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# The role of farming systems in the adoption of pest management practices: the case of the oriental fruit fly *Bactrocera dorsalis* in mango orchards in Senegal

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**Description of the subject.** In Africa, pest pressure has led researchers, policymakers, and international development stakeholders to develop and disseminate innovative pest management strategies. However, farmers reject some pest management strategies due to economic constraints, agronomic problems, or incompatibilities with their strategies, knowledge bases, and visions of desirable change.
**Objectives.** In this paper, we study the pest management practices employed by mango producers from different farming systems against the fruit fly *Bactrocera dorsalis*, as well as the factors determining the level of engagement of these producers in managing this pest.
**Method.** We surveyed 304 Senegalese mango growers affected by the invasive fruit fly *Bactrocera dorsalis* to understand which farming systems' features could explain the adoption level of fruit fly management tools through multivariate data analysis.
**Results.** Three types of farming systems characterized by a coherent set of varietal choices, orchard management, harvest practices, commercial outlets, and fruit fly management practices are identified: (1) Intensive farming systems supplying the export market with the variety Kent and using a large set of orchard management tools and harvest practices to eliminate fruit flies, (2) Extensive farming systems supplying various varieties of mangoes with a dominance of Kent to both export and domestic markets, with access to fruit fly management tools from public services, (3) Gathering farming systems characterized by zero-input, high varietal diversity, difficult market access, non-selective harvest practices, and fruit fly management rarely practiced.
**Conclusions.** The farming systems form a gradient of increasing use of fruit fly management tools and inputs, access to extension services, and export market orientation. Their coexistence in the same territories significantly contributes to the inefficiency of the control measures against *Bactrocera dorsalis*. Our results support the premise that in Africa, the adoption of pest management tools is more deeply integrated into the practices of certain producers compared to others, due to internal and external factors influencing the operation.
**Keywords.** Horticulture, Tephritidae, IPM, Africa.

**Le rôle des systèmes de production agricoles dans l'adoption des pratiques de gestion des ravageurs : une étude de cas sur la mouche des fruits orientale *Bactrocera dorsalis* dans les vergers de manguiers au Sénégal**
**Description du sujet.** En Afrique, l'augmentation de la pression exercée par les ravageurs a conduit les chercheurs, les décideurs politiques et les acteurs du développement international à élaborer et à diffuser des stratégies innovantes de lutte

contre les ravageurs. Cependant, il y a souvent un faible taux d'adoption par les producteurs de ces stratégies de lutte contre les ravageurs en raison de contraintes économiques, de problèmes agronomiques ou d'incompatibilités avec leurs stratégies, leurs bases de connaissances et leurs visions des changements souhaitables.
**Objectifs.** Dans cet article, nous analysons les pratiques de gestion contre *Bactrocera dorsalis* dans divers systèmes de production manguiers, ainsi que les facteurs influençant l'engagement des producteurs dans la gestion de ce ravageur.
**Méthode.** Nous avons enquêté auprès de 304 producteurs de mangues sénégalais affectés par la pression persistante de la mouche des fruits invasive *Bactrocera dorsalis*. Nous cherchons à comprendre quelles caractéristiques des systèmes de production peuvent expliquer le nombre de pratiques de lutte contre la mouche des fruits adoptées par les agriculteurs grâce à une analyse multivariée.
**Résultats.** Trois types de systèmes de culture de mangues, chacun caractérisé par un ensemble cohérent de choix variétaux, de gestion des vergers, de pratiques de récolte, de débouchés commerciaux et de pratiques de lutte contre les mouches des fruits : (1) les systèmes de production intensifs qui approvisionnent le marché d'exportation avec la variété de mangue Kent et qui utilisent un large éventail de pratiques de gestion des vergers et de récolte pour éliminer les mouches des fruits, (2) les systèmes de production extensifs qui fournissent diverses variétés de mangues avec une dominance de Kent à la fois pour le marché d'exportation et pour le marché intérieur, avec un accès aux intrants de lutte contre les mouches des fruits par les services publics, (3) les systèmes de cueillette caractérisés par des intrants nuls, une grande diversité variétale, un accès difficile aux marchés d'exportation, des pratiques de récolte non sélectives et une lutte contre les mouches des fruits rarement pratiquée parce qu'elle est presque impossible (arbres trop hauts, présence de plantes hôtes alternatives) et non encouragée par les acheteurs.
**Conclusions.** Les trois types de systèmes de production forment un gradient d'intensité croissante des pratiques de lutte contre les mouches des fruits, de l'intensité des intrants, de l'accès aux services de vulgarisation, de l'aide publique et de l'orientation vers la chaîne d'approvisionnement pour l'exportation. Leur cohabitation dans les mêmes territoires contribue fortement à l'inefficacité de la lutte contre *B. dorsalis*. Nos résultats soutiennent l'hypothèse selon laquelle, en Afrique, l'adoption de pratiques de lutte contre les ravageurs est fortement ancrée dans le fonctionnement global des systèmes de production.
**Mots-clés.** Horticulture, Tephritidae, IPM, Afrique.

## 1. INTRODUCTION

In tropical regions, insect pests cause significant crop losses, especially to fresh fruits and vegetables value chains, affecting economic sustainability and access to fresh produce (De Bon et al., 2015). Despite efforts to develop innovative pest management strategies (PMS) (Vayssières et al., 2009; Diamé et al., 2015; Mwatawala et al., 2015; Ndiaye et al., 2016; Ray et al., 2016), their widespread adoption is hindered by incompatibility with existing farming systems (Cowan & Gunby, 1996; Frison et al., 2016). In fact, farmers' rejection of new PMS is generally related to economic constraints, agronomic challenges, and inconsistencies with their strategies and values (Belmin et al., 2022).

To tackle this challenge, it is crucial to study the farming systems in the targeted area where innovative PMS are applied (Le Gal et al., 2011; Belmin, 2016). This involves evaluating farmers' motivations, available resources, and strategic trade-offs in resource allocation. The assessment uncovers farm-specific incentives and constraints, influencing the adoption or rejection of new PMS.

This paper investigates the influence of farming systems on the adoption of PMS, focusing on the mango sector in Senegal, where the oriental fruit fly, *Bactrocera dorsalis*, has led to significant fruit losses since its first observation in 2004 (Vayssières et al., 2005). Despite Senegal being a major player in mango production in West Africa, with economic and food security significance, the sector faces challenges from pre- and post-harvest losses caused by the oriental fruit fly (Rey & Dia, 2010; ECOWAS, 2012; FAOSTAT, 2019; Tounkara, 2020). The invasive fly lays eggs in ripening mangoes, leading to larval infestation, premature fruit drop, and subsequent rot (De Meyer et al., 2010).

