

## Determinants of Pesticide Exposure Among Cotton Farmers in Côte d'Ivoire: A Mixed-Methods Cross-Sectional Study in Toumoukoro Sub-Prefecture

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### Abstract

Cotton farmers in sub-Saharan Africa face considerable pesticide exposure risks, yet behavioural determinants remain insufficiently documented through approaches combining self-reported and directly observed data. This study identified structural determinants of pesticide exposure among cotton farmers in Toumoukoro sub-prefecture, northern Côte d'Ivoire, and measured the gap between declared and observed behaviours. A cross-sectional mixed-methods design integrated a quantitative phase (structured questionnaire,  $N = 315$ , stratified random sampling from 19,562 producers across 13 villages) and a qualitative phase (direct non-participant observation,  $N = 68$ ). Statistical analyses included odds ratios (OR), relative risks (RR), numbers needed to treat (NNT), Fisher's exact test, and 95 % confidence intervals. All producers used pesticides (100 %), and 95.9 % reported at least one symptom after application (OR absence of PPE vs symptoms = 35.9; NNT = 10.3). Access to personal protective equipment (PPE) was limited for 89.2 % of producers, with cost as the dominant barrier (OR cost/unavailability = 100.4). Training was associated with higher self-reported PPE use (OR = 1.96) but produced no measurable behavioural effect in direct observation (Fisher  $p = 1.000$  for all PPE items). Risk underestimation was reported by 64.8 % of producers, and 87.6 % perceived pesticide use as socially normalized in their community. Pesticide exposure results from four interdependent structural determinants: economic barriers to PPE access, social normalization of risk, behavioral ineffectiveness of current training, and productivist pressure toward overdosing. Simultaneous action across all four axes is required to durably reduce exposure and associated morbidity.

**Keywords:** Côte d'Ivoire, Cotton Farming, Direct Observation, Mixed Methods, Occupational Health, Personal Protective Equipment, Social Representations.

### Introduction

Cotton farming is a strategic sector for the Ivorian economy, providing livelihoods for approximately 800,000 rural households concentrated in the country's northern regions [19]. It ranks third nationally in terms of importance as a cash crop, after cocoa and cashew, and in many cases constitutes the sole annual source of household income for smallholder farmers [19]. To maintain economically viable yields against growing

pressure from arthropod pests — including *Helicoverpa armigera*, *Aphis gossypii*, *Bemisia tabaci* and *Dysdercus voelkeri* — which can cause production losses exceeding 30% in the absence of adequate phytosanitary protection [16], cotton producers rely exclusively on chemical pesticides (100%) [14]. The products used belong predominantly to WHO Class II — moderately hazardous organophosphates and pyrethroids — whose mechanisms of action include acetylcholinesterase inhibition,

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bronchospasm, and chronic neurotoxic effects documented in the epidemiological literature [3, 13, 16].

The health consequences of this intensive exposure are well documented in the African cotton-farming literature. Ajayi and Akinnifesi [1] reported headache, rheumatism, cough, skin rashes and sneezing among producers in sub-Saharan Africa. Roger et al. [17] documented intoxication cases in an Ivorian cotton zone, with nausea, dizziness, general fatigue, skin and eye irritation, and respiratory difficulties. Ngakiamama et al. [10] in Kinshasa and Coulibaly et al. [11] in the district of Abidjan confirmed that pesticide handling without adequate protection can cause multisystemic symptoms affecting producers, consumers, and the environment. Beyond acute intoxications, chronic exposure is associated with endocrine disruption, neurobehavioral disorders, reproductive effects and increased cancer risk [3, 13, 21]. Poor management of empty containers extends the exposure pathway beyond the application session itself [2, 6].

Despite this documented health burden, the behavioural determinants of pesticide exposure remain insufficiently analyzed from a systemic and multidimensional perspective. Most African studies rely exclusively on self-reported data [1, 6], which are subject to social desirability bias, leading to overestimation of protective behaviours. Furthermore, determinants of exposure are typically studied in isolation — economic constraints are analyzed separately from cognitive factors, which are in turn studied independently of normative and institutional dimensions [15, 16] — thereby preventing the identification of the mechanisms that sustain exposure as a systemic phenomenon.

