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Research Article

Pesticide misuse, health impacts, and knowledge gaps among Cameroonian vegetable farmers: survey findings

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ABSTRACT

Pesticide exposure poses a significant threat to public health in Cameroon, a country reliant heavily on vegetable production. This study aimed to assess the usage, knowledge, and handling practices of pesticides among vegetable farmers. We surveyed 345 farmers across six regions and eight divisions using interviews and on-farm observations from 2021 to 2022. Data were analyzed with descriptive and inferential statistics, including multiple correspondence analysis (MCA) and logistic regression. Farmers applied 43 active ingredients—46.5% insecticides, 41.8% fungicides, and 11.6% herbicides—many of which threaten health, ecosystems, and biodiversity. Of these, 6.9%, such as abamectin and methomyl, are classified as highly hazardous (WHO Ib), while others, including glyphosate, 2,4-D, and chlorothalonil, are probable or possible carcinogens (IARC, 2021). Misuse was prevalent: 80.4% mixed pesticides, 49.2% disregarded recommended dosages, and applications occurred twice weekly on average. Lack of support was evident, with 67.6% of farmers receiving no assistance, 65.3% lacking training, and 42.3% depending on neighbors for advice; additionally, 64.1% stored pesticides at home. MCA revealed that misuse correlated with farming experience, information sources, education level, land tenure, and inadequate support. Strikingly, 88.6% reported post-handling symptoms (e.g., fatigue, dizziness), with risk factors including limited PPE use, higher age, frequent applications, and less experience. Women showed greater vulnerability (OR = 1.09, 95% CI: 0.39–7.80, $P < 0.05$), whereas PPE use reduced risks (OR = 5.86, 95% CI: 2.62–13.09, $P < 0.05$), and lack of assistance exacerbated outcomes (OR = 0.28, 95% CI: 0.12–0.65, $P < 0.05$). Significant knowledge gaps in compliance, health risks, and environmental impacts were evident ($P < 0.01$). These findings highlight a public health crisis driven by pervasive misuse in vegetable cultivation. We recommend urgent training and support for farmers, alongside residue analysis in Cameroon's vegetables to quantify contamination levels and health risks, biomonitoring to assess exposure, and African Union-aligned bans on WHO Ib pesticides to protect communities.

Keywords: Pesticides, Vegetables, Farmers, Cameroon, Knowledge, Health.

RÉSUMÉ

L'exposition aux pesticides constitue une menace significative pour la santé publique au Cameroun, un pays fortement dépendant de la production maraîchère. Cette étude visait à évaluer l'utilisation, les connaissances et les pratiques de manipulation des pesticides parmi les maraîchers. Nous avons interrogé 345 agriculteurs répartis dans six régions et huit départements à l'aide d'entretiens et d'observations sur le terrain entre 2021 et 2022. Les données ont été analysées avec des statistiques descriptives et inférentielles, incluant une analyse des correspondances multiples (ACM) et une régression logistique. Les agriculteurs utilisaient 43 substances actives – 46,5 % d'insecticides, 41,8 % de fongicides et 11,6 % d'herbicides – dont beaucoup menacent la santé, les écosystèmes et la biodiversité. Parmi celles-ci, 6,9 %, comme l'abamectine et le méthomyl, sont classées comme hautement dangereuses (OMS Ib), tandis que d'autres, dont le glyphosate, le 2,4-D et le chlorothalonil, sont des cancérogènes probables ou possibles (CIRC, 2021). Les mauvaises pratiques étaient répandues : 80,4 % mélangeaient des pesticides, 49,2 % ignoraient les dosages recommandés, et les applications avaient lieu en moyenne deux fois par semaine. Un manque de soutien était évident : 67,6 % des agriculteurs ne recevaient aucune assistance, 65,3 % n'avaient aucune formation, 42,3 % dépendaient des conseils de voisins, et 64,1 % stockaient les pesticides à domicile. L'ACM a révélé que les mauvaises pratiques étaient corrélées à l'expérience agricole, aux sources d'information, au niveau d'éducation, au régime foncier et au manque de soutien. De manière frappante, 88,6 % ont signalé des symptômes après manipulation (fatigue, vertiges), avec des facteurs de risque incluant une utilisation limitée des équipements de protection individuelle (EPI), un âge avancé, des applications fréquentes et une moindre expérience. Les femmes étaient plus vulnérables (OR = 1,09 ; IC 95 % : 0,39–7,80 ; p < 0,05), tandis que l'utilisation d'EPI réduisait les risques (OR = 5,86 ; IC 95 % : 2,62–13,09 ; p < 0,05), et le manque d'assistance aggravait les conséquences (OR = 0,28 ; IC 95 % : 0,12–0,65 ; p < 0,05). Des lacunes importantes ont été identifiées concernant la conformité aux normes, les risques sanitaires et les impacts environnementaux (p < 0,01). Ces résultats mettent en lumière une crise de santé publique liée à l'usage inapproprié des pesticides dans la culture maraîchère. Nous recommandons une formation et un soutien urgents pour les agriculteurs, des analyses de résidus dans les légumes camerounais pour quantifier la contamination et les risques sanitaires, un biomonitoring pour évaluer l'exposition, et une interdiction des pesticides de classe OMS Ib, conformément aux directives de l'Union africaine, pour protéger les populations.

Mots-clés : Pesticides, Légumes, Agriculteurs, Cameroun, Connaissances, Santé.

1. INTRODUCTION

Cameroon's agricultural backbone, driving over 20% of GDP and employing 62% of its workforce (FAO, 2022), has pivoted from traditional cultivation to pesticide-intensive systems to counter population growth and secure food supplies. Organic farming lags, practiced by just 28% of growers and spanning only 3% of farmland (Atlas Pesticide, 2023). With over 700 approved agrochemicals, Cameroon ranks seventh among Africa's pesticide importers (MINADER, 2021; Tolera, 2020), part of a 67.8% continental rise in use (105,757 tonnes/ha, 1999–2020), far outpacing Europe's 0.2% drop under policies like France's Ecophyto (Atlas Pesticide, 2023; PAN Europe, 2022). This shift poses critical challenges for sustainable crop management.

Pesticide application in Cameroon is plagued by agronomic mismanagement. Over 87% of farmers disregard label directives, 81% exceed recommended doses, and 93% apply chemicals too frequently (Sopkoutie et al., 2024), often bypassing pre-harvest intervals essential for residue dissipation (Efuetlancha & Kuete, 2020; Tarla et al., 2013). During spraying, risky habits—eating, drinking, or chatting—coincide with reliance on leaking equipment (Matthews et al., 2003; Kamga et al., 2013). Storage near living quarters (64%; Dieudonne et al., 2021) and repurposing containers for food (17%; Abdulai et al., 2019) compromise produce safety. Banned compounds like metalaxyl and dieldrin persist in soils and key crops (Djuidje et al., 2021; Galani et al., 2021), while oncogenic agents such as mancozeb threaten long-term viability (Weis et al., 2019). Globally, pesticide mishandling poisons 385 million people yearly, killing 11,000 (Boedeker et al., 2020), with Cameroon noting fatalities from contaminated harvests (APA, 2010; Tarla et al., 2013). These practices, fueled by a training deficit (65% untrained; Kenko et al., 2017) and minimal oversight (Tarla et al., 2015), are poorly documented in agroecological zones I and II, critical vegetable-producing areas (Sopkoutie et al., 2024).

This study probes how inadequate knowledge, erratic application, and weak regulation in these understudied zones undermine crop health, farmer safety, and environmental integrity. We aim to: (1) profile active ingredients in vegetable systems and (2) scrutinize handling practices and their socio-economic triggers. By tackling these gaps, we offer agronomists insights for optimizing training, refining pest management, and advancing sustainable alternatives across pesticide-reliant Africa.

2. MATERIALS AND METHODS

2.1. Study area

Cameroon spans five agro-ecological zones (AEZs), distinguished by climate, from humid south to arid north. We conducted a cross-sectional study, adapted from Khadda et al. (2021), targeting vegetable farmers in four AEZs across six regions and eight divisions: Menoua, Koung-Khi, Nde, Mbam-Inoubou, Vina, Benoue, Mezam, and Mvilla

(Supplementary Fig. S1). Sites were selected for high vegetable output, covering diverse climates (e.g., 20.96°C, 1800–2400 mm precipitation in AEZ III; 27.43°C, 1500–2000 mm in AEZ I; Supplementary Table 1).

Table 1. Presentation of the different characteristics of study areas and climatic conditions of different divisions in Cameroon.

Divisions of the study and coordinates	Agroeco logical zones	Region of the study	Localities of the study	Surface area of the region in km²	Climate (Average temperature, temperature range, precipitation range)[b]
Menoua 5° 26′ 42″ N 10° 03′ 16″ E	III	West	Dschang, Baleveng, Balessing, Bansoa, Djuitsesta, Balessing	1 380	20.96°C, 29.56-12.36 1800-2400 mm
Nde 5° 08′ 29″ N 10° 31′ 18″ E	III	West	Batoum, Bazou, Projet 1, Projet 2, Bangangte	1,524	20.96°C, 29.56-12.36 1800-2400 mm
Koung khi 5° 20' 59.99" N 10° 23' 59.99" E	III	West	Mbouo, Deng, Batoufam, Bangang, Houpouo, Mbah, Toula	13, 892	20.96°C, 29.56-12.36 1800-2400 mm
Mezam 5° 57′ 15″ N, 10° 08′ 50″ E	III	North west	Mbei, Njong, Bamock, Akum, Meforbe, Mbah,	47, 191	20.96°C, 29.56-12.36 1800-2400 mm
Mbam Inoubou 4° 44′ 33″ N, 11° 13′ 29″ E	IV	Center	Mbappet, Ombessa, Bafia, Bokito	7 125	24.65 °C, 29.9-19.41 1500-2000 mm
Vina 12,82°14,76°E 6,52° 7,99° N	II	Adamaoua	Dang, Darang, Beka, Marza, Chabal, Ngaoudai, Nyassa, Digon	17,196	21.53 °C, 30.43-12.63 1500-2000 mm
Benoue 9° 18′ 20″ N 13° 23′ 39″ E	I	North	Bokle, Gashiga, Batoum	13 614	27.43 °C, 34.96-19.09 1500-2000 mm
Mvilla 2° 55′ 10″ N 11° 09′ 06″ E	IV	South	Oveng, Essiayo, Ngolobang, Biba, Ngat	8 697	24.65 °C, 29.9-19.41 1500-2000 mm

[a] (Okolle *et al.*, 2016),[b] (ONACC, 2023).

2.2. Sampling

The sample size was calculated using the formula used by Kapeleka (2024), with Z=1.96 (95% confidence level), M=0.05 (margin of error), and P=0.5 (maximum variability), yielding n=384 (Cochran, 1977).

$$n = \frac{Z^2 P(1-P)}{M^2}$$

Due to logistical constraints—including limited participant availability, restricted access to certain areas, and time limitations—the final sample was adjusted to n=345. Farmers were systematically sampled across villages in eight divisions, proportional to vegetable production: Menoua (21.73%), Vina (15.65%), Koung-Khi (10.43%), Nde (10.14%), Mvilla (15.65%), Mezam (9.85%), Benoue (11.30%), and Mbam-Inoubou (9.54%). Inclusion criteria required active vegetable farming, pesticide use, age over 18, and informed consent; exclusion criteria eliminated non-users, minors, and unwilling participants (Kenko et al., 2017). Crops included tomato, potato, lettuce, and other unspecified vegetables, necessitating further specification for reproducibility.