In Senegal, the Niayes area and Casamance contribute to 95% of mango production, facing oriental fruit fly losses estimated at 30-60% and 60-80%, respectively (Ndiaye et al., 2014). Due to its quarantine status, fruit fly infestation adversely affects mango exports to Europe, leading to the destruction of intercepted infested consignments (Standard and Trade Development Facility, 2010). *Bactrocera dorsalis* is listed as a significant pest under Regulation (EU) 2019/1702, mandating control measures (Official Journal of the European Union, 2019). Control programs introduced since 2006 include various pest management tools, but growers' commitment varies, posing a challenge for effective control that requires coordinated efforts across all producers in a territory.

Studies in Senegal and sub-Saharan African countries (Rey et al., 2010; Grechi et al., 2013) suggest that fruit fly management practices vary due to diverse production systems. Factors like cropping system intensification, fruit destination markets, and climatic conditions play a role (Van Melle & Buschmann, 2013).

Research in Kenya by Wangithi et al. (2021) links fly control adoption to education, pest management experience, and farm size. However, these studies have limitations, including a lack of understanding of how production systems affect adoption dynamics and insufficient information on fruit fly control practices' implementation in major mango basins like Casamance (Grechi et al., 2013; Van Melle & Buschmann, 2013; Diatta, 2016).

This paper aims to explore factors influencing mango producers' commitment to fight the pest by hypothesizing that the diversity of production systems influences the overall fight in the Senegalese mango sector against the fruit fly.

## 2. MATERIALS AND METHODS

### 2.1. Study area

Mango producers from the two main production areas, namely Niayes and Lower Casamance, were sampled for the survey (**Figure 1**).

Located in the southwest of Senegal, the Lower Casamance region provides 60% of the national mango, mainly for the domestic market (Tounkara, 2020). It is an agro-ecological area characterized by a sub-Guinean climate marked by a rainy season of 5-6 months and average annual rainfall of 1,250 mm. The average annual temperature in Lower Casamance is 26 °C. In comparison, the Niayes area, located in northwestern Senegal, ranks second in terms of national mango production with a 37% share. In this area, 80% of the mango production is dedicated to export due to the proximity of port and airport infrastructures (Rey & Dia, 2010). This eco-geographic zone has a Sudano-Sahelian climate, marked by a long dry season from October to June and a short winter season of three months with an average annual rainfall of 400 mm (Rey & Dia, 2010). It covers the coastal fringe of Senegal and its hinterland from Dakar to Saint-Louis and includes the administrative regions of Dakar, Thiès, Louga, and Saint-Louis. Mango is the leading fruit crop with 80% of the fruit production area (Groupe Syscom, 2013).

### 2.2. Data collection

Data collection occurred in two stages. From June to July 2019, exploratory surveys were conducted in the study areas to comprehend stakeholder perceptions of the oriental fruit fly and document pest management techniques. Eighteen open interviews with mango

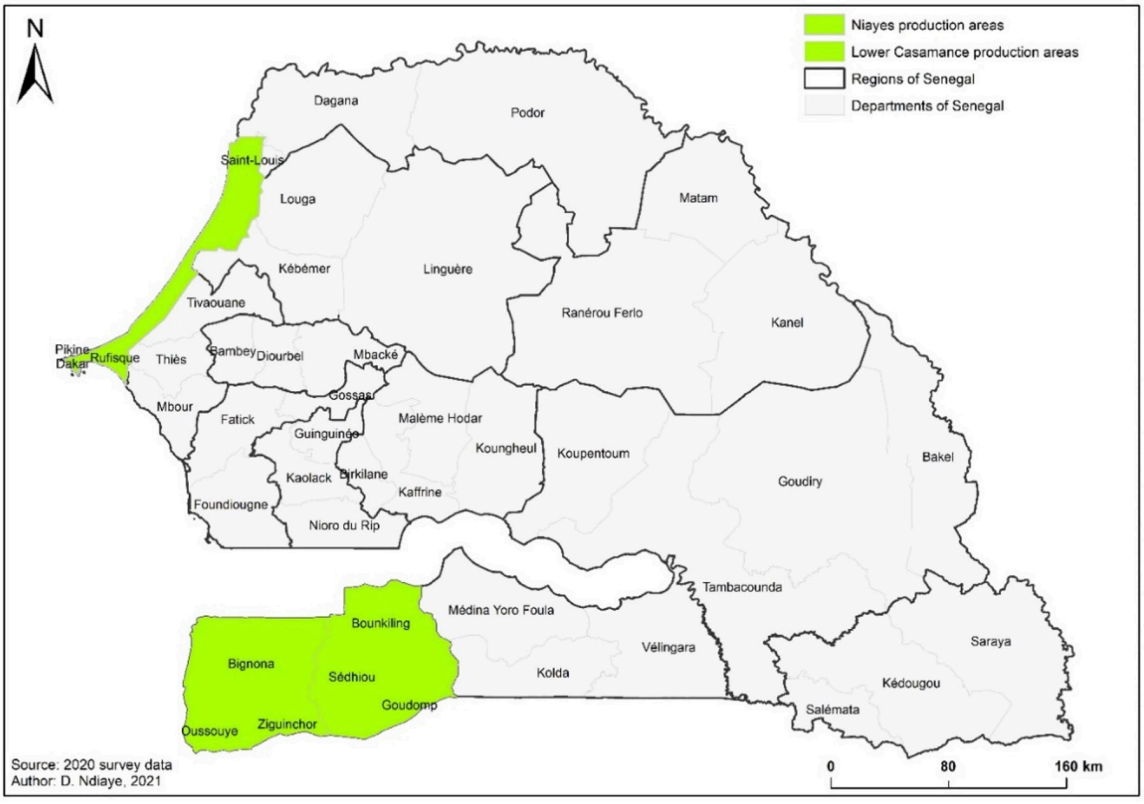


**Figure 1.** Location of the two main mango-production areas in Senegal, Niayes and Lower Casamance — *Localisation des deux principales zones de production de mangues au Sénégal, les Niayes et la Basse Casamance*.

producers and seven with support institutions were conducted purposively. This aimed to establish a tool/method list for fly control and generate hypotheses on structural variables influencing management practices. This knowledge informed the construction of a questionnaire for the second data collection and analysis stage (**Appendix**).

In September 2020, five enumerators supervised by the leading author of this study were recruited to collect quantitative data in the two study areas. The data of interest included 30 variables (**Appendix**) spread over six dimensions:

– general information on farmers and their production system;
– management of mango orchards;
– estimated mango production and losses related to the oriental fruit fly;
– phytosanitary protection of orchards, including fruit fly control practices;
– harvest and post-harvest practices;
– commercialization of mango in the two reference years 2019 and 2020;
– participation of producers in knowledge dissemination networks related to the oriental fruit fly issue.

The surveys were implemented and monitored using the Survey CTO application.