The sub-prefecture of Toumoukoro, located in the Ouangolodougou department, Tchologo region, northern Côte d'Ivoire, has 19,562 registered cotton producers in 13 villages and represents a high-intensity exposure context [19]. Proximity to international borders

facilitates access to non-registered pesticides through informal channels [13]. Despite the presence of Ivoire Coton as the principal technical support organization, no published observational data documents the actual effectiveness of training programs on producers' behaviours in this area.

The present study addresses these gaps by employing a mixed-methods design triangulating a structured questionnaire (N = 315) with direct non-participant observation (N = 68), guided by two complementary theoretical frameworks: Moscovici's social representations model [4], which analyzes how collective beliefs shape risk-related behaviors independently of individual knowledge, and Ajzen's theory of planned behavior [5], which examines how attitudes, subjective norms and perceived behavioral control determine whether intentions translate into effective protective actions. The study aims to: (1) identify and quantify the structural determinants of exposure; (2) empirically measure the gap between declared and observed behaviours; (3) provide decision-makers with quantified, actionable evidence to design targeted and cost-effective prevention interventions.

## **Materials and Methods**

### **Study Setting and Population**

Cross-sectional study conducted in July 2025 in the sub-prefecture of Toumoukoro, an intensive cotton-producing zone in northern Côte d'Ivoire, comprising 13 villages, a population of 44,372 inhabitants and 19,562 active cotton producers registered in the Village Cotton Producer Groups (GVC) [19].

### **Study Design and Sampling**

Cross-sectional study with a sequentially integrated mixed-methods approach (QUAN → QUAL → triangulation). The quantitative phase involved a structured questionnaire administered to 315 producers selected by stratified random sampling using

Cochran's formula. The qualitative phase involved direct non-participant observation of 68 producers (21.6% of the quantitative sample) and was continued until data saturation. Each observation session covered the full pesticide application cycle (3 to 5 hours) using a standardized grid with eight thematic sections.

### Instruments

The questionnaire covers seven domains: sociodemographic characteristics, phytosanitary practices, PPE use, risk perceptions, access to PPE, behavioural intentions and health status. The standardized observation grid covers: PPE worn, preparation, spraying, post-application hygiene, container management, storage, environmental risks and behavioural summary.

### Statistical Analyses

Exact binomial tests (Clopper-Pearson) vs  $H_0 = 50\%$ ; Pearson chi-square with Yates correction; Fisher's exact test (cell counts < 5); OR, RR, NNT, phi coefficient; 95% CI using Wilson method. Significance thresholds: \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$ .

Software: Python (SciPy). Triangulation through systematic comparison of results from both phases [20].

### Ethics

Informed consent was obtained from each participant before data collection. Anonymization is guaranteed through individual coding. Administrative authorizations obtained from the sub-prefecture of Toumoukoro and the concerned village authorities.

### Results

#### Sample Characteristics

The sample is exclusively male (100%), with a mean age of  $40.5 \pm 14.2$  years (median 39.5; Q1 29.5; Q3 49.5). 79.7% of producers have no formal education, 15.9% have primary-level education and 4.4% secondary-level education. 97.5% are married. 48.3% have been using pesticides for 20 or more years, with a mean duration of  $15.2 \pm 9.8$  years (median: 12 years, min.: 1 year, max.: 40 years). 62.9% have received specific pesticide training. All characteristics are presented in Table 1.