Data Collection

From February 2021 to August 2022, we surveyed 345 farmers using a structured questionnaire, pre-tested on 20 farmers (Mubushar et al., 2019) and deployed via a mobile app (Echodu et al., 2019). The tool comprised four sections: (1) sociodemographics and farming practices (e.g., age, education, crops); (2) pesticide knowledge, regulations, and self-reported symptoms (e.g., post-application health impairments); (3) handling practices (e.g., dosage, sourcing); and (4) safety behaviors (e.g., PPE use, disposal). Face-to-face interviews (20–30 min) were conducted in farms, homes, or markets, in French or English, with local language translations as needed (Wumbei et al., 2019). Respondents were not pre-informed to minimize bias (Khadda et al., 2021). Focus groups explored non-compliance drivers (e.g., ignoring labels, PPE avoidance). Direct observations on large-scale, irrigated, and non-irrigated farms assessed handling practices (Negatu et al., 2016). Pesticide identities were cross-checked against MINADER (2021) and PPDB (2022) databases.

The Treatment Frequency Index (TFI) is a standardized metric used to quantify the intensity of pesticide use in agricultural systems, expressed as the number of pesticide applications adjusted for dosage relative to recommended levels and the proportion of treated area. Developed to assess pesticide pressure on crops and inform sustainable pest management strategies (Le Bellec *et al.*, 2015), the TFI enables comparisons across farms, crops, and regions by normalizing application practices against homologated standards. It accounts for the frequency of treatments over a crop cycle, the applied versus recommended doses, and the spatial extent of application, providing a comprehensive indicator of phytosanitary reliance. In this study, the TFI was employed to evaluate pesticide use patterns among Cameroonian gardeners. The treatment Frequency Index (TFI) was calculated as:

$$\mathrm{TFI} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\frac{\text{Applied dose i}}{\text{Recommended dose i}} \times \frac{\text{Treated area i}}{\text{Total area i}}\right)$$

With areas calibrated using 16-L sprayer coverage (Le Bellec et al., 2017). n: Number of pesticide applications during the crop cycle, applied dose i: Dose of pesticide i used by the gardener (e.g., mL/ha), Recommended dose I: Homologated dose for pesticide i (MINADER, 2021), Treated area I: Area treated with pesticide i (m^2), Total area I: Total cultivated area for the crop (m^2).

2.3. Data processing and analysis

Data were processed in Excel 2019, cleaned (e.g., missing entries removed; Ntsoli et al., 2024), and analyzed in R 4.1.1 (Survey package). Descriptive statistics reported means ± SD for continuous variables and percentages for categorical ones. Normality (Shapiro-Wilk), homogeneity, and homoscedasticity were verified before inferential tests: Chi-square, Fisher's exact, or ANOVA for categorical differences; Pearson correlation for continuous relationships ($\alpha \leq 0.05$). Multinomial logistic regression modeled health outcomes against explanatory variables (e.g., training, PPE use). Multiple Correspondence Analysis (MCA) in Jamovi 2.3.21 explored variable associations, with rare categories (<5%) grouped or excluded; total inertia and significance were assessed (Ahmed & Muhammad, 2021).

3. RESULTS

3.1.1. Pesticides usage by gardeners in Cameroon

3.1.2. Socio-demographic and agricultural characteristics of respondents

Table 2 presents the sociodemographic characteristics of the 345 vegetable producers surveyed in Cameroon. A significant difference was observed in terms of gender ($p = 0.013$). Males predominated (81.2%) across all study areas, with no women represented in Dja and Lobo. The highest proportions of female respondents were recorded in Mvila (27.8%) and Mezam (26.5%). Regarding the age of producers, no significant difference was observed between zones ($p = 0.521$). The overall mean age was 36.5 ± 10.6 years, ranging from 18 to 70 years. Average ages varied slightly between zones, from 34.6 years in Bénoué to 39.0 years in Mezam. Marital status showed a highly significant difference ($p < 0.0011$). Overall, 71.6% of producers were married, 26.4% were single, and 2.0% were divorced. Marriage was particularly prevalent in Dja and Lobo (89.7%) and Mvila (83.3%), whereas single individuals were more numerous in Menoua (45.3%).

The level of education also showed a very significant difference between zones (p < 0.0011). Most producers had attained a secondary level of education (52.5%), followed by primary education (20.3%) and no formal education (16.5%). Only 10.7% had higher education. The absence of formal education was particularly high in Mvila (42.6%) and Mezam (23.5%), whereas Ndé stood out with no illiterate respondents and a high proportion of secondary-level education (74.3%).

Table 2. Sociodemographic characteristics of respondents (n=345).

Variables	Benoue (N=39)	Dja et Lobo (N=39)	Koung khi (N=36)	Mbam inoubou (N=33)	Menoua (N=75)	Mezam (N=34)	Vina (N=54)	Nde (N=35)	Total (N=345)	p value
Gender										0.013[1]
Female	4.0 (10.3%)	0.0 (0.0%)	7.0 (19.4%)	4.0 (12.1%)	17.0 (22.7%)	9.0 (26.5%)	15.0 (27.8%)	9.0 (25.7%)	65.0 (18.8%)	
Male	35.0 (89.7%)	39.0 (100.0%)	29.0 (80.6%)	29.0 (87.9%)	58.0 (77.3%)	25.0 (73.5%)	39.0 (72.2%)	26.0 (74.3%)	280.0 (81.2%)	
Ages										0.521[2]
N-Miss	0.0	2.0	0.0	1.0	0.0	0.0	0.0	0.0	3.0	
Mean (SD)	34.6 (10.1)	34.9 (8.2)	36.9 (11.5)	37.0 (9.1)	35.7 (11.6)	39.0 (10.5)	38.2 (11.0)	35.7 (10.4)	36.5 (10.6)	
Range	18.0 - 62.0	22.0 - 54.0	19.0 - 62.0	23.0 - 61.0	20.0 - 70.0	22.0 - 62.0	21.0 - 65.0	19.0 - 62.0	18.0 - 70.0	
Matrimonial statute										< 0.001[1]
Divorcée	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	5.0 (6.7%)	0.0 (0.0%)	0.0 (0.0%)	2.0 (5.7%)	7.0 (2.0%)	
Married	24.0 (61.5%)	35.0 (89.7%)	29.0 (80.6%)	26.0 (78.8%)	36.0 (48.0%)	28.0 (82.4%)	45.0 (83.3%)	24.0 (68.6%)	247.0 (71.6%)	
Single	15.0 (38.5%)	4.0 (10.3%)	7.0 (19.4%)	7.0 (21.2%)	34.0 (45.3%)	6.0 (17.6%)	9.0 (16.7%)	9.0 (25.7%)	91.0 (26.4%)	
Instruction level										< 0.001[1]
Higher	3.0 (7.7%)	0.0 (0.0%)	3.0 (8.3%)	3.0 (9.1%)	15.0 (20.0%)	5.0 (14.7%)	3.0 (5.6%)	5.0 (14.3%)	37.0 (10.7%)	
No formal education	2.0 (5.1%)	2.0 (5.1%)	6.0 (16.7%)	8.0 (24.2%)	8.0 (10.7%)	8.0 (23.5%)	23.0 (42.6%)	0.0 (0.0%)	57.0 (16.5%)	
Primary	5.0 (12.8%)	11.0 (28.2%)	4.0 (11.1%)	6.0 (18.2%)	24.0 (32.0%)	5.0 (14.7%)	11.0 (20.4%)	4.0 (11.4%)	70.0 (20.3%)	
Secondary	29.0 (74.4%)	26.0 (66.7%)	23.0 (63.9%)	16.0 (48.5%)	28.0 (37.3%)	16.0 (47.1%)	17.0 (31.5%)	26.0 (74.3%)	181.0 (52.5%)	

1 Pearson's Chi-squared test, 2. Linear Model ANOVA

3.1.1.2. Land Ownership, Agricultural Assistance, Training, and Pesticide Use Experience Among Vegetable Producers in Cameroon

Table 15 shows significant differences in land ownership (p<0.0011), cultivated area (p<0.0012), agricultural assistance (p=0.0021), and training received (p<0.0011) among 345 vegetable producers in Cameroon, but not in pesticide use experience (p=0.0662). Overall, 56.5% do not own land, with the highest percentage in Dja and Lobo (97.4%) and the lowest in Ndé (17.4%). The average cultivated area is 9,729.1 m², with Ndé having the largest (37,240.0 m²) and Mbam and Inoubou the smallest (1,281.2 m²). Most production occurred on land areas of 1000–10000 m² (44.1%, n=152), followed by 100–1000 m² (31.0%, n=107), >10000 m² (16.3%, n=56), and ≤200 m² (8.6%, n=30). Agricultural assistance is lacking for 67.8% of producers, completely absent in Dja and Lobo (100%), but more common in Mbam and Inoubou (58.8%) and Menoua (44.9%). Training is limited (65.3% have not received any), entirely absent in Dja and Lobo (100%), but more frequent in Ndé (47.6%) and Menoua (43.3%). The average experience in pesticide use (7.3 years) is relatively uniform, with Bénoué (9.2 years) and Ndé (8.9 years) recording the highest averages.

Chi-square tests revealed significant associations between education level and both training ($x2=40.9$, $p<0.01$) and assistance ($x2=37.4$, $p<0.01$), indicating that higher education levels are linked to greater access to training and support. Additionally, land ownership was significantly associated with receiving advice ($x2=35.8$, $p<0.01$), suggesting that landowners may have better access to extension services.

Respondents reported an average of 7.15 ± 5.83 years of experience in pesticide use (range: 1–30 years). A Pearson correlation test showed a weak but significant positive correlation between age and experience in pesticide use ($r=0.24$, $p<0.01$), reflecting that older farmer tend to have more experience. This correlation underscores the role of age as a determinant of practical knowledge in pesticide application.

Statistical analysis showed no significant relationship between land area and training ($x2=73.1$, $p=0.31$), suggesting that access to training is independent of farm size. However, a significant association was found between farm area and training when farm area was categorized differently ($x2=107.9$, $p=0.01$), indicating that the categorization of land area influences this relationship. A Pearson correlation test revealed a weak but significant positive correlation between land area and experience in pesticide use ($r=0.16$, $p=0.01$), suggesting that farmers with larger cultivation areas tend to have more experience.

Table 3. Land Ownership, Cultivated Area, Agricultural Assistance, Training Received, and Pesticide Use Experience Among 345 Surveyed Vegetable Producers in Cameroon.

Variables	Benoue (N=39)	Dja et Lobo (N=39)	Koung khi (N=36)	Mbam inoubou (N=33)	Menoua (N=75)	Mezam (N=34)	Vina (N=54)	Nde (N=35)	Total (N=345)	p value
Land own										< 0.001[1]
No	14.0 (50.0%)	37.0 (97.4%)	22.0 (68.8%)	14.0 (66.7%)	28.0 (41.2%)	20.0 (60.6%)	21.0 (52.5%)	4.0 (17.4%)	160.0 (56.5%)	
Yes	14.0 (50.0%)	1.0 (2.6%)	10.0 (31.2%)	7.0 (33.3%)	40.0 (58.8%)	13.0 (39.4%)	19.0 (47.5%)	19.0 (82.6%)	123.0 (43.5%)	
Area										< 0.001[2]
Mean (SD)	13253.5 (21559.8)	7486.7 (5074.9)	9867.9 (13694.5)	1281.2 (2265.8)	6878.7 (11069.8)	3272.1 (5096.6)	6282.4 (10782.4)	37240.0 (44031.5)	9729.1 (19363.4)	
Range	25.0 - 80000.0	400.0 - 20000.0	200.0 - 50000.0	100.0 - 10000.0	200.0 - 50000.0	100.0 - 20000.0	20.0 - 50000.0	1000.0 - 210000.0	20.0 - 210000.0	
Assistance										0.002[1]
No	17.0 (77.3%)	15.0 (100.0%)	24.0 (85.7%)	7.0 (41.2%)	38.0 (55.1%)	22.0 (73.3%)	30.0 (68.2%)	13.0 (65.0%)	166.0 (67.8%)	
Yes	5.0 (22.7%)	0.0 (0.0%)	4.0 (14.3%)	10.0 (58.8%)	31.0 (44.9%)	8.0 (26.7%)	14.0 (31.8%)	7.0 (35.0%)	79.0 (32.2%)	
Training										< 0.001[1]
No	15.0 (57.7%)	36.0 (100.0%)	21.0 (67.7%)	13.0 (72.2%)	34.0 (56.7%)	16.0 (59.3%)	25.0 (58.1%)	11.0 (52.4%)	171.0 (65.3%)	
Yes	11.0 (42.3%)	0.0 (0.0%)	10.0 (32.3%)	5.0 (27.8%)	26.0 (43.3%)	11.0 (40.7%)	18.0 (41.9%)	10.0 (47.6%)	91.0 (34.7%)	
EOPU										0.066[2]
Mean (SD)	9.2 (8.5)	5.3 (2.3)	8.3 (7.2)	7.5 (7.2)	6.3 (6.7)	5.0 (2.9)	7.7 (3.9)	8.9 (8.2)	7.3 (6.4)	
Range	2.0 - 31.0	2.0 - 10.0	2.0 - 31.0	2.0 - 31.0	1.0 - 40.0	2.0 - 10.0	2.0 - 17.0	2.0 - 31.0	1.0 - 40.0	