### 2.3. Sampling strategy

A total of 304 producers were sampled through a two-stage stratified random sampling method, first by eco-geographical zone and then by department. Lacking a national agricultural census, the sampling base was created by aggregating producer lists from the National Agency for Agricultural and Rural Advice and various farmers' organizations. The first stratification level divided the sample between Niayes (204) and Basse Casamance (100), reflecting the greater diversity of production systems in Niayes based on preliminary surveys. The second stratification level aimed to include producers from each mango-producing department in each eco-geographical zone, assigning relative weights based on department survey rates. Each producer's number of mango tree plots and associated management practices were identified during data collection. The total number of plots is 402 (**Table 1**).

### 2.4. Data analyses

**Cleaning of the database.** For the data processing, a preliminary work of data set cleaning and variables labeling was carried out including checking and addressing missing values. Outliers were also checked and addressed using left or right whiskers depending on whether the value is at the extreme left or right of the observations. As for the missing values, they were imputed using the MCA method. This method computes missing values in a way that the imputed values do not influence the results of the factor analysis (Josse et al., 2012; Josse et al., 2016).

**Construction of qualitative variables.** After univariate analysis, quantitative variables were converted into qualitative ones (**Table 2**) to homogenize the data set in the prevision of the multivariate analysis. The quartile rule was used to build the various modalities for each variable.

**Selection of explanatory variables.** From a database with over a hundred qualitative variables, a systematic selection process was undertaken to identify relevant variables for constructing a classification of mango production systems, as outlined in **table 2**. Chi-square tests were initially used to detect correlations between the dependent variable (number of control methods) and explanatory variables reflecting the seven

**Table 1.** Distribution of the weight of mango growers by the district — *Répartition du poids des producteurs de mangue par district*.

| | District | Survey frame size | Sample size | Survey rate[1] | Weight |
|---|---|---|---|---|---|
| Niayes | Rufisque | 73 | 24 | 33% | 3,0 |
| | Thies | 367 | 125 | 33% | 3,0 |
| Survey rate = 33% | Tivaouane | 167 | 55 | 33% | 3,0 |
| Lower Casamance | Bignona | 382 | 25 | 7% | 15,3 |
| | Goudomp | 47 | 25 | 53% | 1,9 |
| | Oussouye | 32 | 25 | 78% | 1,3 |
| Survey rate = 20% | Ziguinchor | 32 | 25 | 78% | 1,3 |

[1]: Sample size/Survey frame size. Weight was calculated as 1/Survey rate — *Taille de l'échantillon/taille de la base de sondage. Le poids a été calculé ainsi : 1/taux d'enquête*.

**Table 2.** Production system classification variables — *Variables de classification des systèmes de production*.

| Characteristic | Name of variable | Qualitative modalities/classes |
|---|---|---|
| General information* | Average age of orchards | > 30 years; ]15; 30] years; [0; 15] years |
| | Zone | Niayes ; Lower Casamance |
| Orchard management* | Percentage of Kent trees in orchards | High [0,20%[ ; moderate [20%,50%[ ; low [50%,100%[ |
| | Irrigation | Yes ; No |
| | Fertilization | Yes ; No |
| | Frequency of mango harvest | Once a week or more; once a fortnight or less; never |
| | Pruning frequency of mango trees | Twice a year; once a year; once every 2 or 3 years; once every 5 years; never |
| Estimated production and losses | Estimated losses due to fruit flies | Small losses [0,20%[ ; Medium losses [20%,60%[ ; Large losses [60%,100%[ |
| Phytosanitary protection* | Number of fruit fly management techniques | [0-2] ; [3-4[ ; n ≥ 4 |
| | Number of diseases and pests that attack mango trees | 1 ; 2 ; 3 ; ≥ 4 |
| Harvest and post-harvest practices | Selective harvesting based on the presence of punctures due to fruit flies | Yes ; No |
| | Criteria for triggering the harvest | Price; arrival of buyers; mango maturity; arrival of fruit fly; other |
| | Selection criteria for harvested mangoes | Absence of punctures; absence of spots; size; maturity; other |
| | Harvest techniques | Shaking mangoes with floral basket; shaking then picking the mangoes |
| | Fruit sap draining mode | On the ground; on a drip tray; no drip; other |
| Network and access to information | Support for a fruit fly control organization | Yes ; No |
| | Producers informed about the dynamics of fruit fly populations | Yes ; No |
| | Access to fruit fly control tools distributed by support services | Yes ; No |

*: modified quantitative variables — *variables quantitatives modifiées*.

dimensions of farming systems. Subsequent Chi-square tests were conducted to examine the independence of variables within the same dimension that were significantly related to the dependent variable. The final selection comprised two to three independent variables per farming system dimension, resulting in 20 selected variables (**Table 2**). These variables were utilized for Multiple Correspondence Analysis (MCA) followed by Hierarchical Ascending Classification (HAC) (Lesur-Irichabeau & Point, 2009). The MCA included illustrative variables such as "Number of fly control methods" and "study area" (Niayes *vs* Lower Casamance) to address imbalances. MCA was chosen for its stability with a large number of individuals, and AHC automatically determined classes without subjective influence.

Finally, we conducted a regression with the "rate of perceived production losses due to fruit fly" as the dependent variable to more precisely examine the differences between production systems.

## 3. RESULTS

### 3.1. Main features of the Senegalese mango-based farming systems

**Profile of mango orchards.** On average, the surveyed mango farmers owned 5.7 ha of mango orchards, with a maximum of 12 ha in Lower Casamance and 139 ha in the Niayes. Over 40% of farm managers combine farming with other income-generating activities. The

mean age of the orchards is less than 15 years for 18% of the mango plots in the Lower Casamance and 39% of those in the Niayes zone, and more than 30 years old in 49% of the plots in Lower Casamance, while in the Niayes only 21% of the orchards are in this range. In the majority of orchards (67%), mango is grown in association with other fruits (51%) or with vegetables or rainfed crops (38%) such as cowpeas, millet, groundnut or sorghum. The majority of farms use family labor supplemented by temporary labor mainly for harvest and irrigation activities. The dominant land tenure status is customary ownership.

**Orchard management.** The Kent mango variety is grown by 93% of farms in all zones (**Table 3**). Producers also cultivate Keitt, Sierra Leone, Papaya, Boucodiékhal and Séwé. Irrigation and fertilization were carried out by 5% of producers in Lower Casamance and 54.7% in the Niayes area. A small proportion of the respondents (16.2%) practice weeding and soil cleaning. Fertilizers (manure or compost) applied to trees are mostly organic (49.7% of plots). Orchards that receive mineral fertilizers are all located in the Niayes area (14.9%). Pruning is carried out once a year on 35% of plots in both Niayes and Lower Casamance areas. The two main objectives of pruning mango trees are to increase yield (69% of responses) and to aerate the canopy to limit pest damage (68%).