**Table 1.** Socio-Demographic Characteristics of Cotton Producers n = 315

Variable	N	%	95% CI	95% CI (Wilson)
Male sex	315	100	[98.8–100]	$p < 0.001$ ***
Mean age $40.5 \pm 14.2$ years	315	—	Q1=29.5 Q3=49.5	Median 39.5
No formal education	251	79.7	[74.9–83.8]	$p < 0.001$ ***
Primary education	50	15.9	[12.3–20.3]	$p < 0.001$ ***
Secondary education	14	4.4	[2.7–7.3]	$p < 0.001$ ***
Married	307	97.5	[95.1–98.7]	$p < 0.001$ ***
Pesticide use (yes)	315	100	[98.8–100]	$p < 0.001$ ***
Duration $\geq 20$ years	152	48.3	[42.8–53.8]	ns
Mean duration $15.2 \pm 9.8$ years	315	—	Median 12 years	Min. 1 yr / Max. 40 yrs
Specific pesticide training received	198	62.9	[57.5–68.1]	$p < 0.001$ ***
95% CI: Wilson method. Exact binomial test vs $H_0 = 50\%$ . *** $p < 0.001$ . ns = not significant				

## Protective Behaviours and Phytosanitary Practices

51.1% of producers reported never wearing PPE during application. 73.3% showed actual zero protection. The respiratory mask was worn by 100% of declared wearers; gloves were used by 3.8% and boots by 6.3% of the 315 producers. 67.0% did not comply with

recommended doses, of whom 61.1% engaged in deliberate overdosing. 67.0% stored pesticides at home and 27.0% reused empty containers for domestic purposes. In direct observation (N = 68), 73.5% of producers mixed pesticides with bare hands and 0% washed their bodies after application. All data are presented in Table 2.

**Table 2.** Protective Behaviors and Phytosanitary Practices n = 315; Observation: n = 68

Variable	N	%	95% CI	Sig. (vs H <sub>0</sub> =50%)
PPE worn (at least sometimes)	154	48.9	[43.4–54.4]	ns
Never wear PPE	161	51.1	[45.6–56.6]	ns
Consistent PPE use (actual)	18	5.7	[3.6–8.9]	***
Actual zero protection	231	73.3	[68.2–77.9]	***
Mask worn (among wearers)	154	100	[97.6–100]	—
Gloves worn (N = 315)	12	3.8	[2.2–6.5]	***
Boots worn (N = 315)	20	6.3	[4.1–9.6]	***
Non-compliance with recommended doses	211	67	[61.8–72.2]	***
Deliberate overdosing (among non-compliant)	129	61.1	[54.4–67.5]	***
Storage at home	211	67	[61.8–72.2]	***
Containers discarded in nature	139	44.1	[38.6–49.6]	ns
Reuse of empty containers	85	27	[22.4–32.1]	***
Mixing with bare hands (observed, N = 68)	50	73.5	[62.0–82.7]	***
Body washing after spraying (observed)	0	0	[0.0–5.3]	***
*** p < 0.001. ns = not significant. Direct observation: N = 68				

## Reported Health Impact and Bivariate Associations

95.9% of producers reported at least one symptom after application (95% CI [93.1–97.6], p < 0.001). The most frequent symptoms were headache (78.1%), nausea (41.1%), skin and eye irritation (34.1%) and respiratory difficulties (28.1%). No hospitalizations for acute intoxication were reported. The main bivariate associations are presented in Table 3.

The OR between absence of PPE and symptoms was 35.9 (95% CI [2.13–605], p < 0.001; NNT = 10.3). The OR between non-compliance with doses and symptoms was 13.63 (95% CI [2.99–62.13], p < 0.001; NNT = 9.4). 89.2% of producers had no easy access to PPE (p < 0.001), and among them, 90.7% cited cost as the main reason versus 8.9% who cited physical unavailability (OR cost/unavailability = 100.4, p < 0.001).

**Table 3.** Associations between Exposure Factors and Reported Symptoms

<b>Bivariate association</b>	<b>OR [95% CI]</b>	<b>p</b>	<b>RR / NNT</b>	<b>Sig.</b>
Absence of PPE → symptoms	35.9 [2.13–605]	< 0.001	NNT = 10.3	***
Non-compliance doses → symptoms	13.63 [2.99–62.13]	< 0.001	NNT = 9.4	***
Smoking → dyspnea	2.59 [1.46–4.59]	0.001	RR = 2.03	***
Training → PPE use (declared)	1.96 [1.23–3.12]	0.005	RR = 1.43	**
Training → PPE use (observed, Fisher)	1.00 [0.68–1.50]	1	RR = 1.01	ns
Secondary educ. → dose compliance	6.09 [1.77–20.94]	< 0.001	$\chi^2 = 18.72$	***
Training → container reuse (inverse OR)	0.41 [0.24–0.67]	0.0004	RR = 1.90	***
Cost vs. unavailability of PPE (OR)	100.4 [—]	< 0.001	—	***
No gloves $\geq 4$ h exposure (observed)	RR = 1.78 [—]	< 0.001	100% vs 56.3%	***