1 Pearson's Chi-squared test, 2. Linear Model ANOVA, EOPU. Experiences with pesticides used

3.1.3. Crop cultivated

Figure 2 analyses the most cultivated crops and those most subjected to pesticide treatments, revealing interesting trends. Tomato (*Lycopersicon esculentum*) is the dominant crop, representing 62.3% of the cultivated samples (215 out of 345), with 61.7% (213) of these crops being treated with pesticides, highlighting an almost direct correlation between the popularity of the crop and the need for chemical protection. Pepper (C*apsicum* sp.) accounts for 34.8% of the cultivated samples (120), yet only 5.8% (102) are subjected to pesticide treatments, indicating either less intensive management or increased resistance. Potato (*Solanum tuberosum*), although cultivated by 32.2% of the samples (111), is treated with pesticides in only 14.8% of the cases (79). Conversely, crops such as cucumber (*Cucumis sativa*) and green pepper (*Capsicum* spp.), though significantly cultivated at 24.3% (84) and 23.2% (80), respectively, are only treated with pesticides in 0.9% (20) and 3.8% (16) of these cases, suggesting either natural resistance or alternative management practices.

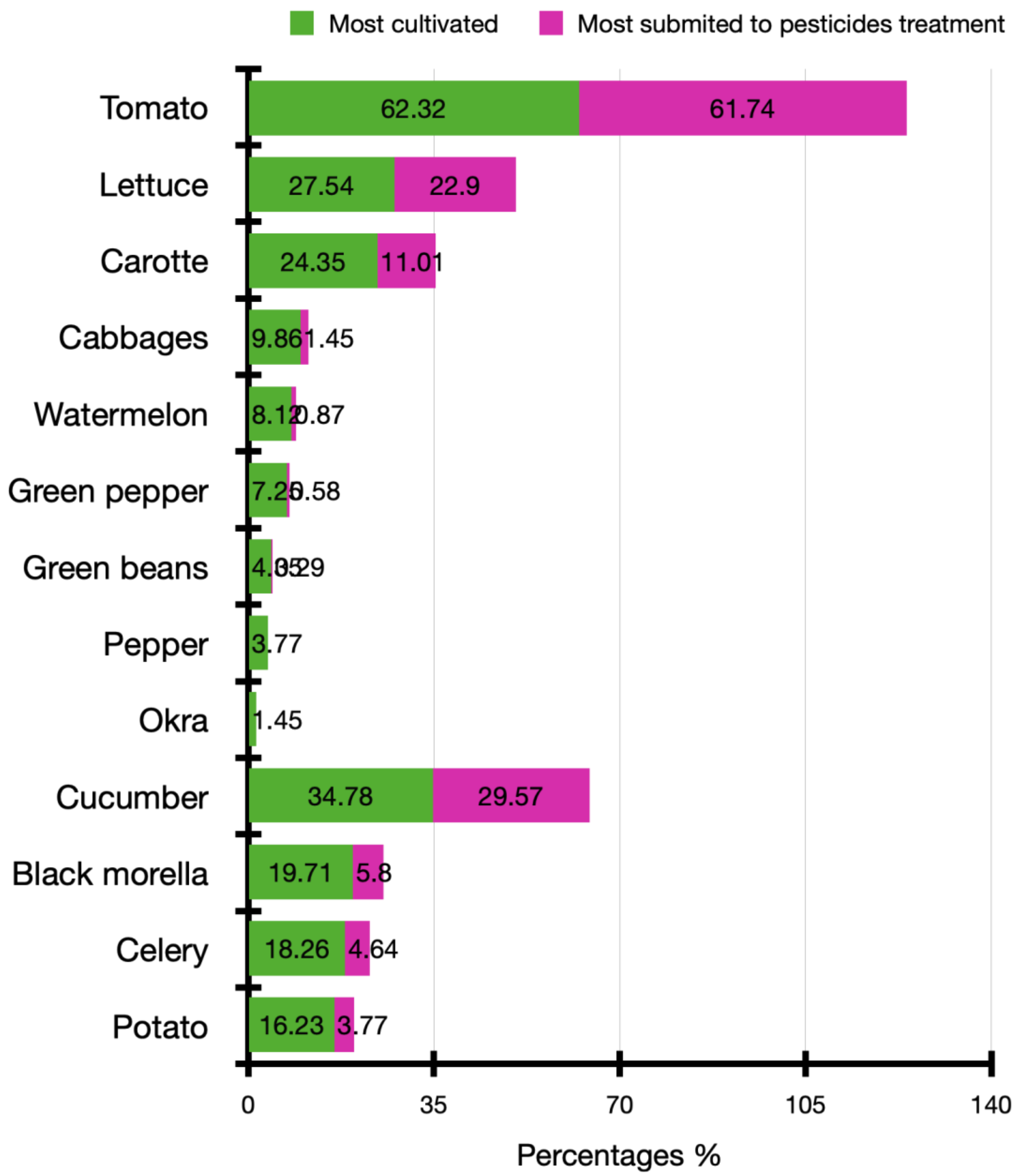


Figure 2. Distribution of farmers based on the crops produced and their answer about the most subjected crops to pesticide treatment.

3.1. Pesticide use and handling information

About 43.3% of farmers revealed that they are using pesticides to eliminate parasites during production, 34.5% used it for weeding, 10.3% in postharvest, 9.2% for the elimination of parasites of domestic animals, 2.25% for the elimination of human parasites, and only 0.37% used it for fishing. Still, a small number of farmers located in the north region (Bokle) of Cameroon have used alternative methods such as plant extract of egusi (*Allium sativum*), pepper, and neem to control unwanted organisms (insects and fungi).

3.2.1. Active ingredients of pesticides used in vegetable production

3.2.1.1. Diversity of active ingredients and their usage level

A total of 43 active ingredients of pesticides were found to be used for the control of biotic constraints in vegetable production in Cameroon (Table 3). About 46.5% were insecticides, 41.8% were fungicides, and 11.6% were herbicides. Our exploration confirmed that Mancozeb was the most used by gardeners in Cameroon (80.9% (++)), followed by Maneb (66.9% (++)), Lambda cyhalothrin (64.6% (++)), Imidacloprid (46.9% (++)), glyphosate (45.2% (++)), Abamectin (35.5% (++)), Indoxacarb, and Metiram, which was the lowest used by farmers (2.8% (+), 2.3% (+)).

3.2.1.2. Distribution of pesticide formulation

The list (Table 3) includes 108 (67 binary, 36 simples, and 5 ternary) unique pesticides, with the following distribution of formulation types: EC (Emulsifiable Concentrate) 36 (33.3%), WP (Wettable Powder) 24 (22.2%), SL (Soluble Concentrate) 15 (13.9%), SC (Suspension Concentrate) 8 (7.4%), WG (Water Dispersible Granules) 6 (5.6%), GR (Granules) 3 (2.8%), WS (Water Soluble Powder/Granules 2 (1.9%), DF (Dry Flowable) 1 (0.9%), OL (Oil-Based Liquid) 1 (0.9%), Ambiguous/No Code 12 (11.1%)

3.2.1.2. Level of hazard

Approximately 39.5% of the active ingredients are moderately hazardous (II), 18.6% are unlikely to pose an acute hazard (U) and slightly hazardous (III), and 6.9% are highly hazardous (Ib) (Table 3).

3.2.1.3. Mobility and persistence of pesticides in soil

Distribution in Soil: Mobility of pesticides in soil is influenced by the coefficient of adsorption (Koc). About 27.9% are non-mobile, 9.3% are mobile, 11.6% are moderately mobile, and 13.9% are slightly mobile. In this study, 18.6% of active ingredients are non-mobile, 11.6% are slightly mobile, and 6.9% are mobile.

Persistence: Half of the pesticides (48.8%) are non-persistent in soil, 16.2% are moderately persistent, 6.9% are persistent, and 4.6% are very persistent.

3.1.4. Pesticide procurement channels and Source of information on pesticides usage (SIPU).

3.1.4.1. Pesticide procurement channel

The outcome of our investigation indicated that those gardeners bought their pesticides from a representative of a phytosanitary company (58.1%), followed by 26.5% who bought from a phytosanitary store, 11.2% from outside sellers, and only 2.2% and 1.9% who had a pesticide provisioned for others and GIC, respectively.

3.1.4.2. Information sources for pesticide use

Information given and used by farmers at times was unavailable. They go to those who can reinforce their capacity with more explanation about pesticides and pest or disease control methods. Farmers: 42.3% took information on pesticides used from neighbors, 39.1% from commercial agents, 7.8% from agricultural agents, and 6.4% from others (Figure 3).

Table 3. Pesticides used by farmers with IARC, toxicological class, persistence, physicochemical characteristics and agrochemicals specialties.