**Production, harvest and commercialization.** The average mango production per farm in 2019 and 2020 was 8.1 tons, with 51.4% sold, 12.3% self-consumed, and 30.2% lost. Oriental fruit fly caused losses of 35% in Niayes and 47% in Lower Casamance. Mango sales constituted 50% of farm income, primarily to "Bana-Bana" wholesalers (90% of producers). Buyers prioritize maturity (82%), absence of fly punctures (62%), no spots (49%), and plot sanitation (27%). Harvest triggers include fruit maturity (96%), buyer arrival (67.4%), fruit fly incidence (28%), and purchase price (23%). Niayes producers (64%) more than Lower Casamance (35%) consider fly punctures for harvestability. One-third of producers perform single-pass harvesting without sorting, relying on visual quality (73%), size (69%), or fly punctures (51%).

**Fruit fly control.** Almost all respondents identified the oriental fruit fly as the primary mango pest, with powdery mildew (66.2%) and anthracnose (70.3%) also frequently mentioned. Weaver ants and mealy bugs were noted by over a quarter of producers in Lower Casamance but less than 2% in Niayes. Common direct control techniques for fruit flies include trapping males, using food baits, and employing insecticide sprays, with higher usage in Niayes, except for food baits. Producers also employ indirect control methods, creating unfavorable conditions for fruit flies, more prevalent in Niayes. In Niayes, 76% use over three control methods, while in Lower Casamance, 96% use two or fewer (**Table 4**).

**Table 3.** Mango varieties grown in the plots of Lower Casamance and Niayes — *Variétés de mangue produites en Basse Casamance et dans la zone des Niayes.*

| | Kent | Keitt | Bouco-diekhal | Papaye | Pomme | Diolla | Dieg-bougate | Diourou | Séwé | Haden | Palmer | Sierra Leone | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Casamance | 92% | 87% | 6% | 22% | 11% | 12% | 6% | 57% | 0% | 12% | 1% | 32% | 36% |
| Niayes | 94% | 38% | 69% | 17% | 5% | 2% | 14% | 0% | 49% | 0% | 13% | 1% | 22.4% |
| **Total** | **93%** | **54%** | **48%** | **19%** | **7%** | **5%** | **11%** | **19%** | **33%** | **4%** | **9%** | **11%** | **36%** |

**Networks and access to information.** Less than half of the producers surveyed do not have access to information on the dynamics of the oriental fruit fly in order to take the necessary action to control it. Less than 40% of growers are members of professional organizations (cooperatives, associations, etc.) and only about 20% of growers receive support from these organizations to combat damage caused by the fruit fly. In addition, very few producers (less than 7% in both zones) have access to financing for mango production activities.

### 3.2. Embeddedness of fruit fly management practices in farming systems

**Multiple Correspondence Analysis (MCA).** Chi-square tests were performed to select 20 variables to construct the MCA. These variables were significantly related to the variable to be explained (number of control methods) and were independent of each other within each dimension (**Table 5**).

The first two dimensions of the Multiple Correspondence Analysis (MCA) explained 17.46% and 10.93% of the dataset variability, respectively, with a cumulative representation of 28.4% (**Figure 2a**). The elbow criterion, applied to eigenvalues, justified selecting the first two factorial axes for MCA. The first dimension (**Figure 2b**) contrasted farms with dominant Kent variety, selective picking, and buyer-influenced harvest plots, against those where fruit fly punctures were not buyer

**Table 4.** Fruit fly control techniques employed by mango growers (in %) — *Techniques de lutte contre la mouche des fruits mobilisées par les producteurs de mangue (en %).*

| Technique | Description | Niayes | Lower Casamance | Total |
|---|---|---|---|---|
| Direct control | | | | |
| Male Annihilation Techniques (MAT) (generally composed of malathion + methyleugenol) | The attraction of male flies with pheromone lures and elimination with insecticides contained in the traps | 76.1 | 31.3 | 61 |
| Food baits (Success Appat, M3, Timay, etc) | Attraction and elimination of male and female flies that feed on the food substance mixed with insecticide | 39.3 | 56.6 | 45 |
| Insecticide sprays (dimethoate, deltametrin) | Aerial and ground spraying of pesticides to eliminate flies at any stage of development | 22.4 | 22.2 | 22 |
| Biological control | Use of biopesticides and natural insect predators of fruit flies: release of parasitoids or conservation of weaver ant nests | 6.8 | 0.3 | 5 |
| Indirect control | | | | |
| Early-maturing varieties | Use of mango varieties that mature before the peak period of fruit fly populations | 8.3 | 0.0 | 6 |
| Non-attractive varieties | Use of fruit varieties whose organoleptic traits do not attract fruit flies | 3.0 | 0.6 | 2 |
| Harvest of fallen fruit | Collecting fallen mangoes with or without disposal by burial, incineration or feeding to livestock in order to destroy fruit fly larvae | 69.5 | 3.3 | 48 |
| Disposal of collected mangos | | 59.9 | 10.8 | 44 |
| Soil treatment | Application of biopesticides (entomopathogenic fungi or nematodes) to block the development of pupae in the soil | 33.1 | 0.0 | 22 |
| Pruning | Pruning and trimming help to aerate the orchard in order to reduce the impact of physical conditions that favor fruit flies | 50.9 | 0.0 | 34 |
| Early harvest | Harvesting plots early, before the peak of fruit fly infestation | 24.7 | 0.6 | 17 |
| Tillage | Shallow ploughing to eliminate larvae by burying | 29.7 | 0.0 | 20 |

or picker criteria. The second dimension opposed farms with irrigated trees and frequent fallen mango collection to those with minimal maintenance, no fallen mango collection, and no tree fertilization.

The Hierarchical Ascending Classification (HAC) based on the Euclidean distances of the variables enabled to retain three classes of farms (three clusters) with a greater number of individuals observed in cluster 2.

Significant variables related to fruit fly control are related to the cropping system, to the types of main buyers and their criteria for selecting plots to be harvested and mangoes. They are represented in **table 6** with their modalities participating in the definition of the different production system classes selected.

