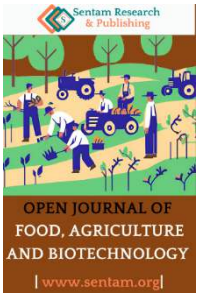
Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

Open Journal of Food, Agriculture and Biotechnology

Volume 2, Issue 1, 2026

Journal homepage: https://sentam.org/journals/ojfab



Residue Compliance and Biopesticide Transition in Kenyan Horticultural Export Chains

Judith A. Wekesa[1*] *& Samson K. Rotich*[2]

[1]School of Agriculture and Environmental Sciences, Kibabii University
[2]Department of Biological Sciences, University of Eldoret

ABSTRACT

Pesticide residue compliance has displaced yield and logistics as the binding constraint on Kenyan horticultural export growth. Successive tightening of European Union maximum residue limits, combined with rising border interception and increased official control frequency, has reduced export volumes of beans and peas in pods sharply and has exposed the residual chemical dependence of the production system. Biopesticides and biological control agents offer a compliance pathway, yet uptake among smallholder producers remains low despite a comparatively well-developed national registration framework. This narrative review synthesises the regulatory, agronomic and adoption evidence bearing on that gap, and integrates descriptive secondary data drawn from European Union legal instruments and Kenyan sector reporting. The review introduces the Compliance Driven Bioinput Transition Model, an original framework that positions destination market residue standards as the exogenous forcing variable and specifies four domestic mediators through which regulatory pressure is converted into changed input practice. Those mediators are registration capacity, efficacy credibility, advisory quality and aggregation structure, and the framework predicts three distinct outcomes ranging from full substitution to exit from the export channel. The synthesis finds that biological products perform credibly against key pests of French bean when integrated into managed programmes, but that they act more slowly and across a narrower spectrum than the chemistries they replace. Efficacy credibility and advisory quality therefore emerge as the mediators that most constrain transition, rather than registration capacity, which is comparatively strong by regional standards. The analysis reframes Bioinput adoption as a trade governance question and identifies advisory reform, group level compliance infrastructure and residue testing access as the priority interventions.

Keywords:
maximum residue limits; biopesticides; French bean; export horticulture; food safety standards; Kenya

INTRODUCTION

Horticultural exports have anchored Kenya's agricultural trade performance for more than three decades and remain among the country's principal sources of foreign exchange. Beans and peas in pods, together with capsicums, herbs and cut flowers, dominate the fresh produce component of that trade and are directed overwhelmingly toward European destinations. The sector has therefore developed with its production practices, quality

*Corresponding Author: School of Agriculture and Environmental Sciences, Kibabii University; Email: j.wekesa.research@outlook.com

Published: August 6, 2026

This is an open access article licensed under CC BY license (http://creativecommons.org/licenses/by/4.0/)

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

systems and marketing arrangements calibrated to the regulatory expectations of a single dominant market bloc.

That calibration has become progressively more demanding over the past decade. The European Union sets maximum residue limits under a harmonised legal instrument, and where no specific limit has been established for an active substance in a given commodity, a default limit at the analytical limit of determination applies (European Commission, 2005). Successive revisions have withdrawn approvals for widely used active substances and reduced permitted concentrations, which converts previously acceptable spray programmes into sources of non-compliance without any change in farmer behaviour.

The consequences have been severe and are visible in the trade statistics. Kenyan beans were placed under increased official control at the point of entry into the Union because of the frequency of detected non-compliance, and the frequency of identity and physical checks was subsequently raised (European Commission, 2020). Fresh vegetable export volumes reported by the national statistical authority fell steeply between 2023 and 2024, and the sector regulator attributed the reduction primarily to residue interceptions and to notifications concerning French beans and snow peas.

Biopesticides and biological control agents present the most direct technical route out of this position. They typically leave no residue of regulatory concern, they carry short or negligible preharvest intervals, and Kenya operates one of the more developed biopesticide registration frameworks on the continent (Alwora et al., 2026). Yet survey evidence places actual use among smallholders at approximately one in ten farmers, which is far below what the regulatory pressure would appear to warrant (Constantine et al., 2020).

This review sets out to address and explain that persistent discrepancy. It reverses the conventional framing of agricultural biotechnology diffusion, in which adoption is driven by producer level agronomic or economic advantage, and instead treats importing market regulation as the primary exogenous driver of bioinput transition. The paper synthesises the regulatory, agronomic and adoption evidence, introduces the Compliance Driven Bioinput Transition Model as an organising framework, and identifies which domestic mediators most constrain the conversion of regulatory pressure into changed practice.

REVIEW APPROACH AND EVIDENCE BASE

The paper is a narrative review supported by descriptive secondary information from regulatory and statistical sources. Peer reviewed literature was identified through structured searching using combinations of terms covering maximum residue limits, food safety standards, biopesticides, entomopathogenic fungi, French bean, western flower thrips and export horticulture, restricted where possible to Kenyan and East African study settings. Studies reporting field efficacy, adoption behaviour or trade effects were prioritised over laboratory bioassays without a field component.

