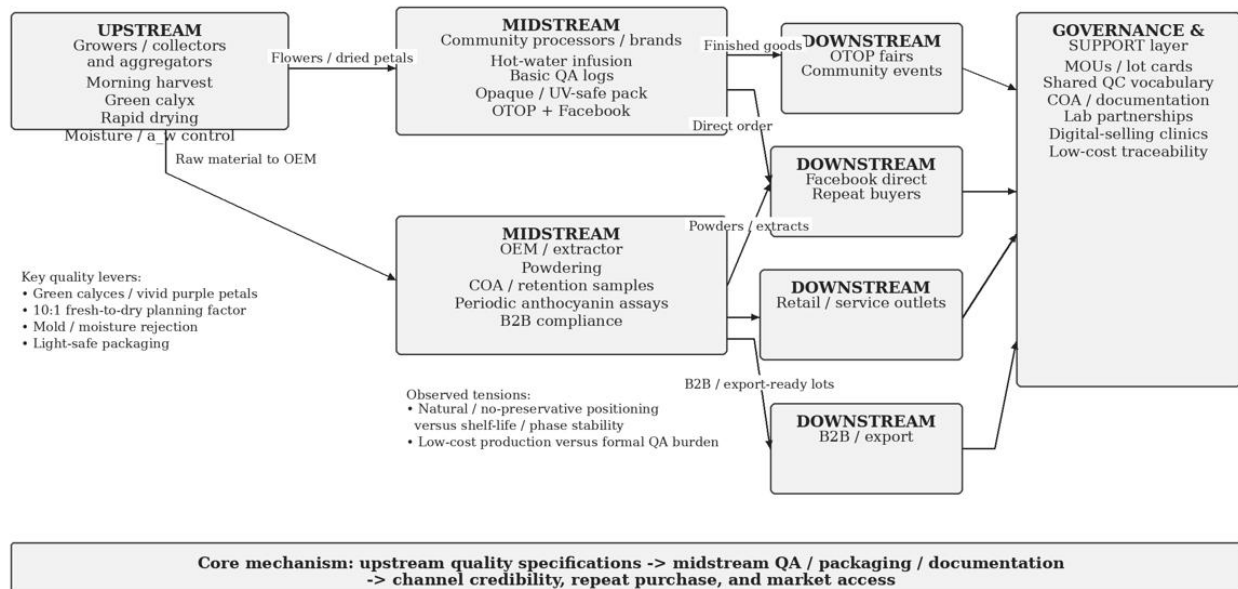


Figure 2 Sector-specific value chain for butterfly-pea SMEs in Thailand

Figure 2 presents the sector-specific butterfly-pea value chain in Thailand and illustrates how value is created and protected across upstream, midstream, and downstream activities. At the upstream stage, growers, collectors, and aggregators supply flowers and dried petals under chemistry-informed specifications such as morning harvests, green calyces, rapid drying, and moisture/a_w control, which function as the first line of quality assurance. The midstream stage is divided between community processors/brands and OEM or extractor firms: community actors rely on hot-water infusion, basic QA logs, opaque or UV-safe packaging, and hybrid channels such as OTOP fairs and Facebook, whereas OEM actors add powdering, Certificates of Analysis (COAs), retention samples, and periodic anthocyanin assays to support more formal B2B compliance. At the downstream stage, value is realized through OTOP/community events, direct social-media orders, retail and service outlets, and B2B/export channels. The figure also highlights a cross-cutting governance and support layer-including MOUs, lot cards, shared QC terminology, documentation, lab partnerships, and digital-selling support-which reduces transaction uncertainty

and helps entrepreneurs convert upstream quality into downstream channel credibility, repeat purchases, and market access.

Overall, the cross-case evidence indicates that chemistry-informed acceptance specifications, low-cost appraisal and documentation, and capability-appropriate hybrid channels jointly underpin quality consistency and commercial viability in small-batch, “natural” butterfly-pea lines. Formal governance routines (e.g., MOUs and shared QC language) further stabilize supply quality and reduce transaction frictions, supporting more reliable market release. However, this study is based on a context-specific set of cases and does not incorporate failure or negative-case evidence. As such, the findings should be interpreted with caution, particularly in SME contexts where resource constraints and market variability may lead to heterogeneous outcomes. Future research should incorporate unsuccessful or contrasting cases to provide a more comprehensive understanding of the conditions under which these practices may not yield expected outcomes, thereby strengthening the robustness and generalizability of the insights.