**Identification of three types of farming systems.**

Cluster 1: Intensive production systems oriented towards the export market

Cluster 1 includes farms with predominantly Kent trees (> 70%) whose production is exclusively for export. Producers fertilize their plots and use more than four methods to control fruit flies. The most common methods are male annihilation techniques, bait stations, orchard sanitation, pruning and early harvesting. Fallen mangoes are collected once a week or more frequently. Producers are informed by support services on fruit fly population dynamics. These farms are 100% located in the Niayes zone. Plantations are generally young with mango trees less than 15 years old. According to producers, mango trees are attacked

**Table 5.** The 20 variables selected for the MCA — *Les 20 variables retenues pour l'ACM*.

| Characteristic | Variables | Significance |
|---|---|---|
| General information | Zone | Supplementary variable |
| | Orchard age | * |
| Orchard management | Kent trees (%) | ** |
| | Irrigation | *** |
| | Fertilization | *** |
| | Frequency of mango picking | *** |
| | Pruning frequency of mango trees | *** |
| Phytosanitary protection | Number of diseases and pests | *** |
| | Number of control techniques | Supplementary variable |
| | Losses due to fruit flies | *** |
| Commercialization | Export market | *** |
| | Maturity criterion | *** |
| | Absence of spots or punctures on fruit | *** |
| Harvest | Selective harvesting according to the presence of punctures | *** |
| | Mango maturity level criterion | ** |
| | Price criterion | *** |
| | Shaking of the trees for harvest | *** |
| | Mode of draining | *** |
| Network and access to information | Support of an organization for fruit fly control | *** |
| | Informed about the dynamics of the oriental fruit fly | *** |

***: < 1% ; ** : < 5% ; * : < 10%.

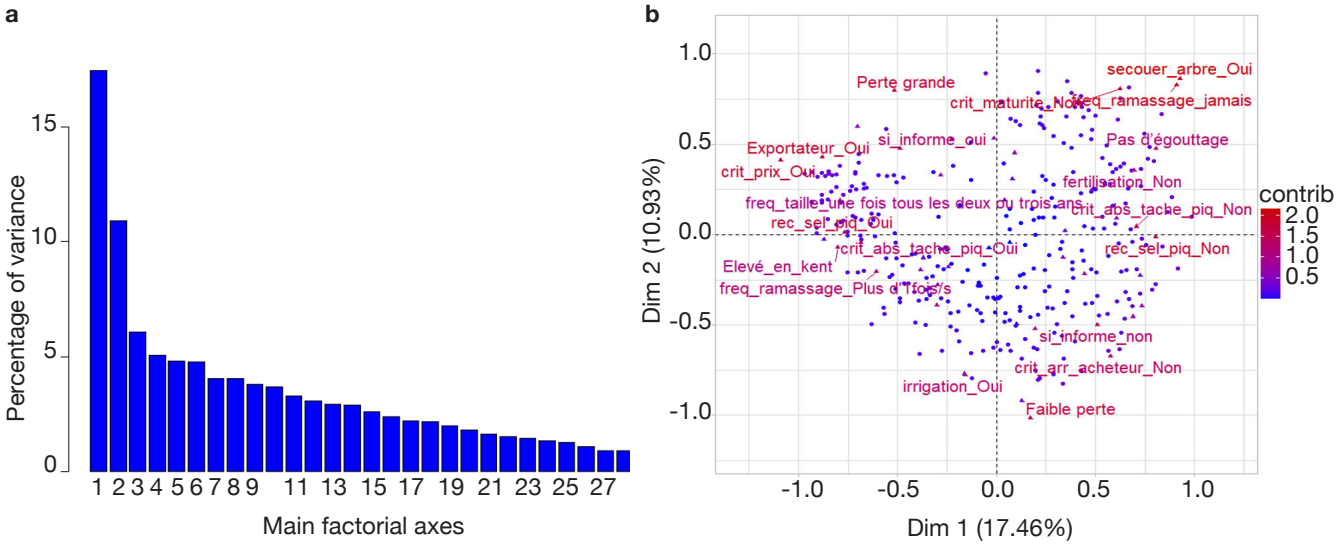


**Figure 2. a.** Eigenvalues of the different factorial axes; **b.** Contribution cloud of the variables — ***a.*** *valeurs propres des différents axes factoriels ;* ***b.*** *nuage de contribution des variables*.

by four or more pests and diseases (anthracnosis, powdery mildew, mealybug, weaver ant, bacteriosis and others). At harvest time, they selectively pick undamaged fruits and drain them on the ground. Their buyers demand ripe fruit without fly punctures. The main factor considered in the decision to initiate

**Table 6.** Characterization of variable classes by modalities — *Caractérisation des classes de variables selon leurs modalités*.

| Variable | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| Number of fruit fly control techniques* | > 4 | [3-4] | < 3 |
| Main buyer | Export | No export | No export |
| Zone* | Niayes (100%) | Niayes (97%) | Lower Casamance (97%) |
| Importance of the Kent variety (%) | High (> 70% Kent) | - (< 35% Kent) | Low |
| Tree age | Young (< 15 year old) | - | Old (> 30 year old) |
| Number of mango diseases and pests | 4 and more | 2 | 3 |
| Pruning frequency | Once two or three year | Twice a year | Once a year |
| Frequency of collection of fallen mangoes | Once a week or more | Once a fortnight or less | Never |
| Irrigation | - | Yes | No |
| Fertilization | Yes | - | No |
| Selective harvest of non-infested fruit | Yes | No | No |
| Absence of spots and punctures on fruit as quality criterion for buyers | Yes | No | No |
| Fruit maturity as quality criterion for buyers | Yes | Yes | No |
| Price as criterion of trigger for harvest | Yes | No | No |
| Harvest through tree shaking | No | No | Yes |
| Draining of harvested fruit | On the soil | On the soil | No fruit draining |
| Perception of losses due to fruit flies | High (> 50%) | Low (< 20%) | Moderate (20-50%) |
| Producers informed about the dynamics of fruit fly populations | Yes | No | - |
| Access to fruit fly control tools distributed by support services | - | Yes | No |

*: supplementary variables — *variables supplémentaires*.

harvest is the selling price. Class 1 growers perceive loss rates due to fruit flies to be over 50%.

Cluster 2: Extensive production systems oriented towards the domestic market

Cluster 2 includes farms whose production is mainly intended for the domestic market. Producers irrigate their plots and use between three and four fruit fly control methods. The most common are orchard sanitation, male annihilation technics and pesticide spraying. Fallen mangoes are collected once a fortnight or less frequently. Producers are not informed by support services on fruit fly population dynamics, but they have access to control techniques. Almost all the farms in Cluster 2 are located in the Niayes zone. Producers report that their orchards are attacked by two major pests and diseases (anthracnosis and powdery mildew). At harvest time, producers pick both punctured and non-punctured fruit and drain them on the ground. They supply various varieties of mangoes with a dominance of Kent to both export and domestic markets. Their buyers demand ripe fruit but tolerate orchards with fly-punctured fruit. Class 2 growers perceive fruit fly loss rates at less than 20%.

Cluster 3: Gathering systems oriented towards the domestic market

Cluster 3 consists of orchards with a low proportion of Kent (< 35%). Their production is destined for the domestic market (buyers are never exporters). Producers use between zero to two fruit fly control methods, and do not irrigate. The most common fruit fly control methods they use are orchard sanitation by only collecting fallen mangoes and the use of male annihilation technics. Fallen mangoes are never collected and producers do not have access to control tools distributed by the support services. Ninety-seven percent of the farms in cluster 3 are located in Lower Casamance. Plantations are old, with mango trees that are 30 years old or more. According to producers, production is threatened by three main diseases and pests (anthracnosis, powdery mildew, mealybug). At harvest time, producers shake the trees to make the fruit fall to the ground. Fruits are sold in bulk,

combining infested and non-infested ones. Buyers do not have specific requirements for fruit maturity and fly punctures. Class 3 growers perceive loss rates due to fruit flies from 20% to 50%.