Sr.No.	Names of actives ingredients	Chemical Family	WHO	IARC	DT_{50}(field)/ in day	Koc	Used level	Agrochemical's specialties
Herbicides (n=5)								
1	Glyphosate	A phosphonate	III	2A	6.45	1424	++	GLYPHOSATE 360SL; SPAPHOSATE 360SL; CLEAN FARM 360SL; FINISH 360SL; KALASH 360SL; LADABA 480SL; ROUNDUP 360SL; SUPER MATCHETTE 888WG; SUPER KILLER 360SL
2	Paraquat	-	III	-	2800	1X10E6	++	APROXONE 200SL; CALLOXONE SUPER 200SL; STAROXONE 200SL
3	Linuron	Phenyluree	III	-	41	842.8	+	TROMISSIL50WP
4	Prometryn	Methylthiotriazine	III	-	-	400	+	WINNER GOLD 400SC; COTOFORCE
5	2,4-D	Phenoxy alkanoic	II	2B	28.8	39.3	+	HERBEXTRA; VOLTRIL; AMISTAR 720SL; DEKAT-D 720 SL
Insecticides (n=20)								
1	Lambda cyhalothrin	Pyrethroids	II	-	26.9	283707	+++	KANNON 90 EC; GALAXY 80 EC ; PACHA 25 EC; LYNX 50 EC PLUSFORT 45 SC; DIAMANT 35 EC ; COFRESH GOLD 90 EC ; JUMPER 75 WG ; KILLAN 50 EC ; K-OPTIMAL 50 EC ; LAMBDA SUPER 2.5 EC ; PARASTAR 90EC, AMIDA80WP ; GREFONSEC COMPLEX 210 WP;
2	Imidacloprid	Neonicotinoids	II	-	174	-	++	KANNON 90 EC; COLIBRI 30 SL ; GALAXY 80 EC ; COFRESH GOLD 90 EC; LAMIDA GOLD 25EC; INSECTOR T WG; SAPHIR 60WS; IMIDALM T 450WS; GREFONSEC COMPLEX 210 WP; KOHINOR STAR
3	Abamectin	Avermectins	Ib	-	1.0	-	++	BOMEC 18 EC, ABALONE 50EC; ABAMEC 50EC;
4	Fipronil	-	II	-	65	-	++	FIXE 50 EC; DIAMANT 35 EC
5	Cypermethrin	Pyrethroid	II	-	21.9	307558	++	CYPER 50 EC; CICAPSIDS 50 SC; ALPHACYGA 180 EC; CYPERCOT 200EC; ONEX SUPER 40 EC; CYPERCAL 50EC; CYPERMAX 336EC; EPERVIER 220EC; EMIR FORT 104 EC; PACHA 25 EC; TROPISTAR 336 EC; CIGONE 40EC, CYPERMULK 50EC; PREDATOR 46 SC
6	Acetamiprid	Chloronicotiniles	II	-	3	200	+	PACHA 25 EC; LYNX EC; ONEX SUPER 40 EC ; JUMPER 75 WG ; K-OPTIMAL 50 EC ; CALLIFARM SUPER 40 EC; DIAMANT35 EC
7	Emamectin benzoate	O.substance	NL	-	1.1	377000	+	EMACOT 50 WG; GREMEC 50 WG; CAIMAN B 50WP
8	Thiametoxam	Neonicotinoids	NL	-	39	56.2	+	MOCAP GR; BASTION SUPER GR
9	Ethoprophos	Organophosphate	Ia	-	1.3	70.0	+	PLUSFORT 45 SC
10	Methomyl	Carbamate	Ib	-	-	72	+	SAVAHALER 250 WP;
11	Chlorpyriphos-ethyl	Organophosphate	II	-	-	-	+	EPERVIER 220EC; PYRICAL480 EC
15	Chlorantraniliprole	Pyridylpyrazole	U	-	204	362	+	CORAGEN 20 SC
16	Profénofos	-	II	-	-	-	+	PROFENOCOT500EC
17	Chlorpyrifos	Organophosphate	II	3	27.6	5509	++	CHLORPIRIFOS 50EC, PYRIFOS 80EC
13	Triazophos	-	II	-	-	-	+	TROFORT 400EC
14	Bifenthrin	Pyrethroid	II	-	86.8	236610	+	BISTAR WP; ACETASTAR 46EC; CALLIFARM SUPER 40 EC; KOHINOR STAR
18	Thiacloprid	Thiazolidine		-	8.1	-	+	PREDATOR 46 SC; PROACTIV A 46 EC
12	Ametoctradin	Triazolopyrimidine	NL	-	19.7	7713	+	ORVEGO
19	Oxamyl	Carbamate	II	-	6.0	14.91	+	BASTION SUPER; FURAPLANT SUPER; FURADANT SUPER 10G; OXAM 240SL;
20	Indoxacarb	Oxadiazine	II	-	5.97	4483	+	MORAN 30 DF;

Fungicides (n=18)								
1	Mancozeb	Dithiocarbamates	U	-		998	+++	MANCOSTAR 80 WP; PENNCOZEB 80 WP; BAOBAB 80WP; MANCO-SAM 80WP; MANCOZAN 80WP; IVORY 80WP; AGROZEB 80WP; MANCOZEB 90EC; TERAZEB 80WP; KOZEB 80WP; AGRIZEB 80WP; AGREB80WP
2	Maneb	Dithiocarbamates	U	3	7	2000	+++	PLANTINEB 80 WP; PLANTIMA 80WP
3	Metalaxyl-m	Anilide	III	-	14.1	-	++	COLLAMIL 66WP; NORDOX 66WP ; SINOMIL480SL
4	Copper oxid	Minerals	II	-	-	-	+	NORDOX 66WP; EA GROWTH CARE 720WP; RIDOMIL GOLD 66WP
5	Copper sulphate	Minerals	II	-	1600	9500	+	GOLDEN BLUE;
6	Chlorothalonil	Chloronitriles	U	2B	3.5	-	+	BONSOIN WP; TROPIK 720 SC; BANKO PLUS ;BRAVO720 SC
7	Dimethomorph	Morpholine	III	-	44	-	+	EA GROWTH CARE 720WP; DIMETALM GOLD; ORVEGO
8	Cymoxanil	C-acetamide oxime	II	-	3.5	-	+	FONGIPRO
9	Mefenoxam	-	-	-	-	-	+	RIDOMIL GOLD 66WP
10	Carbendazim	-	U	-	-	-	+	BANKO PLUS; GREFONSEC COMPLEX 210 WP
11	Pyraclostrobin	Phenylpyrazole	NL	-	33.3	9304	+	COMET PLUS
12	Thiram	Carbamate	II	3	15	-	+	BANGUARD 45SC; INSECTOR T WG; SAPHIR 60WS; IMIDALM T 450WS
13	Fenpropimorph	Morpholine	III	-	25.5	-	+	COMET PLUS, VOLLEY 880L
14	Triadiméfon	Phenylpyrrole	III	-	-	-	+	TROPICAL 250 OL
15	Copper oxychloride	Minerals	II	-	-	-	+	PARASOL; FONGIPRO
16	Difenoconazole	Triazole	II	-	91.8	-	+	ONAZOL 100EC; PALADIUM 250EC,
17	Azoxystrobin	Strobilurins	U	-	180.7	589	+	BANKIT 250SC;
18	Metiram	Carbamate	U	-	7	903012	+	KERN WG

IARC (International Agency for Research on Cancer) / Ib, highly hazardous; II, moderately hazardous; III, slightly hazardous, U, Unlikely to pose an acute hazard in normal use, NL (Not listed), / Group 1—Carcinogenic to human, Group 2A—Probably carcinogenic to human, Group 2B—possibly carcinogenic to humans, Group 3—Not classifiable, Group 5—Probably not carcinogenic to humans (WHO, 2021). DT_{50} (≤30 non-persistent; 99≥P≥30 slightly persistent; >100 persistent), Koc, Kc (>5000 Immobile, 2000-5000 slightly mobile, 500-2000 Moderately mobile, 150-500 Intermediate mobility, 50-150 highly mobile, 0-50 Very mobile). Frequency of utilisation: +++ (used by more than 200 farmers), ++ (Between 10-100 farmers), + (Between 100-200).

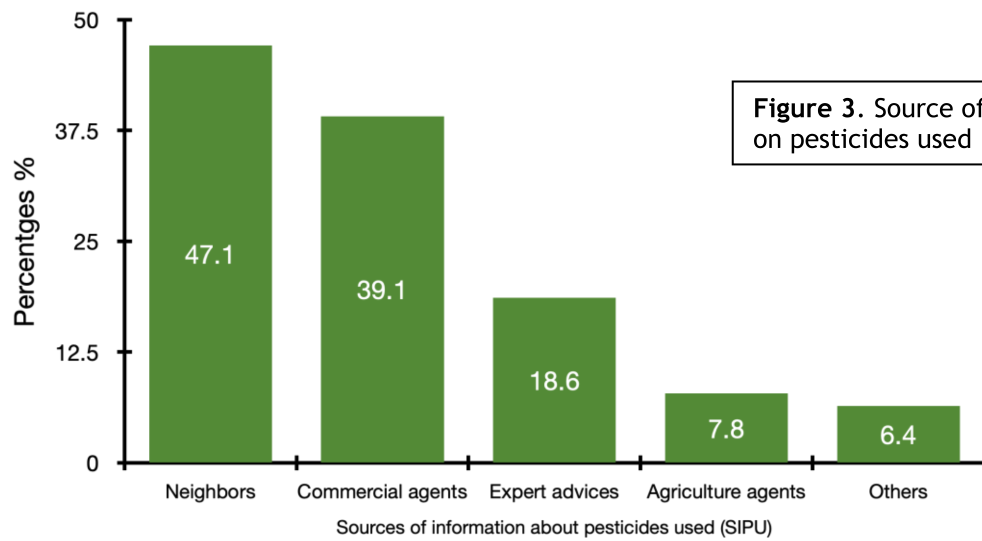


Figure 3. Source of information on pesticides used (SIPU).

3.1.5. Pesticide preparation and spraying equipment

Stickers have been considered the identification card of the pesticides, providing much information necessary for good handling. In fact, to reduce adverse effects on humans, the environment, and biodiversity. In developing countries, the pesticide label is the primary, and sometimes the single, source of risk communication between the manufacturer and the end-user (FAO, 2022). About 55.7% of farmers revealed that they did not respect information on pesticide stickers, 35.1% said they respected it, and only 9.1% said they were not sure. During our investigations, farmers revealed that, using information on the manufacturers, pests and diseases are not well controlled; they always develop their strategies (increasing dose, increasing frequency, mixing pesticides with fertiliser, and fixing) with the chemical to reduce their activities.

The study showed that 80.4% of farmers used pesticides in mixed formulations, whereby they mixed several pesticides in a single tank or sprayer and applied them; 7.6% prepared pesticides depending on the manufacturer's recommendation, and only 11.9% revealed that they mixed the pesticides. The farmers also added liquid nutrients and adhesive substances to their mixtures. While nutrients were added to increase growth rates, adhesive products were included to increase the contact time of pesticides on leaves and fruits as a means to increase their effectiveness. The survey indicated that 97% of farmers measured pesticides with improvised implements—spoons, tin cups, pesticide lids, cups, or beer bottles—highlighting a lack of precision in application. Field discussions further revealed that some farmers dismissed the need for standardized tools, attributing this to their observation of inconsistent pesticide efficacy on their crops.

Knapsack sprayers were the most used by farmers in gardening (79.1%), followed by motorised sprayers (12.6%), watering cans (8.4%), and 7.1% used non-recommended instruments such as brooms, branches of trees, wood, and leaves for splash pesticides; no trailed sprayers or drones were identified during our investigation. Sprayers used by farmers (Matabi, sprayers, Inter, Farmcare, etc.) were generally for the farmers or the workers on the farm, and at other times, they were obtained from friends or rented.

3.1.5.1. Dose and frequency of pesticide use by farmers

The study revealed that 44.1% of farmers spray pesticides depending on the spraying calendar, 41.3% apply pesticides at the moment that they detect the presence of pests and diseases, 6.9% spray depending on the infestation level, and 7.7% use other timings. We observe that farmers did not have any idea or alternatives to reduce pesticide use. About 45.2% revealed that pesticide dose prescriptions by manufacturers are not efficient.

Because of the lack of measuring tools, many chemicals are measured using the same tools at the same dose. Our analysis confirmed that many gardeners did not respect the dose of pesticides. 44.50% had not received any training on pesticide use; for those who respected the dosage of pesticides without training, a percentage of 22.56% of Cameroonian gardeners was identified. A frequency of 13.33% of farmers did not respect pesticide dosage, even though there were trainee gardeners; 13.04% respected the dose after receiving training on pesticides used. No relationship was identified between training and dose of pesticides (X^2=2.36, p=0.123). 44.34% of farmers without assistance did not respect the dose of pesticides, and 32.65% respected it. With advice, 13.04% did not respect the dose of pesticides, and 9.85% respected it. The chi-square test revealed that doses were not influenced by assistance (X^2=0.008, p=0.92).

Concerning the frequency prescribed by the manufacturers, 74.0% revealed that it was good and 26.0% said it was not good. But 80.29% of farmers used a frequency between one or two time per week {(1-2)/7}, followed by 12.46% once per week (1/7), 6.67% two or three time per week {(2-3)/7}, and only 0.58% sprayed more than three time per week (> 3/7) (figure 4). Our exploration confirmed that the pesticide application frequency is 2±0.44 on average, with a maximum of 4 and a minimum of 1. For trainee gardeners in Cameroon, 58.84% spray (1-2 (7), 8.98% spray (1/7), 5.21% (2-3/7), and only 0.57% spray more than (3/7). For those who received training, 21.44% sprayed (1-2/7), 3.47% (1/7), 1.44% sprayed (2-3/7), and no trainee farmers sprayed more than 3/7 (X2=1.55, p=0.48). Farmers advised spraying pesticides (1-2/7) 62.31%, followed by 9.56% (1/7), 4.63% (2-3/7), and 0.57% (>3/7). With advice, most farmers (17.97%) spray pesticides (1-2/7) (X2=1.77, p=0.34).