5. Discussion

This study shows how Thai entrepreneurs convert the chemistry of *butterfly pea* into market value through specification-driven sourcing, low-cost appraisal and QA routines, cost–quality trade-offs, capability-fit channel strategies, and relational governance. Read against recent literature in plant chemistry, green supply-chain management (GSCM), traceability, digital adoption, and omni-channel retailing (2015–2030), the findings illuminate where and how value is captured in small-batch, “natural” lines serving lower-middle-income (LMI) producers: quality is produced upstream by enforcing photolability-aware standards, safeguarded midstream by prevention/appraisal routines, and monetized downstream when verifiable “green” claims meet capability-appropriate omni-channeling. However, practices such as hot-water extraction (6/7 cases) and opaque packaging (5/7 cases) were consistently observed, indicating convergent operational responses to photolability constraints. These numerical descriptors do not support statistical generalization, but they provide a clearer comparative structure for understanding how entrepreneurs balance affordability, safety, and marketability across organizational forms. The findings should be interpreted within the boundary conditions of the study. The sample is limited to seven butterfly-pea SMEs in Thailand and therefore reflects a context-specific configuration of capabilities, market conditions, and institutional support. As such, the transferability of these findings to other crops, industries, or geographical settings may be constrained.

5.1 Chemistry-to-operations: preventing color loss as revenue insurance

Across cases, acceptance specifications—morning harvests of fully opened purple petals, a “green calyx” freshness proxy, rapid drying to a crisp state, and moisture/aw control—directly operationalize properties of *clitoris ternatea* polyacylated anthocyanins (ternatins): robust thermal/storage stability but comparatively weak photostability. Adopting light-safe packaging and minimizing light exposure therefore function as revenue insurance for small-batches by reducing color drift and mold risk. These routines are consistent with plant-science syntheses that confirm hot-water extraction windows (acidic range), relative photolability of ternatins, and process refinements (e.g., mild acidification or ultrasound) that improve yields without compromising stability (Vidana Gamage et al., 2021; Jeyaraj, Lim, & Choo, 2022; Bani et al., 2024). Our cases show entrepreneurs “translating” these molecular constraints into farm-gate and

storage standards that lower rework and claims—evidence of a practical chemistry-to-operations bridge. (Vidana Gamage et al., 2021; Fu et al., 2021).

5.2 The economics of quality for small-batches (CoQ)

Entrepreneurs who combined tight receiving specifications with low-cost appraisal (batch color and odor logs, periodic anthocyanin assays, retention samples) reported higher first-pass QC and fewer complaints or returns. This pattern is consistent with the CoQ literature, which argues that prevention and appraisal activities reduce internal and external failure costs by addressing defects before they reach the market (Schiffauerova & Thomson, 2006). In LMI contexts, these routines appear particularly important because they help stabilize gross margins without requiring major capital expenditure. At the same study of Hariyani et al., (2024), the findings also suggest that the effectiveness of such routines depends on disciplined execution. In this respect, the study contributes to CoQ discussions by illustrating how simplified QA routines can operate as economically meaningful control devices in small-batch, natural product systems, even when formal QA infrastructure remains limited.

5.3 Governance and relational routines as variance-reduction mechanisms

This study observed MOU-style agreements, shared QC vocabularies (ΔE tolerances; moisture/aw thresholds), and documentation (lot cards, COAs, retention samples) that reduced intake disputes and shortened order-to-release cycles.

In transaction-cost terms, picker training for “green-calyx” sorting and dedicated drying create asset specificity, making relational safeguards attractive; in the Relational View, common QC language and documentable processes enable knowledge-sharing rents and reduce coordination failures. These findings are consistent with the broader GSCM and value-chain literature, which emphasizes that governance routines and standards can function as mechanisms for reducing variance and improving coordination in fragmented supply systems (Trienekens, 2011; Hariyani et al., 2024). The study also extends this perspective by showing that even simple governance devices—such as lot cards, common moisture terminology, and agreed acceptance rules—can function as effective variance-reduction mechanisms in SME networks. Rather than relying only on formal certification or contract-heavy arrangements, the cases illustrate hybrid governance forms that combine relational trust with selective formalization.