Regulatory material was retrieved directly from the official legal repository of the European Union rather than from secondary summaries, so that the text of the relevant implementing regulations and the control frequencies specified in their annexes could be read as enacted. Kenyan regulatory material was drawn from the governing statute for pest control products and from the published register of approved biopesticide products maintained by the national regulator.

Trade and interception figures were compiled from national statistical and sector regulator reporting as relayed in the public record. These figures are reported here descriptively and with attribution, and where different sources express the same underlying decline using different aggregates the divergence is noted rather than reconciled. No inferential analysis was applied to any of these series, and the framework advanced later in the paper is offered as an interpretive structure rather than as a tested causal model.

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

EXPORT STRUCTURE AND MARKET DEPENDENCE

The Kenyan fresh vegetable export trade is structurally concentrated in two respects that jointly determine its vulnerability. Destination concentration means that a regulatory change adopted in Brussels propagates through the entire sector rather than affecting one channel among several. Commodity concentration means that beans and peas in pods carry a disproportionate share of the sector's value, so a control measure targeting those commodities is close to a measure targeting the sector as a whole.

Production is organised through a layered arrangement that links exporters to large numbers of small producers. The green bean subsector alone has been estimated to support around fifty thousand smallholder producers, most of whom supply through exporter managed out grower arrangements or through producer groups. This structure delivers the volume flexibility that airfreighted fresh produce requires, and it simultaneously distributes compliance responsibility across a large number of independent decision makers who each control their own spray practice.

The literature on European private standards documented the compliance burden of this configuration well before residue enforcement tightened. Compliance with retailer-imposed food safety and quality standards was shown to require costly investment in both variable inputs and durable farm structures, which raised legitimate concerns that stringency would marginalise resource poor producers from lucrative export channels (Asfaw et al., 2010). Emerging production standards were similarly identified as a challenge to continued smallholder involvement in vegetable export production (Mithöfer et al., 2008).

The empirical picture proved more nuanced than the exclusion hypothesis anticipated. Analysis of five hundred and thirty-nine small scale producers using an extended damage control production framework found that adoption of European retailer standards had a positive and significant effect on revenue from vegetable production (Asfaw et al., 2009). Standards can therefore prevent resource poor smallholders from holding a position in export markets while simultaneously producing positive changes in the production systems of those who do adopt.

Exporters have also used standards strategically rather than merely defensively. Certification and traceability systems function as competitive assets that differentiate suppliers and secure preferential access to demanding buyers, a dynamic documented for Kenyan vegetable exports and comparable origins (Jaffee & Masakure, 2005). The relevance of that observation to the present analysis is that the firms best positioned to absorb residue compliance costs are precisely those that have already invested in standards infrastructure.

Gendered and distributional consequences accompany these shifts and have been documented within Kenyan horticulture specifically. Contractual restructuring in the sector reallocated control over resources and returns within producing households, with implications for who bears the cost of compliance and who captures its benefits (Dolan, 2001). Compliance interventions designed without regard to these internal dynamics risk being absorbed unevenly at household level.

EVOLUTION OF DESTINATION MARKET STANDARDS

The regulatory architecture governing residues in imported produce rests on a harmonised limit setting instrument supplemented by a border control instrument. The first establishes maximum residue levels of pesticides in or on food and feed of plant and animal origin across the Union (European Commission, 2005). The second provides for temporary increases in official controls and for special entry conditions applied to specified commodities from specified third countries where contamination risk has been demonstrated.

Kenyan produce entered this control system progressively over a decade rather than abruptly. The share of consignments subjected to vetting

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

was raised from two percent to ten percent in 2010 following an increase in detected exceedances, and unshelled beans and peas were formally listed for enhanced control from January 2013. A parallel tightening of the permitted concentration for dimethoate took effect in 2012, and industry representatives reported that a substantial share of vegetable consignments was rejected in the months that followed, with several companies and farms delisted as a consequence.

The controlling instrument was consolidated in 2019, when a single implementing regulation replaced the earlier border control measures and established the current annex structure (European Commission, 2019). Annex I lists food and feed of non-animal origin subject to temporary increases in official controls at border control posts, while Annex II covers commodities subject to special entry conditions because of contamination risk. Beans of the genera Vigna and Phaseolus from Kenya, presented fresh or chilled, appear in Annex I under the pesticide residue hazard category.

Enforcement intensity is adjusted through a scheduled review mechanism rather than through discretionary action. The Commission is obliged to review the annex listings at regular intervals not exceeding six months, and control frequencies move up or down according to the compliance record observed by member state authorities (European Commission, 2019). Following a high frequency of detected non-compliance in the first half of 2019, the frequency of identity and physical checks applied to beans from Kenya was increased accordingly (European Commission, 2020).