**Connection between the existence of the three production systems and the effectiveness of fruit fly control.** Diverse mango farming systems coexisting in the same areas pose concerns, with unequal commitments to oriental fruit fly control. This diversity is a key factor contributing to ineffective pest control, as untreated orchards become potential sources of reinfestation in mango-growing regions.

The diversity in commitment levels is reflected in the adoption rates and motivations for choosing fruit fly control tools. Intensive farming systems typically employ over five methods, extensive systems use three to four, and gathering systems utilize fewer than three methods on average to combat *B. dorsalis*.

Male Annihilation Techniques (MAT) are the preferred direct control tools for mango producers, especially Malatrap to directly manage pests. All intensive, extensive, and gathering systems use MAT, with Malatrap as the primary choice (42.8%f of orchards from the intensive farming systems against 40.1% from extensive systems and 17.1% from gathering systems). Invader-B-Lok and DDVP are also employed in intensive orchards by a minority of two orchards.

However, gratuity stands as the predominant motive underlying the adoption of MAT control tools within all farming systems (Malatrap having been distributed through public initiatives), closely followed by the effectiveness and utility of these tools, as well as the ease of their implementation.

Regarding the use of food baits against *B. dorsalis*, the results demonstrate that adoption is higher in intensive and extensive systems, especially for Success Appat. Orchards in the extensive production system generally lead in the use of food bait tools promoted by public initiatives. Additionally, in this system, some producers manufacture their own food bait, such as a mixture of nutmeg and insecticide (**Figure 3**).

In terms of motivation of the use of food baits, gathering and extensive systems emphasize the tool's gratuitous nature (40 extensive system farmers over 50 using food baits and 16 of 20 famers from the gathering system), while the intensive system highlights the ease of implementing these tools for controlling *B. dorsalis* (4 farmers over a total of 5 from that farming system).

Regarding biological control tools only intensive and extensive systems are implicated. Extensive mango farmers use Neem-based biopesticides, either self-produced or obtained at a low cost. This includes Neem oil, sprayed in orchards to combat the fly at various stages of its life cycle, and Neem cake, applied to the soil to eliminate larval and pupal stages of the fly. The utilization rate of natural predators against the oriental fruit fly is notably low; however, among the relevant producers, 100% practice intensive mango farming.

In Lower Casamance, as in Niayes, insecticide spraying is the third method of direct control employed by mango producers, accounting for 22% in each area. This is primarily in orchards of intensive and extensive systems. The extensive system predominates in the spraying of pesticides as methods of control. However, the latter emphasizes the motivation of easy access and low cost in their choice of this tool, unlike producers in the intensive system who highlight the ease of use of these tools. Gratuitousness is the main reason motivating producers in the gathering system to use insecticides against fruit flies.

The most widely adopted prophylactic control method across all production systems is orchard sanitation through the collection then disposal of fallen mangoes. Thus, regarding the collection of fallen mangoes, which constitutes the first step of sanitation, it is observed that the control practice is more frequently applied by orchards in the intensive

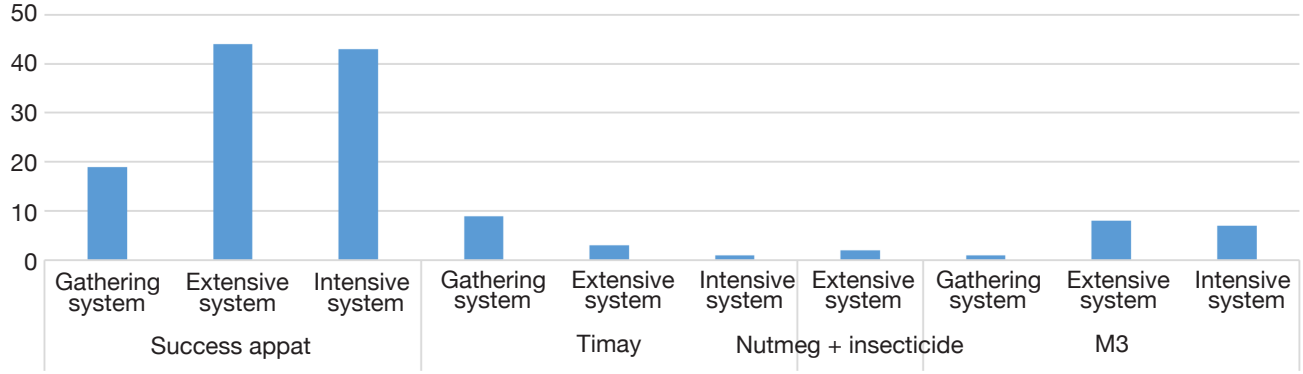


**Figure 3.** Level of utilization of food bait tools according to the mango farming system — *Niveau d'utilisation des outils d'appât alimentaire selon le système de production manguier.*

system, driven by the protection of mangoes against *B. dorsalis*. They are followed by producers in the extensive system for similar reasons, but they justify the adoption by the fact that this method does not require important financial resources. This practice is less commonly applied in orchards of the gathering system (**Figure 4**).

Moreover, there is a positive correlation between orchard sanitation frequency and the number of pest control tools used. In 38% of orchards, sanitation is considered unnecessary and is never implemented, mainly in gathering systems. In 41% of orchards where sanitation is never practiced, the main reason is a lack of production resources, which is also emphasized by 10% of farmers practicing monthly sanitation. Conversely, sanitation is conducted at least weekly in other orchards, targeting fruit fly prevalence (belonging to intensive and extensive systems). However, in the extensive system, 53% practice monthly sanitation among which 21% choose this frequency to allow livestock to pass through for feeding.

By examining the averages of perceived mango production loss rates, the hypothesis linking the number of mobilized tools to effectiveness against fruit fly infestation is refuted. Nevertheless, the linear regression with the gathering system as the baseline category reveals that in the extensive system, fruit losses significantly decrease (coefficient -23.122, standard error 3.106), as well as in the intensive system (coefficient -11.432, standard error 3.168), compared to the gathering system (**Table 7**).

Summing up these analyses, the correlation between sanitation practice, the number of pest control tools used, and the perceived infestation level reveals that higher engagement levels, as seen in intensive systems, indicate a greater interest in observing or measuring the impact of the fruit fly. In conclusion, two contrasting strategies emerge:

– a strategy of coexistence with the pest in gathering and some extensive farming systems;
– a commitment to actively control the presence of fruit flies in intensive and some extensive farming systems.