5.4 Traceability as a staged digital pathway

Given capability constraints, most community cases implemented lot coding, ΔE /aw logs, and retention samples rather than sensor-dense or ledger-intensive systems. This “minimum viable traceability” already produced audit trails sufficient for B2B confidence. OEM actors are structurally positioned to layer IoT sensing or blockchain exports where buyers require deeper provenance. The staged trajectory observed here is consistent with traceability research emphasizing that the value of digital traceability depends on both the breadth and depth of implementation across the supply chain (Liu et al., 2021; Ahmed & MacCarthy, 2023). It is also consistent with recent work on Southeast Asian agriculture, which suggests that digital tools are more likely to diffuse when they are practical, function-specific, and compatible with the realities of smallholder-linked systems (Montesclaros & Teng, 2023). Evidence across emerging-economy reveals that digital adoption and targeted online engagement raise SME performance, albeit with

capability gaps and uneven benefits. In contrast, the findings suggest that highly sophisticated systems are not necessarily appropriate for all SME contexts. Rather, in resource-constrained environments, practical and incremental traceability appears more feasible than comprehensive digital transformation. For rural Thai SMEs, hybrid channel portfolios—face-to-face fairs plus light-weight social media—are pragmatic transitional equilibria (OECD, 2021; Apedo-Deku, Wang, & Preko, 2024).

5.5 Barriers to Digital Technology Adoption and Capability Constraints

While the staged traceability pathway suggests a feasible route for digital upgrading, the findings also reveal persistent barriers that limit broader technology adoption among butterfly-pea SMEs. These barriers extend beyond the availability of technology and reflect financial, capability, and structural constraints commonly observed in SMEs in developing economies. Cost constraints remain central, as the investment and operational burden of digital systems may exceed short-term returns, thereby weakening incentives for adoption (Jongwanich & Kohpaiboon, 2025). Capability gaps further constrain effective use: limited digital literacy, weak data-management practices, and restricted access to ICT-skilled personnel keep many SMEs at the level of low-intensity applications. This pattern is consistent with broader SME evidence showing that adoption costs, human resources, digital culture, and trading partner pressure jointly shape digital technology adoption (Faiz et al., 2024), and with evidence from Southeast Asian agriculture suggesting that smallholder-linked systems require capability development before digital access can translate into productivity gains (Montesclaros & Teng, 2023). In addition, uncertain returns weaken adoption incentives, especially in niche markets characterized by localized and repeat-based demand. Digital tools do not uniformly improve performance unless they are aligned with specific functions such as e-commerce or digital payments (Jongwanich & Kohpaiboon, 2025). Compared with these broader SME studies, the present findings suggest that in small-batch natural product settings, digital tools are most effective when they are low-cost, incremental, and directly linked to specific functions such as traceability, communication, or order management. Value chain fragmentation further limits coordinated upgrading, as traceability and data integration depend on cross-actor alignment that is often absent in smallholder-dominated systems (Montesclaros & Teng, 2023). Finally, a technology–context misalignment is evident, with advanced solutions often exceeding the operational needs and capacities of small-batch SMEs. Taken together, these findings suggest that digital adoption should be understood as a capability-aligned, incremental process rather than a discrete technological shift. In practice, effective upgrading is more likely to emerge from low-cost, function-specific tools supported by shared infrastructure and targeted capability development, enabling SMEs to strengthen traceability, market access, and value capture while remaining consistent with resource constraints.

5.6 Channel strategy: capability-appropriate omni-channeling

All community cases used hybrid portfolios that combined OTOP fairs with Facebook-based selling, while paid digital advertising remained limited. Where content cadence and response-time norms were instituted, sales volatility fell and repeat purchase stabilized—consistent with systematic reviews showing that integrating offline touchpoints with basic digital routines enhances reach and resilience (Cai & Lo, 2020). In beauty and personal care, verifiable eco-claims and packaging quality shape intentions and loyalty, strengthening online conversion

when claims are auditable (Suphasomboon & Vassanadumrongdee, 2022; Del Greco et al., 2024). The present findings extend this literature by suggesting that documentation-backed “green” signals (e.g., COAs plus opaque/UV-safe containers) can anchor capability-fit omni-channel strategies for even when firms lack the resources for more sophisticated digital expansion in SME settings (Cai & Lo, 2020; Suphasomboon & Vassanadumrongdee, 2022; Del Greco et al., 2024).