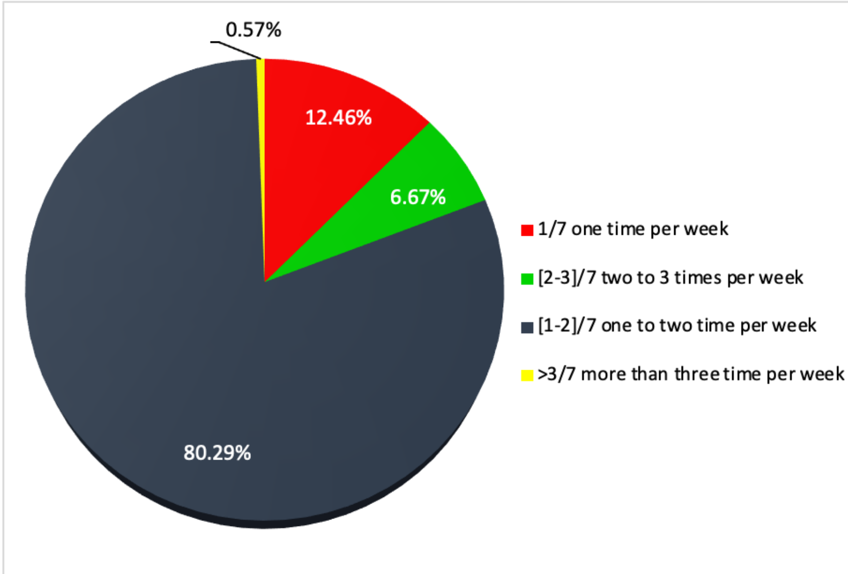


Figure 4. Distribution of farmers according to the different frequencies of pesticides.

3.1.4.2. Treatment frequency index (TFI) of gardener crops in Cameroon

The analysis of treatment frequency index (TFI) across garden crops reveals highly significant differences (ANOVA P-value of 0.03 for the mean number of sprays and 0.00 for mean TFI) (Table 4), confirming substantial variations in pesticide application practices among crops. The results show that tomatoes exhibit a high mean TFI of 34.5±7.67, with considerable variability (ranging from 19.16 to 49.84), indicating intensive pesticide management. Potatoes follow with a mean TFI of 14.7±6.82, while crops such as green beans and celery have notably lower TFIs of 3.4±0.45 and 3.4±0.43, respectively, reflecting less frequent pesticide applications. Green pepper and cucumber, with mean TFIs of 12.9±12.71 and 6.78±13.65, show substantial intra-crop variability in treatment frequency, ranging from 3.7 and 3.89 to maximums of 38.3 and 34.05, respectively. This variability, coupled with an average spray count of 17.5±5.43 for green pepper and 12.5±5.74 for cucumber, suggests highly divergent pest management strategies among growers. Crops like watermelon (7.3±8.93) and carrots (5.89±10.8) also exhibit a wide range of TFIs (from 0 to 25.16 and 27.49), indicating that some plots receive few or no treatments, while others are heavily treated.

Table 4. Treatment frequency index (TFIs) of each crop produced by gardeners in Cameroon.

Crops	MNS	TFI mean	TFI Min	TFI Max
Tomato	30±10.53[a]	34.5±7.67[a]	19.16	49.84
Potato	25.8±8.44[ab]	14.7±6.82[b]	1.1	28.3
Green pepper	17.5±5,43[b]	12.9±12.71[b]	3.7	38.3
Pepper	17.5±1,23[b]	8.75±2.90[c]	2.95	14.55
Green beans	8±3,20[d]	3.4±0.45[d]	2.5	4.3
Cabbages	16.5±8.41[b]	9.4±3.87[c]	1.66	17.14
Watermelon	7±1.40[d]	7.3±8.93[c]	2.09	25.16
Cucumber	12.5±5,74[bc]	6.78±13.65[c]	3,89	34.05
Celery	10±1,9[c]	3.4±0.43[c]	2.54	4.26
Lettuces	7±4.59[d]	4.89±1.34[c]	2.21	7.57
Carrot	14.5±1.30[bc]	5.89±10.8[bc]	1.5	27.49
Okra	12.5±1,20[bc]	5.78±1.24[c]	3.30	8.26
Black nightshade	16.5±6.71[b]	12.8±1.45[b]	9.9	15.7
P-value ANOVA	0.03	0.00	-	-

MNS. Mean number of sprays of the crop during the whole cycle, TFI. Treatment frequency index. Means with different letters are significantly different according to Turkey's statistical test.

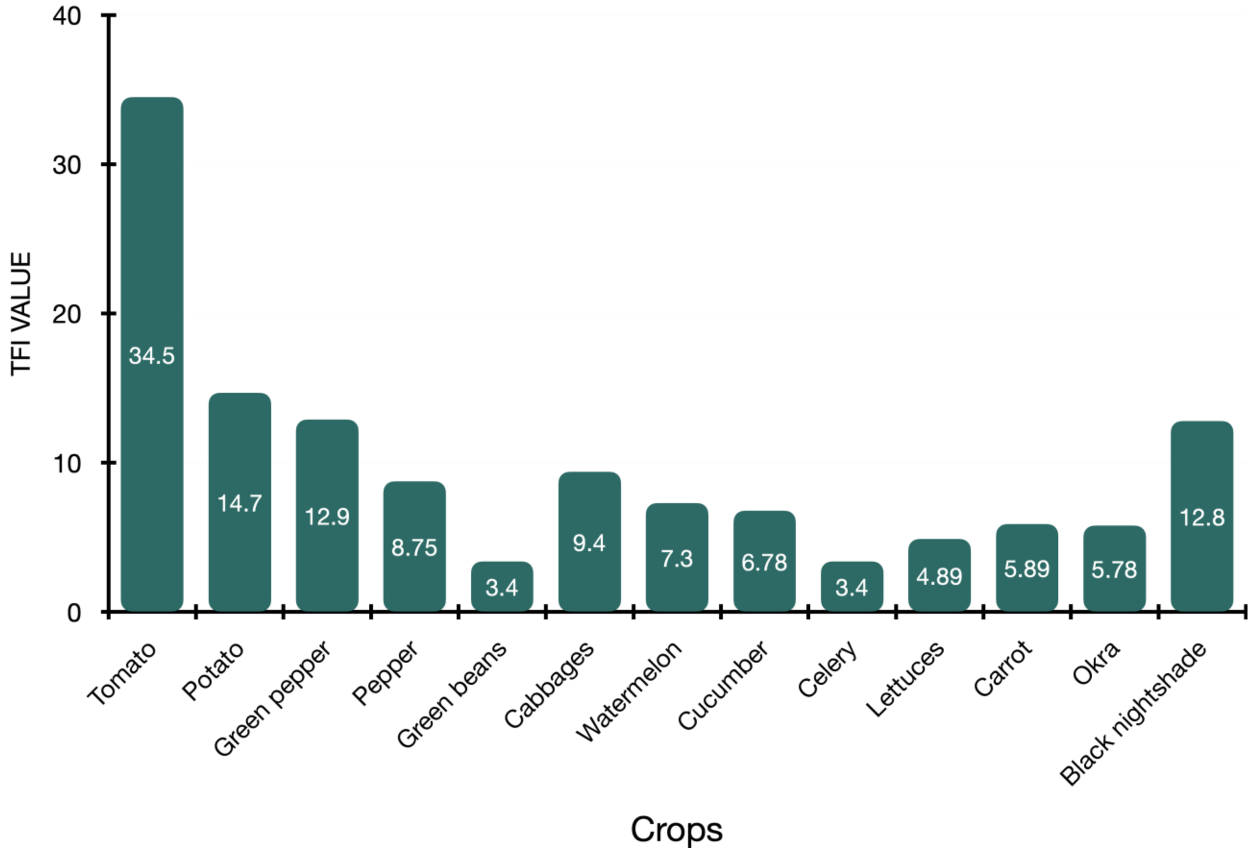


Figure 5. Treatment frequency index of vegetables crops produce in Cameroon.

3.1.5.2. Factors influencing the use of pesticides

Figure 6 below illustrates the influence of certain subjective factors on pesticide use. According to the results, the first canonical axes represent approximately Dim128.2% of the variance in characteristics related to pesticide use, while the two axes together account for Dim2 16.7%. The results of the ACM reveal that the level of education, training, divisions, assistance, and experience in pesticide use (EOPU) are key factors associated with pesticide use among producers in Cameroon. Producers with higher levels of education, benefiting from training and assistance, and generally having over 10 years of experience in pesticide use (EOPU), tend to adhere to pesticide doses within the Menoua division.

Conversely, producers with secondary and primary education, lacking adequate assistance or training in pesticide use and mostly belonging to the Nde and Mezam divisions, tend to use pesticides at frequencies exceeding 3 times per week and not adhere to recommended doses. These results highlight the importance of education, assistance within divisions, and training sessions to promote more sustainable agricultural practices and reduce pesticide exposure among farmers. Producers receiving assistance from agricultural and commercial agents tend to adhere to pesticide doses with frequencies ranging from 1 to 2 times per week, while those receiving advice from neighbours do not adhere to pesticide doses for the most part.

The analysis revealed significant differences in pesticide use between producers with access to technical assistance and training and those without, suggesting that public policies should focus on strengthening agricultural extension services to help producers adopt safer and more effective practices.

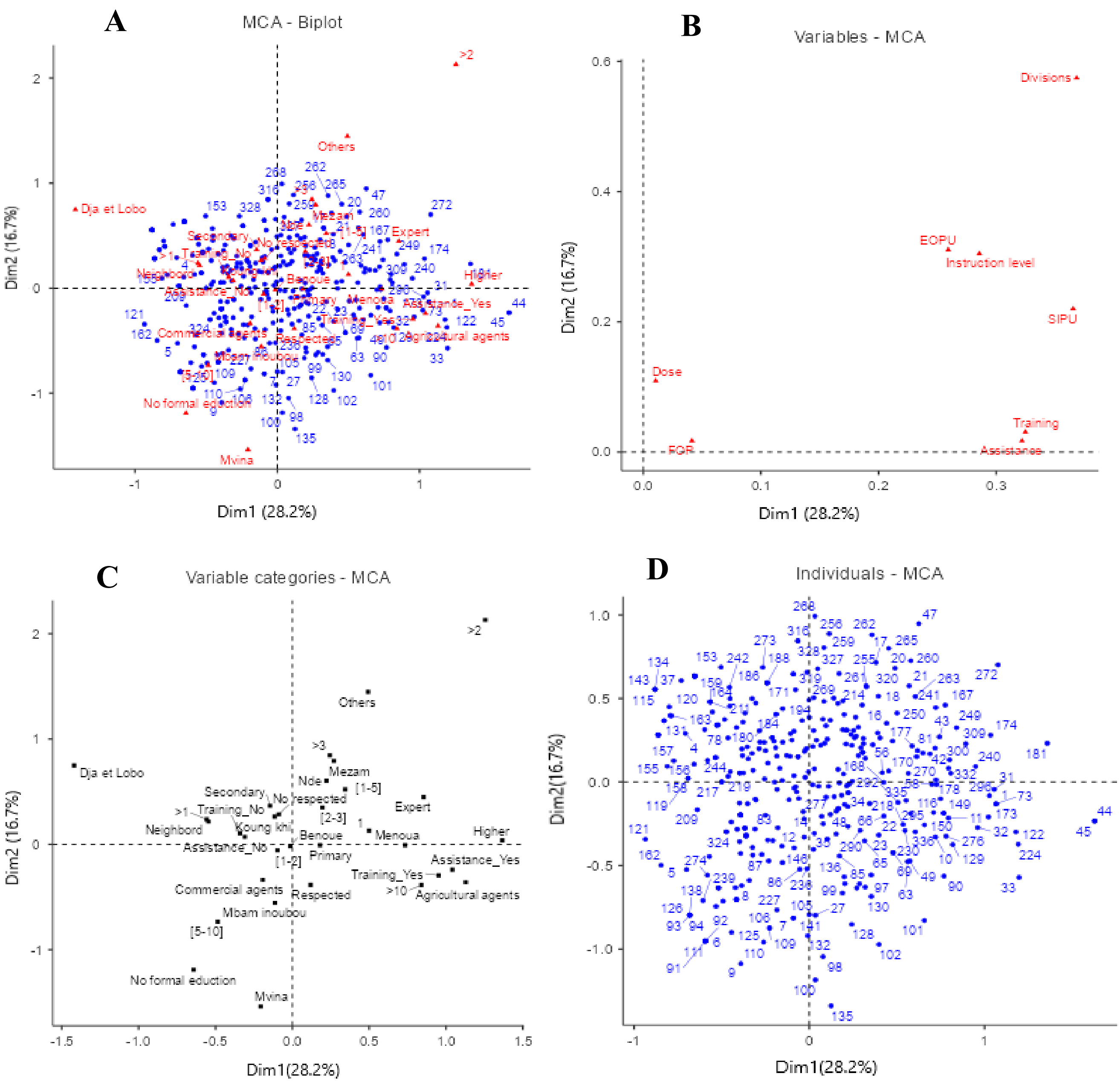


Figure 6. MCA Biplot (A), Variable-MCA (B), Variable Categories-MCA (C), and Individual-MCA (D): Exploring Factors Influencing Pesticide Usage Among Producers. The first two canonical axes (Dim1 and Dim2) are represented in the vertical and horizontal directions, respectively. FOP: Frequency of Application; SIPU: Sources of Information on Pesticides Used; TBH: Time Before Harvest; REI: Restricted Entry Interval; EOPU: Experience On Pesticides Used.