Two features of this system deserve emphasis because they shape producer incentives directly. The first is that enforcement is collective at the level of the origin country and commodity, so a single non-compliant consignment raises inspection burden for every exporter of that commodity regardless of individual performance. The second is that the review cycle creates a slow feedback loop, in which improved compliance takes many months to translate into reduced control frequency and consequently into lower transaction cost.

Table 1: Regulatory milestones affecting Kenyan produce entering the Union

Period	Measure	Effect on Kenyan consignments
2005	Regulation (EC) No 396/2005 establishes harmonised maximum residue levels for pesticides in food and feed of plant and animal origin	Creates the substantive limit against which all subsequent border testing is assessed, including default limits where no specific value is set
2010	Vetting share for listed consignments raised following an increase in detected exceedances	Proportion of consignments subject to identity and physical checks increased from two percent to ten percent
2012	Permitted concentration for dimethoate sharply reduced	Rejections of vegetable consignments reported in the months following; several companies and farms delisted by exporters
2013	Unshelled beans and peas from Kenya listed for enhanced control under the then applicable border control regulation	Formal listing established a standing testing obligation at Union points of entry
2019	Commission Implementing Regulation (EU) 2019/1793 consolidates border control measures into a single instrument with two annexes	Beans of Vigna and Phaseolus from Kenya listed in Annex I under the pesticide residue hazard category
2020	Commission Implementing Regulation (EU) 2020/625 amends the annex following non-compliance detected in the first half of 2019	Frequency of identity and physical checks on beans from Kenya increased

Source: compiled from European Commission (2005, 2019, 2020) and contemporaneous sector reporting.

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

INTERCEPTION PATTERNS AND TRADE CONSEQUENCES

Interception counts provide the most direct available measure of compliance performance, although they are an imperfect proxy because they reflect testing intensity as well as underlying contamination. Sector regulator reporting recorded sixty-two interceptions of fresh produce consignments destined for Union markets in 2022, against fifty-seven in the preceding year, with France, the Netherlands and Germany as the principal destinations concerned. Acephate, an active substance not approved in the Union but in continued use domestically, was among the compounds detected in beans.

More recent reporting indicates measurable improvement from what was a high base. Interceptions attributable to residue exceedance were reported to have fallen from forty-four in 2024 to thirty-three in 2025, a reduction of approximately a quarter attributed to an intensified verification drive by the national plant health inspectorate. Notifications concerning commodities other than green beans fell more sharply still, from thirteen across capsicums, basil, tea, snap peas and chillies in 2024 to three in the following year.

The trade consequences of the preceding period were substantial by any measure. National statistical reporting recorded fresh vegetable export volumes falling from approximately one hundred and sixty-four thousand tonnes in 2023 to approximately seventy-four thousand tonnes in 2024. The total value of fresh horticultural produce exported in 2024 was reported to have declined by twenty point one billion shillings to one hundred and thirty-six point six billion shillings, with residue interceptions identified as a principal cause alongside air cargo constraints.

Reported percentage declines vary across published accounts because different aggregates are used. Accounts drawing on the sector regulator's annual reporting have described a fall in vegetable export earnings of roughly two thirds, while accounts drawing on the national economic survey have described the fall in fresh vegetable earnings as approximately halving. The divergence reflects differences in commodity coverage and reporting period rather than disagreement about direction or severity, and both accounts attribute the decline primarily to residue interceptions.

Table 2: Reported interception and trade indicators for Kenyan fresh produce

Indicator	Reported value	Reporting basis
Interceptions of fresh produce consignments, 2021	57	Sector regulator reporting, principal destinations France, Netherlands and Germany
Interceptions of fresh produce consignments, 2022	62	Sector regulator reporting for the same destination group
Residue triggered interceptions, 2024	44	National plant health inspectorate reporting relayed in the sector press
Residue triggered interceptions, 2025	33	Same source; reduction of approximately one quarter year on year
Notifications for commodities other than green beans, 2024	13	Capsicums, basil, tea, snap peas and chillies combined
Notifications for commodities other than green beans, 2025	3	Chillies, coffee and snow peas
Fresh vegetable export volume, 2023 and 2024	Approximately 164,000 and 74,000 tonnes	National statistical reporting; decline attributed principally to residue interceptions
Fresh horticultural export value, 2024	Decline of 20.1 billion shillings to 136.6 billion shillings	National economic survey reporting; residue interceptions and air cargo constraints cited

Note: values are reported as published by the cited sources and are presented descriptively. Interception counts reflect testing intensity as well as underlying compliance, so they should not be read as direct contamination prevalence estimates.

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

The distributional pattern of these losses is important for policy design. Because enforcement operates at origin and commodity level, certified farms with compliant spray programmes bear inspection cost and delay generated by consignments they had no part in producing. This externality weakens the private incentive to invest in compliance beyond the level required for individual certification, and it creates a collective action problem that individual firms cannot resolve through their own conduct.