The findings also indicate important differences across SME types and channel strategies. Community enterprises, typically operating at smaller scales, relied on low-cost production, informal QA routines, and hybrid offline–social channels, reflecting resource constraints and local market orientation. In contrast, OEM actors demonstrated higher levels of formalization, including standardized QA systems, documentation (e.g., COAs), and compliance with B2B requirements. These differences suggest that the effectiveness of quality management and channel strategies is contingent on firm scale, capability, and market positioning. Similarly, firms adopting structured digital routines (e.g., consistent posting, response-time norms) experienced more stable sales outcomes than those relying solely on traditional channels, indicating that channel capability plays a critical role in value capture.

5.7 Implications for LMI entrepreneurs and policy

For LMI entrepreneurs, income growth depends on value capture via (i) enforcement of photolability-aware acceptance specifications, (ii) prevention/appraisal bundles that are light-touch but targeted, (iii) relational contracting with shared QC language, (iv) staged traceability aligned to capabilities, and (v) omni-channel routines that are simple yet disciplined. These implications are consistent with prior research showing that channel integration can enhance reach and resilience when firms adopt routines that fit their operational capacity, rather than pursuing digital expansion for its own sake (Cai & Lo, 2020). Similarly, the present findings support the view that upgrading in agricultural value chains is strengthened when coordination and learning occur through collaboration among multiple actors rather than through isolated firm-level efforts alone (Mishra et al., 2025).

Policymakers and ecosystem actors (local laboratories, universities and OTOP facilitators) these findings suggest the importance of practical, capability-sensitive support mechanisms. Such support may include subsidized micro-assays for anthocyanin and color testing, the dissemination of specification templates and ΔE charts, and digital-selling clinics that institutionalize content cadence and response-time norms. Such interventions are consistent with GSCM and omni-channel literatures on performance uplifts from quality/green routines and channel integration, while respecting the budget and skill constraints of rural SMEs (Cai & Lo, 2020). Moreover in Southeast Asian agricultural contexts, where digital adoption remains uneven and often depends on institutional support and implementation feasibility rather than on technology access alone (Montesclaros & Teng, 2023). In this respect, quality upgrading and digital adoption should be approached as progressive, context-sensitive processes rather than as immediate transitions to highly formalized systems.

To strengthen practical relevance, a pilot implementation scenario can also be proposed. For example, a local university or provincial agency could partner with a cluster of community enterprises (e.g., 3–5 SMEs) to implement a “minimum viable QA and digital upgrade program.” This pilot could include (i) standardized intake specifications and lot-card templates, (ii) periodic low-cost anthocyanin and color testing through local laboratories, and (iii) basic digital-selling

training focused on content scheduling and response-time targets. Preliminary assessment may track indicators such as rejection rates, product returns, and monthly sales stability before and after implementation. This would provide context-specific evidence on feasibility, cost-effectiveness, and scalability. The rationale is consistent with Thai evidence that the benefits of digital adoption vary according to the specific business function involved and may improve income more clearly than profit when implementation costs are high (Jongwanich & Kohpaiboon, 2025).

The findings also suggest several practical lessons from implementation. First, quality upgrading is most effective when aligned with market positioning; attempts to improve quality without clear differentiation may increase costs without generating equivalent returns. Second, low-cost QA systems can improve consistency, but only when they are supported by disciplined execution and documentation. Third, digital channel adoption requires capability development—simply establishing an online presence does not necessarily translate into stronger sales without sustained engagement and content management. In addition, knowledge-sharing mechanisms should be strengthened through collaboration among entrepreneur networks, farmer groups, and local associations. Such platforms can facilitate the diffusion of quality standards, processing techniques, and market practices, thereby supporting collective learning and continuous improvement across SMEs.