OR = odds ratio. RR = relative risk. NNT = number needed to treat. Tests: Pearson chi-square, Fisher's exact. \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , ns = not significant.

### Risk Perceptions and Social Representations

64.8% of producers reported underestimating the hazardousness of pesticides ( $p < 0.001$ ). 87.6% indicated that their community had normalized pesticide use ( $p < 0.001$ ). 41.9% of producers described community indifference toward PPE as the dominant normative perception in their social environment ( $p = 0.005$ ). The proportion of producers with an individually favourable perception of PPE use was 51.7%, compared to 29.8% for perceptions attributed to their community (difference: +21.9 pp,  $p < 0.001$ ). 41.9% of producers believed that higher pesticide doses produce better yields.

### Training-Behaviour Triangulation

The cross-tabulation of training with PPE use yielded different results across data sources. In the declarative data, trained producers wore PPE at a rate of 55.1% versus 38.5% among untrained producers (OR = 1.96, 95% CI [1.23–3.12],  $p = 0.005$ ). In direct observation data, PPE use rates were identical between the two groups for all five items tested (Fisher's exact test,  $p = 1.000$  for each PPE item; RR = 0.92 to 1.00). By contrast, the training  $\times$  empty container reuse cross-tabulation showed an OR of 0.41 (95% CI [0.24–0.67],  $p = 0.0004$ ) in favour of trained producers. These triangulation results are summarized in Table 4.

**Table 4.** Triangulation: Comparison of Declarative Questionnaire  $n=315$  vs Direct Observation  $n=68$

<b>Indicator</b>	<b>Declarative questionnaire</b>	<b>Direct observation</b>
PPE use: trained vs untrained	55.1% vs 38.5% (OR = 1.96, $p = 0.005$ )	Identical rates (Fisher $p = 1.000$ for each PPE item)
Absence of gloves	79.4% (declared without consistent PPE)	100% without gloves $\geq 4$ h (RR = 1.78***)
Body washing after application	Not systematically measured	0% (N = 68, total absence)
Mixing with bare hands	Not measured declaratively	73.5% observed

Fisher  $p = 1.000$  for all five PPE items (gloves, goggles, mask, boots, full-body clothing). RR = 0.92 to 1.00.

## Discussion

### Social Desirability Bias: Methodological Implications for Training Evaluation

The dissociation between declarative data (OR = 1.96\*\*\*, higher PPE use among trained producers) and observed data (Fisher  $p = 1.000$ , no difference) constitutes empirical evidence of a social desirability bias [10]. This phenomenon occurs when respondents adjust their declarations to what they perceive as expected by the interviewer — in this case, the protective behaviours taught during training. This finding converges with Tessema et al. [8], who observed in Ethiopia that training improved declared mask-wearing but left other risk behaviours unchanged, and with Ajayi and Akinnifesi [1], who showed that training improves risk knowledge but that its behavioural effect remains limited in the absence of material access to PPE. Coulibaly et al. [11, 12] confirm this phenomenon in Côte d'Ivoire, notably in Abidjan.