3.1.6. Pesticide application practices: timing, environmental security measures, and handling behaviour

3.1.6.1. Timing of application

About 42.8% of farmers spray pesticides in the morning, usually between 6 am and 9 am; 40.3% spray at any moment of the day; and only 16.9% apply pesticides in the evening. A chi-square test showed that there is a significant relationship between the moment of application and experience with pesticide use, assistantship, and training (X^2=130.2, p<0.01), (X^2=18.4, p=0.018), and (X^2=25.4, p<0.01).

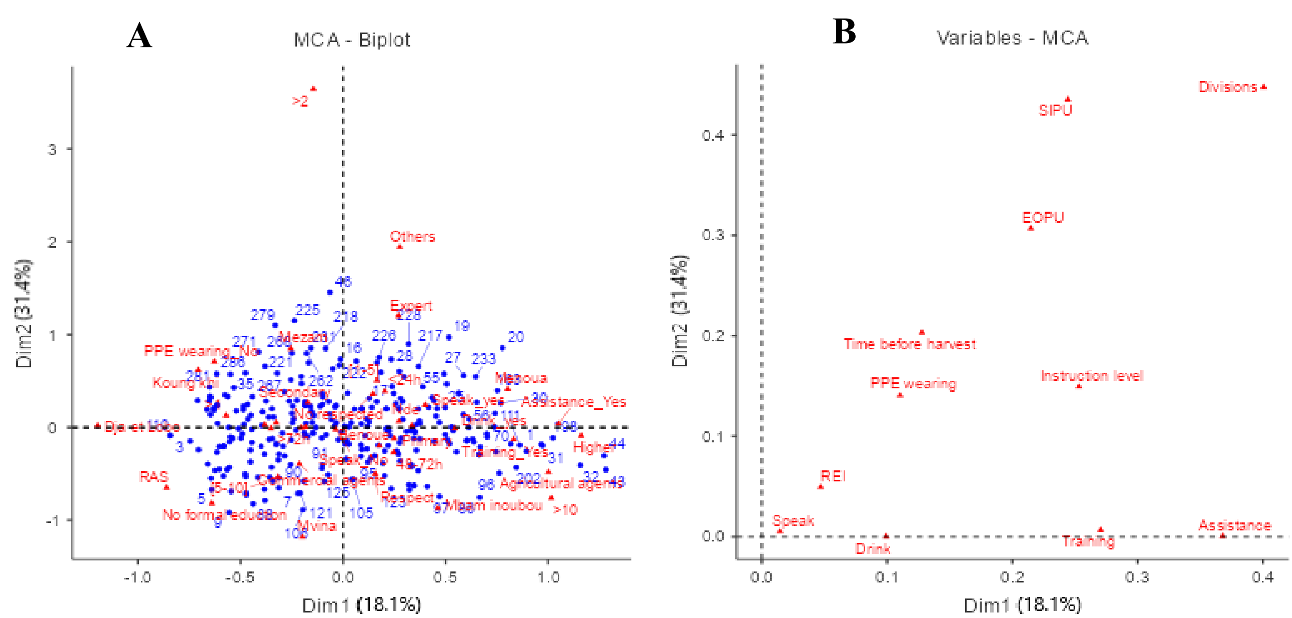
3.1.6.2. Environmental security measures

According to the wind direction, 49.2% of the farmers spray pesticides in the direction of the wind, 32.0% apply pesticides in the absence of the wind, 11.3% did not consider wind direction during spraying, and 7.5% apply pesticides against the wind direction.

Approximately 98.3% spray chemicals at a distance >100 m from habitats, and 1.7% apply at a distance <100 m from habitats. The study shows that 62.2% of the farmers construct their nurseries near rivers. Generally, the farmers spray pesticides to control pests that affect the growth of the seedlings. During our investigation, we found that the majority (100%) don't have data information about the quality of water related to pesticide utilisation. All the farmers revealed that they are not aware of local regulations regarding pesticide use and don't have information about international standards for pesticide use.

3.1.6.3. Behaviour during pesticide handling

The study further reveals that during pesticide handling, 75.2% did not drink, and 24.8% of farmers did drink. About 98.2% of their farmers did not carry children during the handling of pesticides; 1.8% carried children when they sprayed pesticides. The majority (92.4%) of them did not speak during pesticide application, while 7.6% revealed that at some moment they spoke during pesticide handling. Figure 7 represents the relationship between sociodemographic characteristics and habits developed during pesticide use. The first canonical axes account for approximately Dim1=18.1% of the variation in the relationship between behaviour and sociodemographic characteristics, while the first two axes together represent about Dim2=34.1%. The results from Figure 6 indicate that EOPU, assistance, instruction level, training, and SIPU influence farmers' habits during pesticide use. Farmers with 1-5 years of experience do not adhere to TBHs, while those with 5-10 years of experience do follow TBHs. Our study reveals that depending on the SIPU information source, farmers who rely on experts as their information source tend not to follow TBHs. In contrast, those relying on agricultural extension agents adhere to TBHs. The study shows that farmers with higher education and primary education levels drink during spraying sessions. Farmers with more than 10 years of experience do not drink during spraying. Producers with primary and higher education levels have an REI of less than 24 hours, while those with secondary education are associated with an REI of more than 72 hours.



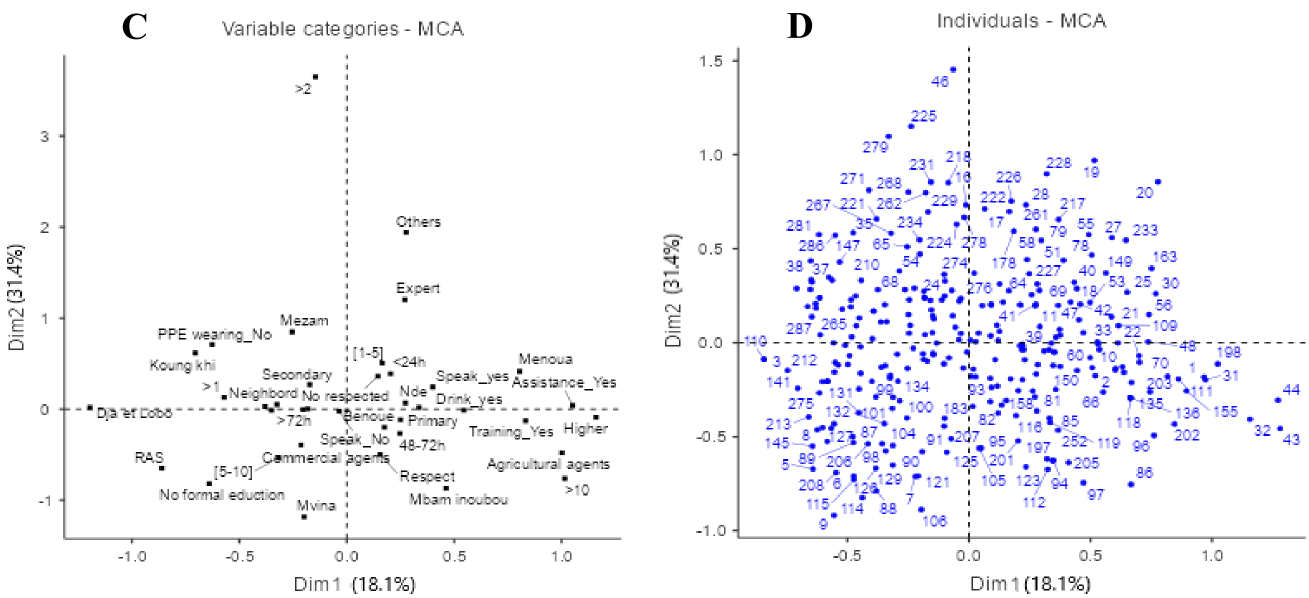


Figure 7. MCA Biplot (A), variable-MCA (B), variable categories-MCA(C), and individual-MCA (D). Exploring Correlation Factors influencing behaviour during pesticide handling: Insights through the Correlation Circle, the first two canonical axes (Dim1 and Dim2) are in the vertical and horizontal directions. The arrows represent variables of different variables. PPE: Personal Protection Equipment; FOP: Frequency of application; SIPU: sources of information on pesticides used, TBH: Time before Harvest, REI: Restricted entry Interval.

3.1.7. Post-application activities

3.2.4.1. Time before harvest (TBH) and restricted entry interval (REI)

Most pesticide sprayers (52.0%) go into the farm >72h after the last application of pesticides, 27.6% enter the farm after 48-72h, and only 20.3% go into the farm after <24h. The majority (59.6%) were harvested after a few days, 25.3% during a few weeks, and 15.1% don't know. During further exploration, it was identified that those farmers located behind DAADER generally used 7 days for TBH after spraying lettuce. The result showed that assistance and training are factors that highly influence the time before harvest (X^2=39.2, p<0.01) (X^2=17.6, p<0.01). However, there was no relationship with REI (X^2=6.1, p=0.4) or (X^2=4.8, p=0.56). This indicates a need for training and assistance for farmers to understand the importance of adhering to the time before harvest (TBH).

3.2.4.2. Storage of pesticides and disposal of empty pesticide containers

Most farmers (54.1%) preferred to keep their chemicals at home in a dedicated storage room, precisely in the kitchen, close to the cupboard, and in the room; only 25.9% preferred to keep their pesticides near the crops, 9.6% in an agricultural shed, and 10.4% in others (underground storage facility, warehouse, etc.). Our exploration shows that farmers have specific storage locations (68.9%) and conserve at many places (31.1%). To ensure the security of pesticide storage, 77% of them make regular monitoring, and 23% use secure locking. The study related that farmers can dispose of the pesticides very well if they have a good source of information and training (X^2=55.5, p<0.01), (X^2=14.3, p<0.01). Generally, farmers kept pesticides with other chemicals in the same place. During the investigation, it was identified that farmers in the south region, non-indigenes of the region, kept pesticides and other farm materials in their rooms. However, 61.4% of the farmers also reported disposing of leftover pesticide solution or old pesticide stocks on-farm in the mixing container, 45.2% redistributed the rest on the farm, 13.6% stored the rest in a hole on the farm, and only 7.2% and 4.6% stored it in the plastic container and diluted and redistributed it elsewhere, respectively. A chi-square statistical test showed that this variable was related to experience with pesticides used (X^2=1467.1, p<0.01), sources of information on pesticide use (X^2=918.2, p<0.01), and training (X^2=100.3, p<0.01). Some pesticide applicators (49.1%) preferred empty pesticide containers being left on farmland, 25.0% signalled that they burnt them after utilisation, 8.6% conserved them in the dump, 6.1% cleaned them for reuse at home for different purposes such as water storage, oil conservation, cereal conservation, and wine, 5.5% threw them in waste dumps, while only 3.5% and 2.2% threw them in rivers and other places, respectively.