Finally, the findings indicate that demand-side insights should be incorporated more directly into quality and market strategies. Direct consumer engagement may therefore be promoted as part of both quality evaluation and product development. SMEs can gather feedback on key product attributes—such as color, packaging, and perceived naturalness—through social media interactions, product testing, and local market activities. This is consistent with prior studies showing that consumer responses to green cosmetics and personal care products are shaped by perceived value, ethical concern, and the credibility of product claims, while packaging also functions as a salient cue in shaping attitudes toward eco-friendly beauty products (Suphasomboon & Vassanadumrongdee, 2022; Del Greco et al., 2024). In this sense, consumer feedback mechanisms can help SMEs align quality standards more closely with market expectations, improve product–market fit, and support more adaptive value creation in resource-constrained contexts.

6. Conclusion and future research

This study demonstrates how Thai SMEs convert the chemistry of butterfly pea into market value through chemistry-informed acceptance specifications, low-cost appraisal and documentation, and capability-appropriate hybrid channel strategies. These practices jointly underpin quality consistency and commercial viability in small-batch, “natural” product lines. In addition, formal governance routines (e.g., MOUs and shared QC language) contribute to stabilizing supply quality and reducing transaction frictions, thereby supporting more reliable market release. Interview evidence further indicates emerging consumer and market tendencies. Customers show a preference for “natural/no-preservative” products, are sensitive to visual quality (particularly color intensity), and rely on trust and repeat purchasing rather than formal certification. As a result, market demand remains largely localized and relationship-driven, with limited expansion through paid digital channels.

However, the findings should be interpreted within the boundary conditions of the study. The evidence derives from seven Thai cases focusing on anthocyanin-rich products and does not

incorporate negative-case evidence. As such, generalization to other botanicals, industries, or larger-scale operations should be approached with caution, particularly in SME contexts where resource constraints and market variability may lead to heterogeneous outcomes.

Future research should extend this work by examining similar value-creation mechanisms across different agricultural products, industry segments, and country contexts. In particular, further studies could (i) experimentally test ΔE thresholds and consumer acceptance under different packaging and lighting conditions, (ii) estimate cost-of-quality (CoQ) components before and after process improvements, (iii) evaluate traceability depth (e.g., IoT or blockchain) in relation to willingness-to-pay in B2B and retail markets, and (iv) investigate how evolving consumer behaviour, digital engagement patterns, market dynamics influence value capture over time and (v) explore other industries or crops. It would be beneficial to include more comparative data, real-world outcomes, or lessons learned from actual implementation, to enhance the realism and credibility of widespread application. Given ongoing innovations in extraction and stabilization methods (e.g., ultrasound and green solvents), future research may also explore whether process intensification complements or substitutes current light-minimization strategies (Bani et al., 2024; Fu et al., 2021). Longitudinal and mixed-method designs would be particularly useful for tracking changes in SME performance, cost structures, and consumer behaviour over time following the adoption of new standards and channel strategies. In addition, pilot implementations could provide stronger evidence on the practical benefits and limitations of digital upgrading in SME contexts.

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Appendix

Appendix A: Cross-case descriptive summary

Practice	Cases (x/7)
Morning harvest	6/7
Green calyx sorting	5/7
Opaque packaging	5/7
ΔE logging	3/7
COA	2/7
Facebook selling	5/5 (community)

Appendix B: Case Profiles and Integrated Analysis

Case A — OEM/ODM Cosmetics & Extractor (Midstream)

Business type/role. Contract manufacturer and formulator operating at the midstream, converting *butterfly pea* into powders (spray/freeze-dried) and finished goods for client brands.

Sourcing. Procures raw material against explicit intake specifications (color, moisture/aw, absence of mold), frequently formalized via MOUs with suppliers.

Processing & QA. Systematic lot-level QC (color/odor), periodic anthocyanin assays, retention samples, and full COA documentation; packaging guidance for clients.

Channels. Predominantly B2B OEM/ODM.

Constraints. Capital-intensive equipment and documentation burden; the need to harmonize heterogeneous client specifications.

Opportunities (theory-consistent). Position “**Powder + COA + Packaging Guide**” as a service bundle (CoQ logic), stabilize supplier variance via shared QC vocabulary (ΔE , aw) under TCE/Relational governance, and stage lightweight digital traceability (lot coding, color/aw logs) with optional IoT expansion.