BIOPESTICIDE REGISTRATION AND AVAILABILITY

Kenya regulates all pest control products, biological products included, through a statutory board established under the governing pest control products legislation. The board assesses safety, efficacy, quality and economic value before granting registration, and its mandate spans importation, manufacture, distribution, sale and use (Alwora et al., 2026). Among East African jurisdictions, Kenya operates comparatively well-developed legislation specific to biopesticides, with mechanisms designed to assess microbial products on their own terms rather than through criteria designed for synthetic chemistry.

The regulatory framework has been revised in ways that favour biological products. Under the registration regulations adopted in 2022, biocontrol agents are evaluated using guidelines harmonised at East African Community level, and provision is made for temporary and emergency registration where invasive pests or emerging phytosanitary threats require rapid response (Alwora et al., 2026). Pre-submission consultation between applicants and the regulator is recommended as a means of shortening approval timelines.

Regional harmonisation of pesticide standards is advancing on a parallel institutional track. The Community has drawn substantially on United States and European regulatory practice in revising its pesticide standards, and the Kenyan regulator has been active in domesticating those standards through new instruments and revised regulations (Akidiva et al., 2024). Comparative work on Southern African jurisdictions reinforces the general finding that flexible and biologically informed registration guidelines are a precondition for product availability (Mawcha et al., 2025).

Product availability has grown correspondingly, although reported counts of registered biopesticides vary with the year of reporting and with the product definition applied. Published survey work describes Kenya as having a relatively high number of registered biopesticide products by regional standards, and the regulator maintains a public register of products approved for use on crops (Constantine et al., 2020; Pest Control Products Board, n.d.). The register is the authoritative source, and counts cited in secondary literature should be checked against it rather than carried forward.

Registration capacity is therefore not the primary constraint, which is an important negative finding. Practitioner accounts nevertheless identify persistent frictions on the supply side, including registration processes that remain lengthy and costly relative to product shelf life, inadequate production, distribution and storage infrastructure, and the circulation of adulterated products that undermines confidence in the category. Biological formulations are particularly exposed to the last two of these because viability depends on cold chain integrity from manufacture to application.

The development pipeline behind these products is regionally grounded rather than imported wholesale. Sustained research and product development on entomopathogenic fungi in Africa has produced commercialised isolates for arthropod pests of crops and livestock, developed through partnerships between regional research institutions and private formulators (Akutse et al., 2020). That pipeline matters for the transition question because locally developed isolates are selected against locally prevalent pest populations and climatic conditions.

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

FIELD EFFICACY OF BIOLOGICAL ALTERNATIVES

Field evidence on the pests that matter most to bean exports is reasonably well developed and broadly encouraging. Western flower thrips is the pest whose control most directly drives the spray programmes that generate residue exceedance, because it damages pods cosmetically and has developed resistance to many conventional insecticides. Trials conducted in Kenya evaluated an entomopathogenic fungal isolate, a predatory mite and a neonicotinoid soil drench against this pest on French bean under field conditions across two planting periods (Nyasani et al., 2015).

The reported results indicate that biological options are agronomically credible against this pest. Single and combined treatment applications reduced thrips population density by at least three times and reduced damage to bean pods by at least one point seven times relative to untreated controls (Nyasani et al., 2015). The fungal component was applied as a weekly foliar spray and the predatory mite was released fortnightly, which establishes that the programme is operationally feasible within a standard bean production cycle.

Related work by the same research group mapped the ecological context within which such programmes operate. Studies characterised thrips species composition and abundance on French beans and associated vegetation, examined how intercropping alters species composition and population abundance, and documented seasonal abundance of the pest and its natural enemies across different bean agroecosystems (Nyasani et al., 2010; Nyasani et al., 2012; Nyasani et al., 2013). This body of work supplies the ecological baseline that area wide biological programmes require.

Evidence for aphid management points in a similar direction while illustrating the characteristic limitation of biological products. A two-factor field experiment combined fungal biopesticides with sunflower and wheat border crops against black bean aphid on French bean (Emaru et al., 2024). Damage severity was lowest under the synthetic pyrethroid treatment, followed by the two fungal products, and the synthetic insecticide reduced aphid populations by margins that exceeded those achieved by the biological treatments.

That efficacy gap is the crux of the adoption problem and should be stated plainly rather than minimised. Entomopathogenic fungi act more slowly than synthetic insecticides, their performance is modulated by temperature, humidity and ultraviolet exposure, and their spectrum of activity is narrower. A farmer comparing products on the criterion of visible knockdown will consistently rate the biological option lower, even where season long damage outcomes and residue compliance favour it decisively.