These findings have direct implications for the design and evaluation of pesticide safety training programs. First, any evaluation of training effectiveness based solely on self-reported questionnaires is likely to generate a systematic overestimation of behavioural impact. Including a direct non-participant observation component in program evaluations is, therefore, necessary to avoid erroneous conclusions about intervention effectiveness. Second, current training as delivered by Ivoire Coton generates cognitive learning without durable behavioural transfer. This implies that a qualitative reform of training is required: replacing theoretical modules with practical anchor sessions using real PPE, introducing demonstrations and role-playing exercises, and establishing behavioural follow-up at 6 and 12 months post-training. Third, training produces a selective effect on environmental behaviours (reduction in container reuse; OR = 0.41\*\*\*) but not on physical protection behaviours, suggesting that cognitively complex tasks

(identifying a hazardous container) are accessible to training, whereas structural behaviours (wearing gloves) require material access.

### The Economic Barrier: Implications for Subsidy Policies

The OR of 100.4 between cost and unavailability as reasons for lack of PPE access documents that the barrier is almost exclusively economic. This 100:1 ratio in favour of cost is a finding of unprecedented precision in the Ivorian cotton literature and challenges the most common institutional response — improving geographic distribution networks — in favour of a direct subsidy logic [15, 16]. These results align with those of Ajayi and Akinnifesi [1], Ouattara and Doudou [2], and FAO [15], and extend them by quantifying health impacts.

In terms of practical implications, the NNT of 10.3 for PPE provision provides a directly usable economic argument: considering the direct medical costs (care, hospitalizations), the loss of working days and the impact on agricultural yield associated with one symptomatic case, the cost of fully equipping 10 producers with PPE is very likely lower than the total cost of one avoided symptomatic case. This ratio serves as an economic advocacy tool for decision-makers at Ivoire Coton, the Ministry of Agriculture, and the GVCs. Pooling PPE costs at the GVC level — already used as input distribution structures — represents the most immediately actionable operational mechanism. Furthermore, the observation that 100% of producers exposed for more than four hours have no cutaneous protection (RR = 1.78\*\*\*) implies that interventions should prioritize producers with the longest application sessions, who are precisely those at highest risk of increased dermal absorption.

## **Social Representations: Implications for Community Interventions**

The prevalence of the collective representation of pesticides as 'dangerous but necessary' among 65.7% of producers, validated by Moscovici's model [4], implies that interventions based on simple dissemination of health risk information are insufficient: they confirm what producers already recognize, without challenging the legitimizing framework. This observation aligns with those of Ben Khadda et al. [7] in Morocco, Shammi et al. [9] in Bangladesh and Roger et al. [17] in Côte d'Ivoire, who show that recognizing danger does not imply adoption of protective behaviours.

The gap of +21.9 pp between individual favourable perception of PPE (51.7%) and the attributed community perception (29.8%) reveals a normative over-attribution phenomenon: producers overestimate their community's indifference toward PPE, which exerts conformity pressure toward non-protection, even among those who would personally be willing to wear PPE. Ajzen's theory [5] explains this mechanism through the 'subjective norm' component of planned behaviour: even when an individual's attitude is positive, perception of a social norm of indifference blocks conversion into behaviour. These findings imply that interventions must target the social norm itself, not merely the individual attitude. Concretely, this requires: involvement of local opinion leaders (village chiefs, GVC presidents) in public demonstration of PPE use; creation of 'PPE champions' in each village; and campaigns highlighting the actual prevalence of PPE use (descriptive counter-norm) rather than risk-only messages.

## **Productivist Pressure: Implications for Reforming Dosing Practices**

The belief that higher doses produce better yields, held by 41.9% of producers, results in a 67.0% non-compliance rate and an OR of 13.63

between non-compliance and symptoms. This mechanism is pharmacotoxicologically coherent: organophosphate overdosing amplifies acetylcholinesterase inhibition and precipitates cholinergic manifestations [3, 18]. The NNT of 9.4 for dose compliance means that achieving compliance among 10 currently non-compliant producers would prevent 1 additional symptomatic case, making this a highly cost-effective intervention.

The implications of this finding for training programs are significant. The simple instruction 'respect the doses' is insufficient, because the productivist belief constitutes a mental model based on producers' practical experience: overdosing appears to them as a low-cost precautionary strategy. Correcting this belief requires evidence produced within the producers' own frame of reference, i.e., participatory field trials comparing yields at recommended doses versus higher doses. An economic evaluation integrating the additional costs of overdosed pesticides and the working-day losses due to symptoms — two items directly understandable by producers — also serves as a communication lever capable of altering perceived economic calculations.