3.1.8. Use of personal protective equipment (PPE)

Farmers wearing inappropriate PPE or no PPE at all are mostly affected by pesticide exposures (Miyittah et al., 2020; Wumbei et al., 2019). In fact, this current study identified that in Cameroon, vegetable producers mostly wear boots (65.8%), normal clothing (62.9%), nose masks (27.2%), plastic gloves (24.9%), impermeable combinations (17.4%), shoes (11.6%), glasses (9.6%), and caps (8.7%).

Our exploration shows that there is no restriction according to the type of PPE; men and women can wear the same type of PPE (X^2=101.4, p=1.0). The chi-square statistical test highlights that there is an association between age and type of PPE worn (X^2=3875.2, $p<0.01$), as older farmers are very sensitive to heated coveralls and nose masks. In the course of the study, it was revealed that farmers preferred to wear free pants and shirts to spray pesticides. Experience on pesticide use (EOPU) highly influences the type of pesticides that are used. In fact, farmers who have experience with pesticide use are already aware of the negative effects of pesticides and the level of PPE needed to avoid uncomfortable situations during pesticide handling (X2=2019.6, $p<0.01$).

Assistance and training processes are mostly associated with the use of pesticides (X^2=230.5, $p<0.01$) (X^2=277.8, $p<0.01$). Frequency developed by farmers is a factor that influences the type of PPE used (X2=213.2, $p<0.01$). In fact, when the farmers use pesticides more and regularly, they can use normal clothes or change clothing every day because of farm activities. In fact, when the frequency of application is respected, farmers have the time to clean the PPE after use and dispose of it properly for further activities. The study further revealed that about 39.0% of the farmers use pesticides for protection against pests and diseases, 34.4% for ease of work and to protect themselves against unwanted organisms, 12.6% use them to control animal birth, while 1.5% have given no answers.

3.1.9. Type of symptoms and factors influencing the health of vegetable farmers

Pesticide spraying has caused many cases of health problems suffered or reported by vegetable producers. However, the majority of farmers (88.6%) have already observed or suffered some illnesses during and after pesticide handling in the field; 11.4% revealed that they have not suffered any illnesses caused by pesticides. Men farmers are mostly subjected to pesticides on their health (73.4%), and women (15.6%). Women are most susceptible to developing health issues due to pesticides used (OR = 1.09 (0.39, 7.80), p = 0.01). PPE wearing (OR=5.86, 95% CI: 2.62 to 13.09) and the lack of assistance (OR=0.28, 95% CI: 0.12 to 0.65) are significant factors influencing health experience. Training, although not significant, shows a tendency to improve health experiences (OR=2.26, 95% CI: 0.84 to 6.047).

Several types of illnesses linked to the use of pesticides are frequently found in the vegetable producers' area and can affect different parts of the farmers, such as the body, digestive tract, head, sex organs, and respiratory system. The most common diseases affecting pesticide users in Cameroon are dizziness (54.0%), followed by tiredness (53.90%), runny nose (50.40%), eyes itching (46.10%), and cough (41.10%) (Figure 8).

With regards to the route of entry of pesticides into the human body, 34.8% of the farmers mentioned the skin (mostly by irritation), 44.8% mentioned the digestive tract (which is mostly associated with vomiting, appetite loss, nausea, stomach discomfort, and diarrhoea), 2.6% mentioned the eye (mostly associated with lachrymation), while 51% mentioned the respiratory tract (affected by cough and dizziness). Many of the farmers also suffer from a few long-term effects (some farmers in the south region were having skin irritation for more than two weeks after spraying Croison X + Glyphader without recommended PPE, but with normal clothes).

Our exploration showed us that experiences on health have been associated with certain spatial and subjective variable divisions (X2=77.86; $p<0.01$), gender (X2=5.52; p=0.019), age (X2=3.48; $p<0.01$), matrimonial status (X2=28.03; $p<0.01$), and instruction level (X2=14.45; $p<0.01$). Behavioural factors of our study showed that PPE wearing was the factor that was mostly associated with the experience of health (X2=18.81; p<0.01), drinking (X2=1.89; p=0.39), and speaking (X2=1.62; p=0.02), having a significant influence on health.

According to Figure 9, our study showed that experience with health has been most correlated with the dosage of pesticides by farmers. Farmers who did not respect the dose of pesticides have more experience with health problems. Farmers aged between 20 and 30 years old wearing PPE have been recognised to have experience with health. The age of farmers has been correlated with PPE wearing; farmers aged between 30 and 40 did not wear PPE, while farmers of other ages wore PPEs. Farmers with experience between 5-10 years don't drink during pesticide handling. Farmers with EOPU >10, >20, and >3 years old drink and speak. Farmers who spread pesticides 1/7 drink and speak during pesticide applications.

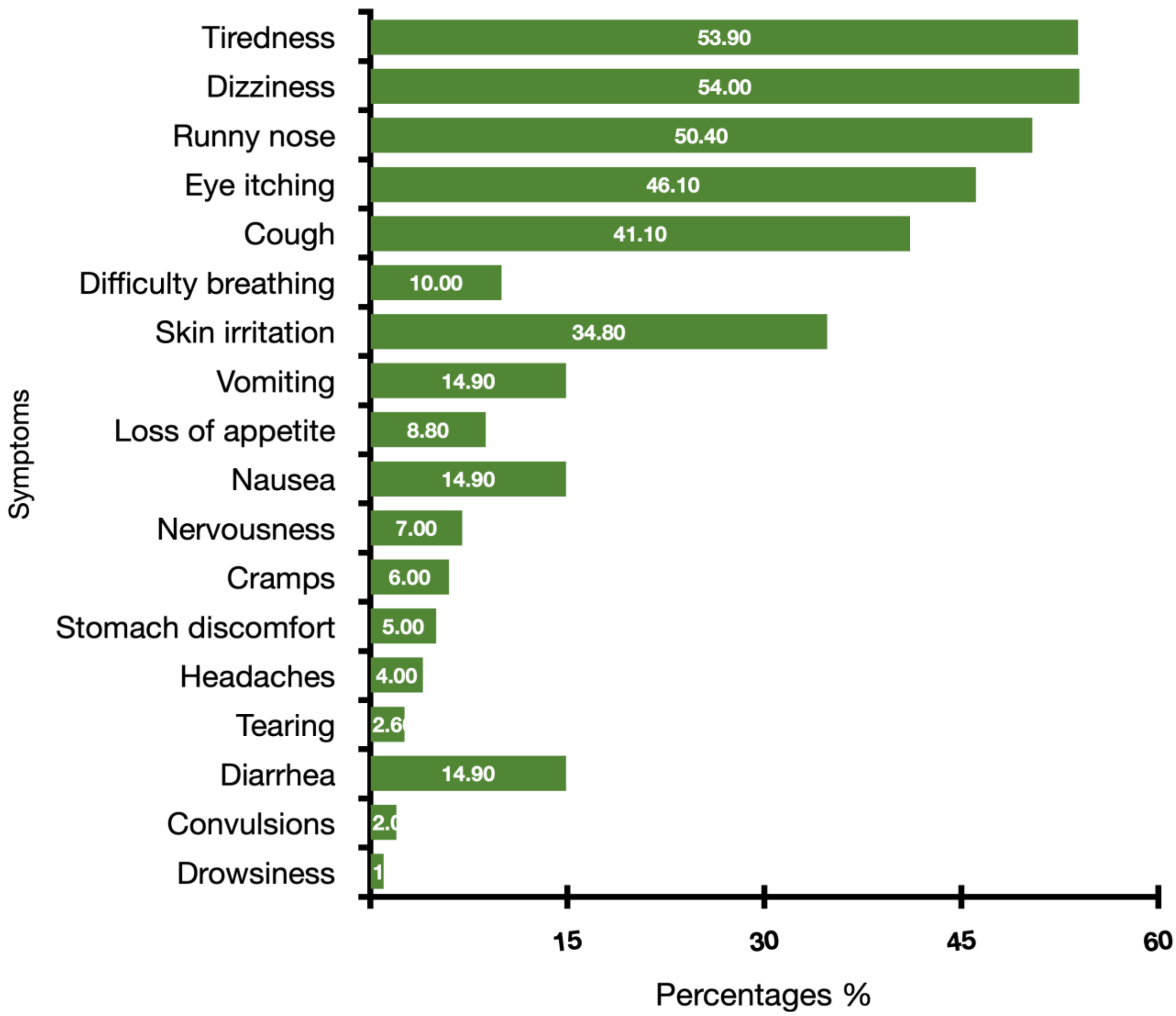


Figure 8. Adverse effects of pesticides on health.

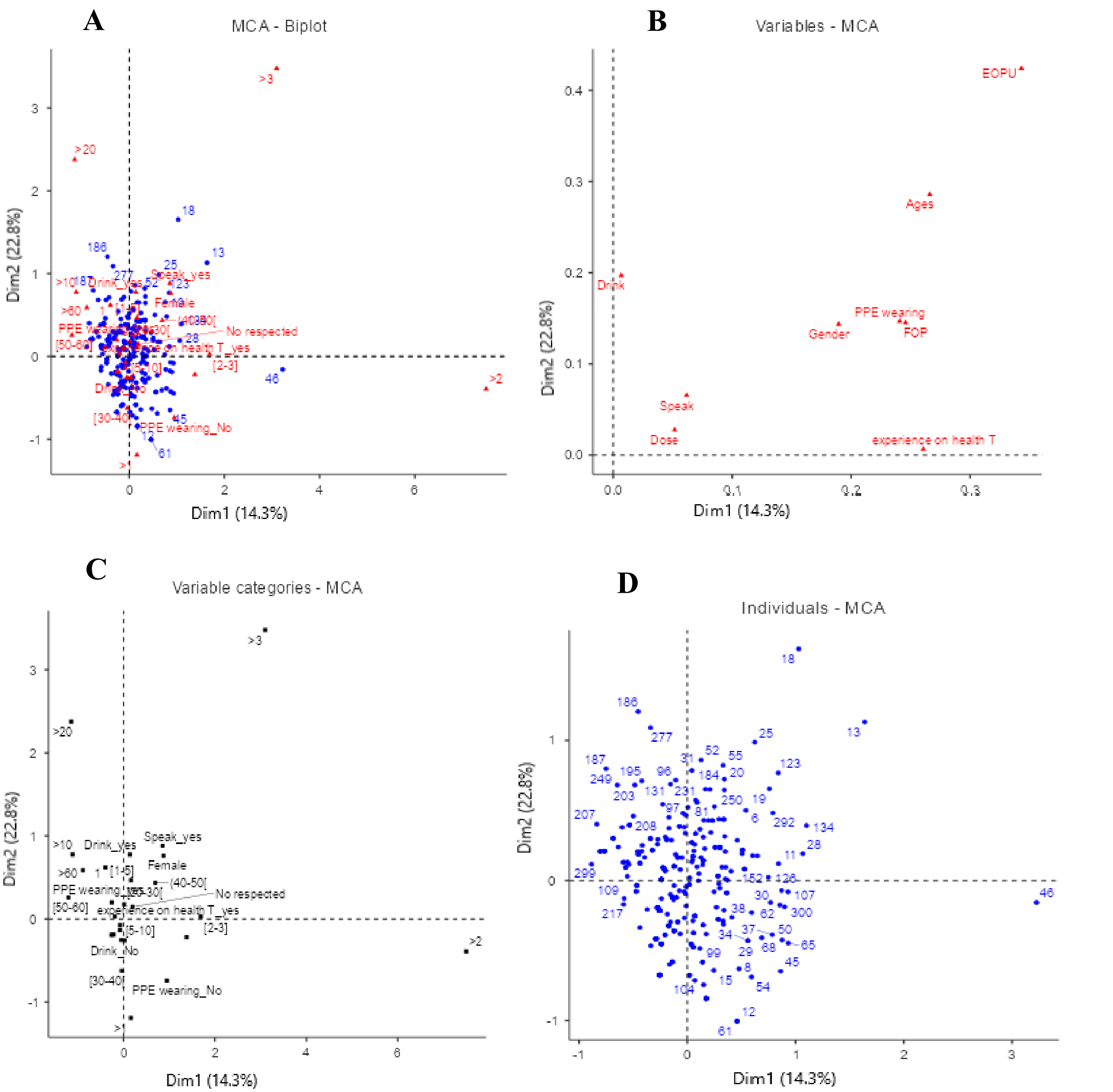


Figure 9. MCA Biplot (A), variable-MCA (B), variable categories-MCA(C), and individual-MCA(D). Exploring Correlation Factors influencing experience on health: FOP: Frequency of application; SIPU: sources of information on pesticides used, EOPU: Experience On Pesticide Use.