Integration rather than substitution is therefore the realistic near-term model, and the evidence supports that framing. Combining a fungal isolate with a parasitoid against an invasive lepidopteran pest produced an additive control effect, although the fungus reduced parasitoid longevity and performance, which shows that biological components interact and must be sequenced deliberately (Sambo et al., 2022). Integrated pest management providing the organising logic for such combinations has an established evidence base across Asian and African smallholder systems (Pretty & Bharucha, 2015).

SMALLHOLDER ADOPTION AND AGGREGATION DYNAMICS

Adoption evidence establishes the size of the gap that the regulatory pressure has not yet closed. A survey of smallholders across central, eastern and Rift Valley areas of Kenya found that chemical pesticides were used widely despite farmer awareness of health and environmental risks, that almost half of respondents were aware of biopesticides, and that current use in the survey localities stood at approximately ten percent (Constantine et al., 2020).

The stated reasons for non-use are specific and actionable rather than diffuse. Farmers cited perceptions of effectiveness, and within that

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

category speed of action and spectrum of activity in particular, together with availability and affordability (Constantine et al., 2020). Farmers who did use biological products cited effectiveness, recommendation by advisory services and perceived safety as the reasons for their choice, which indicates that positive experience and credible advice reinforce one another.

Willingness to pay is nevertheless present and has been quantified with reasonable precision. Average willingness to pay above current chemical pesticide expenditure was estimated at nine-point six percent of that expenditure per cropping season, and the overwhelming majority of current non-users indicated willingness to try biological products as part of an integrated approach (Constantine et al., 2020). Price is therefore a constraint at the margin rather than an absolute barrier, and a modest premium appears to be acceptable where efficacy is credible.

Advisory quality emerges from this evidence as a distinct and underweighted constraint. Reported experience indicates that biological products are rarely recommended by advisers even where they appear in nationally produced pest management decision guides. Agrodealers occupy the position of first advice for most smallholders, and their product recommendations reflect stocking economics, margin structure and their own confidence in product performance rather than the compliance requirements of a distant export market.

Aggregation structure conditions the operation of all three of the preceding factors. Producers supplying through exporter managed schemes receive spray programmes, record keeping systems and in many cases the inputs themselves, which converts an individual decision into a managed one. Producers selling through spot arrangements to consolidators make input decisions alone, without access to residue testing and often without reliable information about which active substances have lost approval in the destination market.

Information failure at this point has been identified as a live operational problem. Agronomists working in bean producing areas have observed that farmers switching products in response to new prohibitions frequently lack accurate guidance on what to use instead, which produces substitution toward alternatives that may themselves be non-compliant. The problem is not resistance to change but the absence of a reliable channel through which regulatory change is translated into field level instruction.

Health outcomes provide an additional and frequently overlooked argument for transition. Compliance with retailer standards was associated with reduced pesticide related health risk costs among Kenyan export vegetable growers relative to non-adopters, which indicates that the benefits of moving away from hazardous chemistry accrue partly to the producing household itself (Asfaw et al., 2009). Framing bioinput transition solely as a market access requirement understates the case that can be made to farmers.

COMPLIANCE DRIVEN BIOINPUT TRANSITION MODEL

The evidence assembled here does not fit the standard model of agricultural technology diffusion. In that model, adoption follows from a demonstrated agronomic or economic advantage at farm level, and the analytical task is to explain why the advantage fails to translate into uptake. Biological products in Kenyan export horticulture do not consistently offer such an advantage on the criteria farmers apply, yet the pressure to adopt them is intense and originates entirely outside the production system.

The Compliance Driven Bioinput Transition Model is advanced to accommodate this structure. The framework positions destination market residue standards and the associated border control frequency as an exogenous forcing variable that is not responsive to producer level conditions. Regulatory pressure is transmitted into the production system through interception, notification, delisting and reputational spillover, and is then filtered through four domestic

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

mediators before producing an observable outcome.

Mediator One: Registration Capacity

The first mediator concerns whether compliant products lawfully exist in the domestic market at the moment the regulatory pressure arrives. Its indicators include approval timelines, data requirements imposed on applicants, provision for temporary registration and the breadth of the approved product range relative to the pest complex. On the evidence reviewed, this mediator is comparatively permissive in Kenya, which distinguishes the case from jurisdictions where regulatory absence is the primary obstacle.

Mediator Two: Efficacy Credibility

The second mediator concerns whether farmers believe that available biological products will protect their crop. Its indicators include field performance under local conditions, speed of visible effect, spectrum of activity and compatibility with the other products in the programme. This mediator is restrictive because the attributes farmers weight most heavily are precisely those on which biological products compare least favourably with synthetic chemistry.

Mediator Three: Advisory Quality

The third mediator concerns whether accurate and timely guidance reaches the point of decision. Its indicators include extension reach, the quality of agrodealer recommendation, the speed with which regulatory changes are translated into field instruction and farmer capacity to interpret product labels. This mediator is restrictive because commercial advice channels are not aligned with compliance outcomes and because the information cycle lags the regulatory cycle.