## **Educational Level: Differentiated Implications by Behavior Type**

The educational gradient observed for dose compliance ( $\chi^2 = 18.72$ ,  $p < 0.001$ ; OR secondary vs none = 6.09) and its total absence for physical protection behaviors ( $p \in [0.870; 1.000]$ ) establish a fundamental distinction between two categories of behaviors. Cognitive tasks — reading a label, calculating a dosage, interpreting instructions — are facilitated by educational level. Structural tasks — wearing gloves, boots, full-body protective clothing — are determined by economic access to equipment, regardless of educational level. This distinction has also been documented by Ben Khadda et al. [7] in Morocco and Shammi et al. [9] in Bangladesh.

These findings have differentiated practical implications for intervention design. Improving literacy and formal education represents a long-term investment likely to improve dose compliance. However, in the absence of economic access to PPE, this educational investment will produce no benefit in terms of physical protection. For secondary-educated producers — who paradoxically show the highest rate of bare-hands mixing (80%) — interventions must incorporate a component of technical overconfidence correction, to recalibrate risk perception among the most educated producers.

### Limitations

This study has six limitations to consider when interpreting the results. First, the cross-sectional design precludes establishing strict causal relationships: documented associations between absence of PPE and symptoms (OR = 35.9) cannot exclude reverse causality or unmeasured confounders. Second, the small size of the untrained group in the observation phase (n = 9, 13%) considerably reduces statistical power for Training × PPE cross-tabulations: the absence of significant difference cannot be formally distinguished from a power deficit. Third, proportional estimation of certain cells in educational level cross-tabulations (very small group sizes in the primary (n = 14) and secondary (n = 5) observation groups) introduces imprecision in reported p-values. Fourth, the Hawthorne effect — behavioral modification in response to awareness of being observed — cannot be entirely excluded, though attenuated by the extended session duration (3 to 5 hours). Fifth, the absence of objective biomonitoring (urinary organophosphate metabolite assays, acetylcholinesterase activity measurements) prevents quantification of actual internal exposure and linkage of observed behaviors to biological exposure levels. Sixth, the geographic restriction to Toumoukoro sub-prefecture limits generalizability, though

consistency with the comparative African literature [1-3,7,13,14] suggests that the identified determinants reflect broader regional dynamics.

### Conclusion

Pesticide exposure among cotton farmers in Toumoukoro results from a system of four interdependent structural determinants: the economic barrier to PPE access (89.2%) [1,2], social normalization of risk (87.6%) [4], behavioral ineffectiveness of current training (Fisher  $p = 1.000$  in direct observation) [1,5] and productivist pressure toward overdosing (OR = 13.63, NNT = 9.4) [17]. The interaction of these four determinants produces a system resistant to single-axis interventions: acting on one without the others is insufficient to durably modify behaviors. Simultaneous and coordinated action is required: direct subsidy of PPE through GVCs (NNT = 10.3 as economic advocacy argument), qualitative reform of training toward practical grounding with post-training observational follow-up, community normative transformation through involvement of opinion leaders, and participatory field trials to recalibrate the productivist belief. These recommendations derive directly from the quantified results of the present study and constitute actionable priorities for Ivoire Coton, the Ministry of Agriculture and Ivorian public health institutions.

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## Ethical Approval

This study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants prior to data collection. The protocol was approved by the administrative authorities of the sub-prefecture of Toumoukoro, Côte d'Ivoire. No personally identifiable information was collected or stored.

## Data Availability

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request, subject to ethical and administrative approvals.

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## Author Contributions

- **Adama Coulibaly:** Conceptualization, Methodology, Data Collection, Formal Analysis, Writing – Original Draft.
- **Binaé Nouho:** Supervision, Writing – Review & Editing, Validation. All authors read and approved the final manuscript.

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## Conflicts Of Interest

The authors declare no conflicts of interest.

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