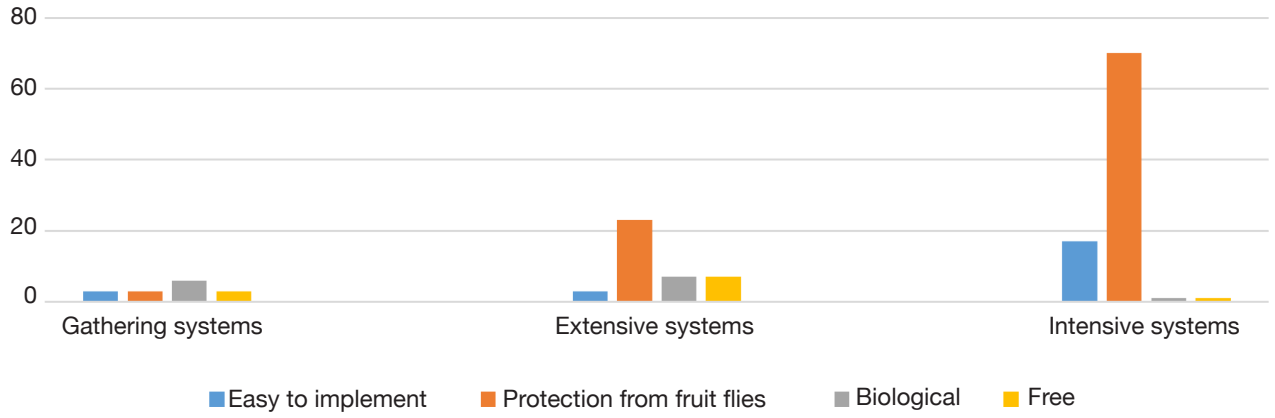


**Figure 4.** The orchards sanitation and the reasons motivating it according to the mango farming system — *L'assainissement des vergers et les raisons qui le motivent selon le système de production de mangue*.

**Table 7.** Linear regression of estimated production losses due to *B. dorsalis* according to farming systems — *Régression linéaire des estimations de perte de production dues à la mouche des fruits selon le système de production*.

| **Fruit loss_fly** | **Coef.** | **St. Err.** | **t-value** | ***p*-value** | **[95% Conf** | **Interval]** | **Sig.** |
|---|---|---|---|---|---|---|---|
| Gathering system | 0 | . | . | . | . | . | |
| Extensive system | -23.122 | 3.106 | -7.44 | 0 | -29.234 | -17.009 | *** |
| Intensive system | -11.432 | 3.168 | -3.61 | 0 | -17.666 | -5.198 | *** |
| Constant | 53.689 | 2.553 | 21.03 | 0 | 48.665 | 58.712 | *** |

| | | | |
|---|---|---|---|
| Mean dependent variable | 39.641 | SD dependent variable | 21.735 |
| R-squared | 0.164 | Number of observations | 301 |
| F-test | 29.267 | Prob > F | 0.000 |
| Akaike crit. (AIC) | 2658.732 | Bayesian crit. (BIC) | 2669.853 |

***: $p < 0.01$ — p < *0,01*; **: $p < 0.05$ — p < *0,05*; *: $p < 0.1$ — p < *0,1*.

It is noteworthy that the commercialization of mangoes to exporters leads to a 40% increase in the use of control techniques compared to local market sales.

## 4. DISCUSSION

Hence, three types of mango farming systems were identified based on a set of variables including varietal choice, orchard management, harvest practices, commercial outlets, and fruit fly control. Other studies highlighted the important variability of mango-based production systems in West Africa (Vayssières et al., 2005; Vannière et al., 2007; Rey & Dia, 2010) and proposed similar typology, either based on the level of intensification of cropping systems (Vayssières et al., 2008; Grechi et al., 2013) or orchard composition (Vayssières et al., 2004; Ndiaye et al., 2012). Vayssières et al. (2008) identified four types of systems in West Africa: the "gatherer production system", "production system under improvement", "more intensive production system" and "large industrialized orchards". In the Niayes area, Vayssières et al. (2004) distinguished pluri-specific and mono-specific orchards while Ndiaye et al. (2012) differentiated "traditional" and "modern (intensive) orchards". However, these classifications meet some limitations:

– they are based on expert knowledge of mango production systems, without utilizing quantitative data collected on-farm;
– they carry a normative vision of agronomic performances rooted in the rules of the export mango supply chain (underlying vision revealed by the names chosen for orchards categories such as "under improvement" or "traditional/modern");
– their focus was not to explain the diversity of fruit fly management practices.

Grechi et al. (2013) carried out farmers' surveys and quantitative assessment of orchards' planting design, management, vegetative state, hedgerow structure, and infestation by the fruit fly. The study was implemented on 64 farms in the Niayes area. Authors subsequently distinguished (1) "No-input mango diversified orchards", (2) "Low-input mango orchards", (3) "Medium-input citrus-predominant orchards" and (4) "Medium-input large mango- or citrus-predominant orchards". They showed that fruit fly infestation was high in orchards of system 4, whereas it was low in those of system 2. Our research led to partly convergent types. In particular, Grechi's types (1), (2), and (4) could respectively be assimilated to our gathering (class 3), extensive (class 2) and intensive (class 3) production systems. The absence of a convergent class with type (3) probably results from differences in analytical approaches. While Grechi et al. (2013) chose to focus on the diversity of species/varieties, we built our typology with the unique objective of understanding the variability of fruit fly management practices. Thus, our specific contribution is to accurately describe fruit fly management practices (using 12 variables *vs* only 2 for Grechi) and to build a new classification using only variables that show a statistical link with the number of fruit fly management practices. We also covered a higher spatial variability since we sampled orchards not only in the Niayes area but also in Lower Casamance.

### 4.1. The influence of the functioning of farming systems on fruit fly management practices

In this study, we assessed to what extent the functioning of farming systems could influence the adoption of PMS. Existing literature has pointed out several farms' features with significant influence on adoption of new PMS. These include household characteristics (gender, age, education, and family size), household resources (farm size, income, assets, and labor), social capital and networks (membership in farmer groups and other rural associations and leadership positions), and access to information and institutional services (markets and market structure and government extension services) (Jones, 1963; Dasgupta, 1989; Feder & Umali, 1993; Rogers, 2010; Kassie et al., 2012). Our results are in line with this body of literature and add a new contribution. The factors highlighted demonstrate how they interact and synergize within farming systems, influencing the adoption or non-adoption of Pest Management Strategies (PMS). In Senegal, farmers' dedication to fruit fly management correlated with variables reflecting diverse aspects of production systems. The three identified classes form a gradient of production systems, varying in intensity, inclusion in knowledge networks, connection to the export sector, and adherence to its rules. Producers' positions along this gradient significantly impact yield objectives, access to control resources, commercial incentives, and overall commitment to fruit fly control. Notably, the mango destination market strongly shapes planting choices, orchard management, harvesting practices, and fruit fly management (**Figure 5**). Several international studies show that rules imposed by actors in the first links of the value chains can influence agricultural practices (Le Bail, 2005; Belmin et al., 2018; Belmin et al., 2022). In Senegal, Grechi et al. (2013) and Ndiaye et al. (2012) found similar results, showing that export-oriented production systems are more input-intensive and less diverse (tree species and varieties) than domestically oriented systems. In a comparative study conducted in Benin, Burkina Faso, and Ghana, Van Melle & Buschmann (2013) demonstrated that the level of engagement of producers in fruit fly control