Mediator Four: Aggregation Structure

The fourth mediator concerns whether the producer sits within an arrangement capable of managing compliance collectively. Its indicators include scheme membership, traceability system coverage, access to residue testing before consignment and the capacity to share fixed compliance costs across members. This mediator sorts producers into sharply different circumstances, since scheme members face a managed transition while independent producers face an unmanaged one.

Table 3: Mediator definitions, indicators and assessed status

Mediator	Definition	Principal indicators	Assessed status in Kenya
Registration capacity	Whether lawful compliant products exist in the domestic market when regulatory pressure arrives	Approval timelines; data requirements; temporary registration provision; approved product range	Comparatively permissive; well-developed biopesticide specific legislation by regional standards
Efficacy credibility	Whether producers believe available biological products will protect the crop adequately	Field performance; speed of action; spectrum of activity; compatibility within the programme	Restrictive; slower action and narrower spectrum weigh heavily in producer assessment
Advisory quality	Whether accurate and timely guidance reaches the point of the input decision	Extension reach; agrodealer recommendation quality; translation lag; label literacy	Restrictive; commercial advice channels not aligned with compliance outcomes
Aggregation structure	Whether the producer sits within an arrangement able to manage compliance collectively	Scheme membership; traceability coverage; residue testing access; cost sharing capacity	Bifurcated; scheme members face a managed transition and independent producers an unmanaged one

Source: constructed by the authors from the reviewed evidence.

The framework predicts three distinct outcomes rather than a single adoption probability. Full transition occurs where a biological programme replaces the flagged active substance across the production cycle, and requires all four mediators to be permissive. Partial transition occurs where biological products are confined to the preharvest interval window while conventional chemistry is retained earlier in the cycle, which is the most common observed pattern. Transition failure

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

occurs where the producer exits the export channel or diverts production to the domestic market, where residue enforcement is weaker.

A feedback loop closes the system and is essential to its dynamics. Aggregate transition outcomes determine subsequent interception rates, which in turn determine the control frequency applied at the border under the scheduled review mechanism. Because that review operates on a cycle of months, the feedback is slow, and producers who invest in compliance do not observe a proportionate reduction in transaction cost within the season in which they invest.

GOVERNANCE AND COMPETITIVENESS IMPLICATIONS

The framework redirects intervention priorities away from where most current effort is concentrated. Considerable attention has been devoted to expanding the registered product range, yet registration capacity is the mediator assessed here as least restrictive. Interventions that add further products to a register while leaving efficacy credibility and advisory quality unaddressed will not produce proportionate change in field practice.

Advisory reform therefore constitutes the highest priority among the available interventions. Agrodealers are the effective extension system for most smallholders, and their recommendations currently reflect commercial rather than compliance logic. Accreditation schemes that condition the right to sell into export supply chains on demonstrated knowledge of destination market requirements would align incentives at the point where the input decision is actually made, and would do so at lower cost than parallel public extension.

Efficacy credibility is better addressed through demonstration than through communication. Farmers assess products against visible knockdown, so evidence presented in that idiom will be discounted regardless of how it is framed. Farmer managed demonstration plots that compare season long damage and marketable yield outcomes rather than immediate pest mortality would engage the criterion that matters commercially, and results generated locally carry credibility that trial data from elsewhere does not.

Residue testing access is the intervention with the clearest leverage on the fourth mediator. Producers currently learn that a consignment is non-compliant when it is intercepted at destination, by which point the loss is fully realised and is shared across all exporters of the commodity. Accessible group level testing before consignment would convert a destructive collective externality into a manageable private cost, and would allow producer groups to identify and correct problems within their own membership.

Regional harmonisation offers a further avenue that is already under development. Community level standards drawing on international practice are being domesticated through national instruments, and extending that process to biopesticide registration specifically would allow products approved in one partner state to reach markets in others without duplicated data requirements (Akidiva et al., 2024; Mawcha et al., 2025). Wider markets improve the commercial case for formulators to invest in local production and distribution.

A final implication concerns how the sector understands its own position. Residue compliance is frequently discussed as a technical problem of spray management, but the analysis here indicates that it is a governance problem concerning how a dispersed production system responds to an external regulatory signal it cannot influence. Framing it accordingly directs attention toward coordination infrastructure rather than toward the conduct of individual farmers.

LIMITATIONS OF THE EVIDENCE BASE

Several limitations constrain the conclusions offered here. The adoption evidence rests substantially on a single large survey conducted in specified regions of Kenya, and its findings may not generalise to the bean producing areas that supply export markets most intensively. Adoption

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

behaviour among producers embedded in exporter managed schemes may differ systematically from that of the broader smallholder population surveyed.