Case B — Community Brand: Herbal Shampoo (Midstream)

Business type/role. Small-batch personal-care producer emphasizing “natural/no preservatives.”

Sourcing. Morning harvest of fully opened purple petals; drying to a crisp state; occasional purchase from local networks.

Processing & QA. Hot-water infusion and filtration; basic batch records with color/odor checks; retention samples in selected runs.

Channels. OTOP fairs, word-of-mouth, and a Facebook page; repeat purchasers are the primary revenue base.

Constraints. Short shelf-life (~3 months) and occasional phase separation; limited digital marketing capability.

Opportunities. Tighten prevention/appraisal (opaque/UV-safe containers; ΔE and aw mini-logs), scale micro-assays through local labs, and institutionalize content cadence/response SLAs to improve online conversion (omni-channel evidence).

Case C — Micro-producer/Collector (Upstream → Micro-processing)

Business type/role. Collector and micro-processor producing dried petals and small household products.

Sourcing. Morning harvest; “green calyx” used as freshness proxy; sun-drying to low moisture.

Processing & QA. Visual inspection and odor checks; documentation is ad hoc.

Channels. Neighborhood and community networks.

Constraints. Minimal QA instrumentation and limited process formalization; quality variance across lots.

Opportunities. Introduce simple intake forms and lot cards, adopt handheld aw checks, and formalize rejection criteria; negotiate basic MOUs with aggregators to reduce intake disputes (TCE logics).

Case D — Upstream Aggregator with MOU to Factory (Upstream)

Business type/role. Farmer-group aggregator performing collection and primary processing before factory delivery.

Sourcing. Codified practices: morning harvest, green calyces, crisp drying; documented lots; MOU terms on volume, quality, and delivery cadence.

Processing & QA. Screening for moisture, bleaching, and visible mold; progressive adoption of color/moisture recording aligned to factory specs.

Channels. B2B delivery to factories on scheduled cycles.

Constraints. Seasonal variability in quality; coordination costs.

Opportunities. Deploy intake aw testing at collection points, adopt a visual ΔE scale, and issue “mini-COA” (moisture + visual/color grading) to harmonize expectations and reduce incoming variance downstream (Relational View).

Case E — Community Brand with Repeat Buyers (Midstream)

Business type/role. Small-batch herbal products with strong reliance on repeat, seasonal buyers.

Sourcing. Mixed: self-collection and local purchases; standard visual/odor checks.

Processing & QA. Hot-water infusion; light batch documentation; on-label usage guidance.

Channels. Community events/OTOP and a small Facebook presence; no paid digital advertising.

Constraints. Limited production capacity and uneven digital capability; color fade and stability complaints in hot seasons.

Opportunities. Transition to opaque/UV-safe containers, add simple ΔE charting at release, and standardize posting/response rhythms to smooth orders (capability-appropriate omni-channeling).

Case F — OEM Extractor (Herbal Tea/Powders) with Halal/GMP/FDA (Midstream)

Business type/role. Contract extractor for herbal powders and teas; documented compliance (Halal/GMP/FDA).

Sourcing. In-spec raw materials with formal intake checks; traceable documentation across lots.

Processing & QA. Spray/freeze-dry operations; COA per lot; periodic potency assays; end-to-end traceability.

Channels. B2B OEM/ODM; value proposition anchored in compliance and documentation.

Constraints. High fixed costs; continuous compliance upkeep.

Opportunities. Provide templated spec/COA kits for micro-SMEs, offer fee-for-service color and anthocyanin testing, and pilot staged blockchain-ready data exports for premium B2B buyers (traceability pathway).

Case G — Community Brand “Oboon” (Midstream)

Business type/role. Local personal-care products (bath/hair) using butterfly pea; community-embedded.

Sourcing. Community network plus self-procurement; morning harvest and crisp drying where feasible.

Processing & QA. Hot-water infusion; basic QC; packaging adjustments subject to budget.

Channels. OTOP, Facebook, and word-of-mouth.

Constraints. Short product life; occasional color drift; limited resources for QA instrumentation.

Opportunities. Define intake specs formally; adopt $\Delta E/aw$ mini-logs and on-label usage advice; institute periodic micro-assays with a local academic or hospital lab to benchmark potency and reassure customers.