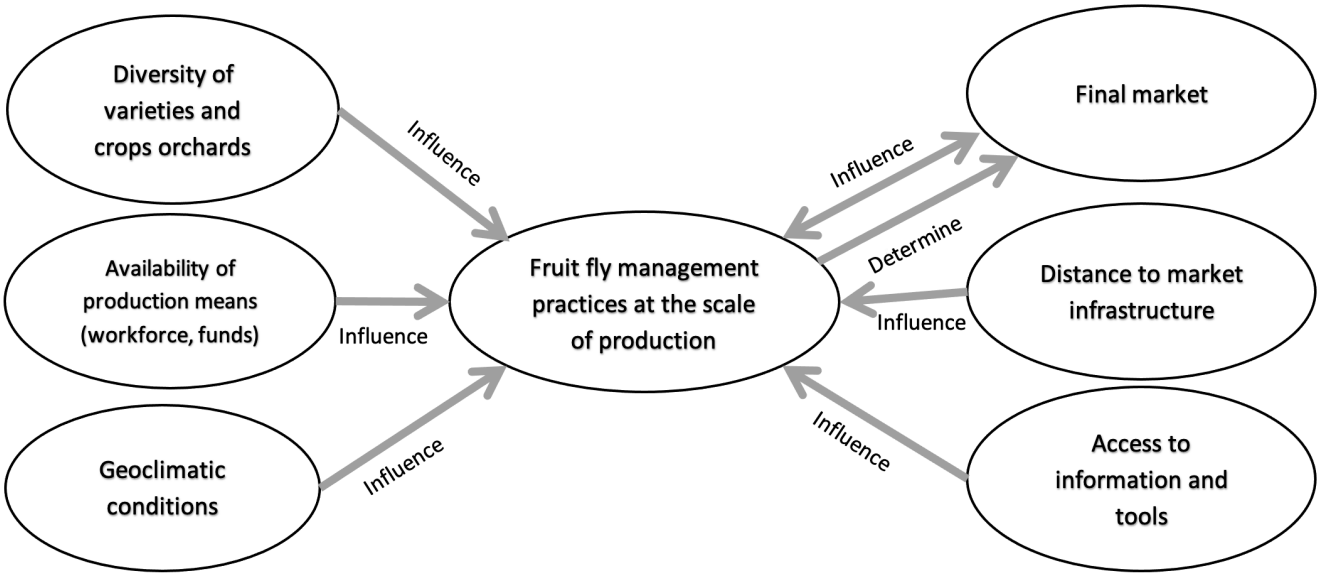


**Figure 5.** Factors influencing fruit fly control practices in mango production systems in Senegal — *Les facteurs qui influencent les pratiques de lutte contre les mouches des fruits dans les systèmes de production de mangues au Sénégal.*

was highly dependent on the destination market for mangoes and the nature of the relationship with buyers. Growers in a contractual relationship with a fixed buyer have greater access to fruit fly control tools.

Surprisingly, producers perceive the most fly-related fruit losses in intensive production systems where a higher number of control techniques are deployed. Based on our observations and the existing literature, we infer that:

– varietal specialization in Kent mango makes export orchards vulnerable to fruit fly insofar as mango maturity coincides with the peak of the pest abundance (PIP COLEACP, 2013; Vayssières et al., 2014);
– the practice of irrigation in intensive production systems contributes to maintaining hygrometric conditions favorable to the maintenance of fruit fly populations;
– the presence of alternative host plants (fruit trees, vegetable crops) within orchards or at the edge contributes to extend the period of the presence of fruit flies (Grechi et al., 2013).

According to our results, mango is grown in association with citrus or vegetables in 78% of the orchards surveyed in the Niayes.

### 4.2 Geographical determinants of the diversity of farming systems

The diversity in mango production systems in Senegal is influenced by the geographical dualism of the Niayes and Lower Casamance regions. Intensive and extensive farming systems are prevalent in the Niayes, associated with exporters supplying the European market (Rey & Dia, 2010), who influence producers' practices. The Niayes receive support from various projects focused on knowledge dissemination and fruit fly management, driven by the goal of achieving "zero flies" for export (Ndiaye et al., 2014). In contrast, Lower Casamance, located far from Dakar, lacks export investment due to its distance and historical conflicts. Mango producers in Lower Casamance prioritize minimizing production costs and often sell to domestic informal markets. The region's unique challenges, including old and tall mango trees and limited harvesting capabilities (Diatta, 2016), lead to significant exposure to fruit flies, prompting the use of gathering systems and shaking trees at harvest.

### 4.3 Limitations of the study

An important limitation of this study is that we did not carry out a quantitative assessment of fruit fly infestation, so the infestation level of orchards is only based on farmers' perceptions. We observed an inconsistency in the declared percentages of losses attributed to the fruit fly in different farming systems. These perception gaps probably result from variable sensitivity of farmers towards this phytosanitary issue. Thus, to deepen this study, it would be recommended to measure the level of infestation of orchards over different periods of the year for each production system.

## 5. CONCLUSIONS

The study explores the influence of farming system functionality on the adoption of pest control methods in mango production. It identifies three distinct mango farming systems through multivariate data analysis:
– input-intensive systems focused on the export market with the Kent variety and comprehensive fruit fly control;
– input-extensive systems supplying both export and domestic markets, utilizing public services for fruit fly management;
– gathering systems with zero-input, diverse varieties, limited access to export markets, non-selective harvest practices, and infrequent fruit fly management due to practical challenges and lack of buyer encouragement.

These systems create a gradient indicating decreasing use of control techniques, access to extension services, public support, and alignment with export supply chain rules. The spatial distribution of mango farming systems, especially in Niayes and Lower Casamance, contributes to the observed diversity in mango production systems.

Our results show that pest management for the Senegalese mango is intricately tied to the overall dynamics of farming systems. The way farmers perceive and address pests is intertwined with the structural and functional characteristics of their farms. Past failures in fly control projects may be attributed, in part, to overlooking the pivotal role of farming systems in pest management strategies (PMS).

In Africa, future pest management programs must thoroughly consider the diversity of coexisting farming systems in a given intervention area. To ensure the adoption, operational effectiveness, and sustainability of pest control tools under real life conditions, research and development projects should integrate that diversity into pest management strategies. These strategies should account for systemic phenomena influencing farmers' decisions and actions, encompassing the endogenous characteristics of the farming system and broader external forces such as market dynamics, agricultural extension services, and public regulations.

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