Trade and interception figures are drawn from statistical and regulator reporting relayed through the public record rather than from primary datasets accessed directly. Interception counts additionally confound testing intensity with underlying contamination prevalence, so a decline in counts is consistent with improved compliance, with reduced export volume, or with altered inspection practice. These series should therefore be read as indicative of direction rather than as precise measures.

The efficacy literature is concentrated on a small number of pests, principally thrips and aphids, and on a small number of fungal isolates. Whole programme evidence covering the full pest complex of an export bean crop across a complete season is scarce, and it is that evidence rather than single pest trial data which would determine whether full transition is agronomically achievable at commercial scale.

Finally, the framework advanced here is constructed from the reviewed literature and has not been tested against independent data. Its mediator assessments reflect the balance of the evidence reviewed rather than measurement against defined thresholds. Empirical assessment using producer level survey data linked to consignment level compliance records would be the appropriate next step, and until such work is conducted the model should be treated as an interpretive structure.

CONCLUSION

Pesticide residue compliance has become the binding constraint on Kenyan horticultural export performance, and the mechanism through which it operates is unusual. The regulatory pressure originates entirely outside the production system, it is enforced collectively at the level of origin and commodity, and it is adjusted through a review cycle that responds slowly to improved performance. Producers therefore face a requirement they cannot influence and a reward for compliance that arrives with substantial delay.

This review has synthesised the regulatory, agronomic and adoption evidence and proposed the Compliance Driven Bioinput Transition Model as an organising framework. The model treats destination market standards as an exogenous forcing variable and specifies four domestic mediators, namely registration capacity, efficacy credibility, advisory quality and aggregation structure, through which that pressure is converted into changed input practice or fails to be. It predicts full transition, partial transition or transition failure according to which mediators are permissive.

Applying the framework to the assembled evidence produces a diagnosis that runs against intuition. Registration capacity, the mediator that attracts most policy attention, is comparatively permissive in Kenya by regional standards. Efficacy credibility and advisory quality are the restrictive mediators, because biological products compare unfavourably on the attributes farmers weight most heavily and because the commercial advice channels that reach farmers are not aligned with compliance outcomes.

The interventions that follow from this diagnosis are correspondingly specific and actionable. Accreditation of agrodealers supplying export supply chains would align advice with compliance requirements at the point of decision. Farmer managed demonstration comparing season long marketable yield rather than immediate knockdown would engage the criterion farmers actually apply. Accessible group level residue testing before consignment would convert a destructive collective externality into a manageable private cost borne by those able to act on it.

The wider contribution of this analysis lies in its reversal of the conventional diffusion framing. Where an innovation is driven by external regulation rather than by farm level advantage, the standard adoption literature offers limited purchase, because the technology need not be superior on producer criteria for the pressure to

© 2026 The Authors. Published by Sentam Research and Publishing | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

adopt it to be overwhelming. Frameworks that make the external forcing variable explicit, and that specify the domestic conditions mediating its transmission, offer a more tractable basis for policy design in export oriented agricultural systems across the region.

DECLARATIONS

Funding: This review received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Conflicts of interest: The authors declare no competing financial or non-financial interests relating to this work.

Ethical approval: Ethical approval was not required for this review, which analysed publicly available regulatory data, trade statistics and published literature.

Data availability: All sources analysed in this review are publicly available and are listed in the reference list.

REFERENCES

Akidiva, A., Nyangori, G., Kinoti, D., & Amukhoye, R. (2024). Partnerships for improved food safety: MESPT's engagements in effective pesticides governance and management in selected counties in Kenya. *Frontiers in Sustainable Food Systems, 8*, Article 1454379. https://doi.org/10.3389/fsufs.2024.1454379

Akutse, K. S., Subramanian, S., Maniania, N. K., Dubois, T., & Ekesi, S. (2020). Biopesticide research and product development in Africa for sustainable agriculture and food security: Experiences from the International Centre of Insect Physiology and Ecology. *Frontiers in Sustainable Food Systems, 4*, Article 563016. https://doi.org/10.3389/fsufs.2020.563016

Alwora, G. O., Gichuru, E. K., Ogendo, J. O., & Okumu, O. O. (2026). An overview of biopesticides use and analysis of the Kenyan legal frameworks regulating biocontrol agents: A review. *Frontiers in Sustainable Food Systems, 10*, Article 1734372. https://doi.org/10.3389/fsufs.2026.1734372

Asfaw, S., Mithöfer, D., & Waibel, H. (2009). EU food safety standards, pesticide use and farm level productivity: The case of high value crops in Kenya. *Journal of Agricultural Economics, 60*(3), 645–667. https://doi.org/10.1111/j.1477-9552.2009.00212.x

Asfaw, S., Mithöfer, D., & Waibel, H. (2010). What impact are EU supermarket standards having on developing countries' export of high value horticultural products? Evidence from Kenya. *Journal of International Food and Agribusiness Marketing, 22*(3–4), 252–276. https://doi.org/10.1080/08974431003641398

Constantine, K. L., Kansiime, M. K., Mugambi, I., Nunda, W., Chacha, D., Rware, H., Makale, F., Mulema, J., Lamontagne-Godwin, J., Williams, F., Edgington, S., & Day, R. (2020). Why don't smallholder farmers in Kenya use more biopesticides? *Pest Management Science, 76*(11), 3615–3625. https://doi.org/10.1002/ps.5896

Dolan, C. S. (2001). The good wife: Struggles over resources in the Kenyan horticultural sector. *Journal of Development Studies, 37*(3), 39–70. https://doi.org/10.1080/00220380412331321961

Emaru, A., Nyaanga, J. G., & Saidi, M. (2024). Integrating Metarhizium anisopliae entomopathogenic fungi with border cropping reduces black bean aphids (Aphis fabae) damage and enhances yield and quality of French bean. *Heliyon, 10*(12), Article e33037. https://doi.org/10.1016/j.heliyon.2024.e33037

European Commission. (2005). Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin. *Official Journal of the European Union*, L 70, 1. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32005R0396

European Commission. (2019). Commission Implementing Regulation (EU) 2019/1793 of 22 October 2019 on the temporary increase of official controls and emergency measures governing the entry into the Union of certain goods from certain third countries. *Official Journal of the European Union*, L 277, 89. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02019R1793-20260218

European Commission. (2020). Commission Implementing Regulation (EU) 2020/625 of 6 May 2020 amending Commission Implementing Regulation (EU) 2019/1793 on the temporary increase of official controls and emergency measures governing the entry into the Union of certain goods from certain third countries. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX%3A32020R0625

Jaffee, S., & Masakure, O. (2005). Strategic use of private standards to enhance international competitiveness: Vegetable exports from Kenya and elsewhere. *Food Policy, 30*(3), 316–333. https://doi.org/10.1016/j.foodpol.2005.05.009

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org

Vol. 2, Iss. 1 (2026)
Pages: 64-76
Doi: 10.65965/sentam.202608.YIgLffFf

Mawcha, K. T., Kyampaire, D., Marciale, C., Simiyu-Wafukho, S., Chinyama, C., Babalola, O. O., Kinyanjui, G., & Ndolo, D. (2025). An overview of biopesticide regulatory frameworks in selected countries in Southern Africa. *Frontiers in Sustainable Food Systems, 9*, Article 1522526. https://doi.org/10.3389/fsufs.2025.1522526

Mithöfer, D., Nang'ole, E., & Asfaw, S. (2008). Smallholder access to the export market: The case of vegetables in Kenya. *Outlook on Agriculture, 37*(3), 203–211. https://doi.org/10.5367/000000008785915476

Nyasani, J. O., Meyhöfer, R., Subramanian, S., & Poehling, H. M. (2010). Thrips species composition and abundance on French beans, associated crops and weed species in Kenya. *Journal of Insect Science, 10*, Article 166. https://bioone.org/journals/journal-of-insect-science/volume-10/issue-166

Nyasani, J. O., Meyhöfer, R., Subramanian, S., & Poehling, H. M. (2012). Effect of intercrops on thrips species composition and population abundance on French beans in Kenya. *Entomologia Experimentalis et Applicata, 142*(3), 236–246. https://doi.org/10.1111/j.1570-7458.2011.01217.x

Nyasani, J. O., Meyhöfer, R., Subramanian, S., & Poehling, H. M. (2013). Seasonal abundance of western flower thrips and its natural enemies in different French bean agroecosystems in Kenya. *Journal of Pest Science, 86*(3), 515–523. https://doi.org/10.1007/s10340-013-0491-0

Nyasani, J. O., Subramanian, S., Poehling, H. M., Maniania, N. K., Ekesi, S., & Meyhöfer, R. (2015). Optimizing western flower thrips management on French beans by combined use of beneficials and imidacloprid. *Insects, 6*(1), 279–296. https://doi.org/10.3390/insects6010279

Pest Control Products Board. (n.d.). Biopesticides on crops. Pest Control Products Board, Kenya. https://www.pcpb.go.ke/biopesticides-on-crops/

Pretty, J., & Bharucha, Z. P. (2015). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects, 6*(1), 152–182. https://doi.org/10.3390/insects6010152

Sambo, S. M., Akutse, K. S., du Plessis, H., Aigbedion-Atalor, P. O., Mohamed, S. A., & Ndlela, S. (2022). Interactions between the entomopathogenic fungus Metarhizium anisopliae ICIPE 20 and the endoparasitoid Dolichogenidea gelechiidivoris, and implications for combined biocontrol of Tuta absoluta. *Biology, 11*(9), Article 1323. https://doi.org/10.3390/biology11091323

© 2026 The Authors. Published by **Sentam Research and Publishing** | www.sentam.org