3.2. Farmers' knowledge of pesticides

Knowledge of pesticide effects and management exhibits significant gaps (Figure 9), as evidenced by survey data indicating that "Poor knowledge" exceeds 60% for most parameters (e.g., 65.2% for dermal penetration, 64.9% for biodiversity impacts). While 44.3% of respondents recognize pesticides' adverse health effects, 55.7% do not, and critical concepts such as Time Before Harvest (TBH; 60.3% Poor) and Restricted Entry Interval (REI; 67.8% Poor) remain poorly understood, reflecting limited awareness of safety and regulatory frameworks. Exposure pathways—ingestion via food (56.5% Poor), inhalation (59.1% Poor)—and environmental persistence (soil: 61.4% Poor; water: 62.2% Poor; air: 62.9% Poor) are similarly underappreciated, posing risks to human health and ecosystems. Notably, practical skills fare better, with 62.9% demonstrating good pesticide identification and 55.7% adept at reading labels, contrasting with a weak grasp of abstract regulatory (registration: 69% Poor) and ecological principles. Chi-square Statistical tests showed that, in general, there was a significant relationship between the level of education, training, assistance, and source of information with knowledge on pesticides of gardeners in Cameroon (p<0.01). These findings suggest an urgent need for targeted education to bridge knowledge deficits, particularly in agricultural contexts where pesticide use is prevalent, to mitigate health and environmental hazards.

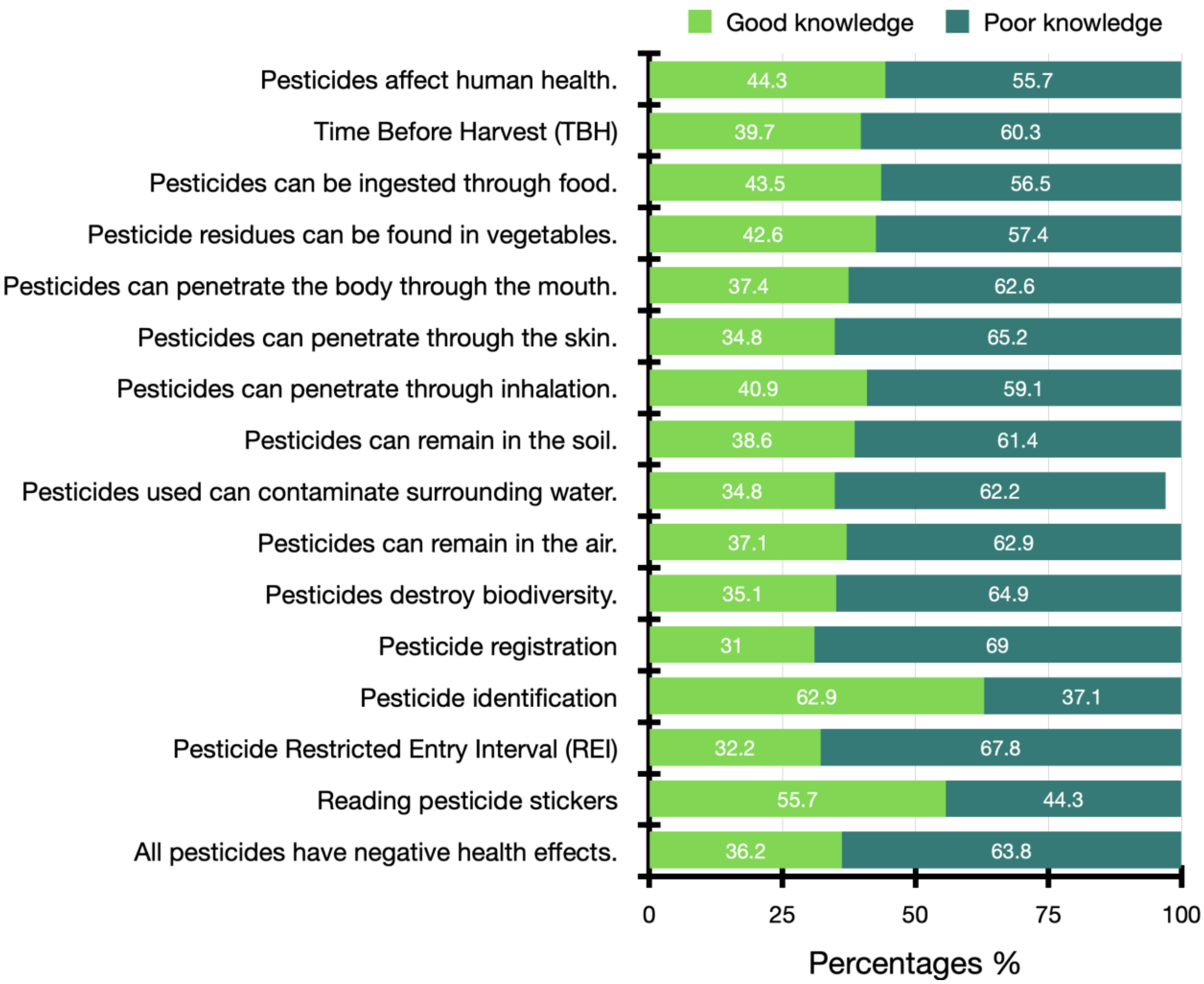


Figure 10. Knowledge of participants about pesticides (n=345).

4. DISCUSSION

Vegetable farming in Cameroon is male-dominated (81.9%), consistent with Sopkoutie et al. (2024) reporting 72.9% male farmers. Traditional gender roles, men's preferential access to resources, and cultural barriers limiting women's options underpin this disparity. Education influences compliance: 51.8% of farmers with secondary schooling read labels, aligning with findings that literacy enhances adoption of safe practices (Houbraken et al., 2016; Okolle et al., 2016). Yet, experience (mean 7.1 ± 5.8 years) does not improve label adherence (x^2 = 48.4, P = 0.16), contrasting with Pan et al. (2020) in China but echoing Marete et al. (2021) in Kenya—experience alone is insufficient without training. Land tenure also matters: 51.7% rent land, and owners show better phytosanitary practices (P < 0.01), unlike tenants' opportunistic overuse (67%), as seen in Mauritania (Le Bellec et al., 2017). Training and assistance—lacking for 67.6% and 65.4%, respectively—reduce pesticide reliance (Sopkoutie et al., 2024). In Benoue, farmers use plant extracts (e.g., pepper, garlic), but logistical barriers (distance, transport costs, few agents) limit access to support, necessitating mobile solutions (Kamga et al., 2013).

The study reveals a high reliance on pesticides for crop protection. During our investigation, we identified that certain agrochemical formulations are not applied to their recommended crops. In the Vina division, farmers commonly use pesticides registered for cotton production on garden crops, particularly tomatoes. A similar situation was reported by Son et al. (2018) in their study on the assessment of tomato (*Solanum lycopersicum* L.) producers' exposure to pesticides in Burkina Faso, noting that most plant protection products (PPPs) intended for cotton are frequently applied to tomato crops. Schiffers and Mar (2011) highlighted that these PPPs are not recommended for vegetable production due to their high toxicity and elevated concentrations of active substances.

Pyrethroids, one of the most commonly used pesticide families (Table 3), have been associated with resistance in key tomato pests, such as *Bemisia tabaci, Helicoverpa armigera,* and *Tuta absoluta,* to insecticides within this chemical group (Siqueira et al., 2000; Gnankiné et al., 2013). This resistance often leads to intensified pesticide applications, consequently increasing the risk of poisoning due to exposure. Among the formulations used, liquid emulsifiable concentrates (EC) predominate. This aligns with findings by Son et al. (2018), who reported that 75% of pesticides used for tomato production in Burkina Faso are liquid formulations. These substances are more readily absorbed through the skin and other tissues compared to solid formulations (Kim et al., 2017). Furthermore, Berenstein et al. (2014) found that exposure to liquid agrochemical formulations is 22 to 62 times higher than that of solid PPPs.

Pest resistance, crop phenology, and economic pressures fuel pesticide misuse. Farmers spray twice weekly, akin to Vietnam's Mekong Delta (Berg, 2001), with insecticide doses peaking in dry seasons and fungicides in rainy periods, tied to pest incidence and crop stages (Sopkoutie et al., 2021). Unconventional tools (e.g., spoons, beer cups) deviate from recommended doses, a practice also noted in Ivory Coast (Doumbia & Kwadjo, 2009). Mixtures dominate (80.4%), aimed at efficiency and cost-saving, mirroring Tanzania (Ngowi, 2003), but heightening exposure risks (Ngowi, 2003). In South Cameroon, glyphosate is mixed with banana pulp to kill trees, while northern farmers misuse cotton pesticides (Sougnabe et al., 2010)—irrational practices confirmed by Sopkoutie et al. (2024). *Tuta absoluta* drives overuse of tomatoes, Cameroon's top crop, paralleling Nepal (Bhandari, 2018).

Our study reveals significant differences in Treatment Frequency Indices (IFTs) among gardeners' crops in Cameroon ($p < 0.05$). Tomatoes exhibit the highest IFT (34.5), driven by their heavy reliance on phytosanitary treatments due to pest and disease susceptibility, as supported by Fontem *et al.* (2003). Sopkoutie *et al.* (2021) and Tarla *et al.* (2015) further confirmed this in Cameroon's major tomato-producing zones, noting intensive pesticide use—sometimes mixed with petroleum—to combat *Tuta absoluta*. Similarly, Le Bellec *et al.* (2017) reported an IFT of 23.25 for tomatoes in Mauritius. In Morocco, Abbou et al. (2022) found a peak IFT of 28.10 for potatoes in Loukkos, with an average of 19 treatments, while Soudani *et al.* (2024) recorded IFTs ≥ 10 in Ain Naga and Doucen, indicating high phytosanitary pressure (IPP ≥ 2.1).

Knapsack sprayers (79.1%) prevail due to cost, with some using brooms or leaves—hazardous improvisations seen in Ghana (Afari-Sefa et al., 2015).

This study ties misuse to a public health crisis, defined by the WHO (2008) as an event overwhelming local health systems and threatening widespread harm. Here, 97% of farmers using inadequate tools, 80.4% mixing pesticides, and 64.1% storing them in homes (Sopkoutie et al., 2024) drive acute symptoms (88.6%; tiredness, cramps) and can be subjected to chronic risks from carcinogens like glyphosate and chlorothalonil (IARC, 2021; Smith et al., 2017). Home storage has caused fatal poisonings (e.g., Yagoua maize; Tarla et al., 2013), while spraying near homes (98.3% >100 m) contaminates water and food (Bombardi, 2017). Of 43 active ingredients, 6.9% (e.g., abamectin) are highly hazardous (Khadda et al., 2021), and organophosphates amplify toxicity (Sapbamrer, 2018). Unlike Europe's pesticide decline (-0.2%; Atlas Pesticide, 2023), Cameroon's practices mirror Africa's 67.8% surge, signaling a crisis through pervasive exposure and knowledge gaps (35.1% grasp biodiversity impacts). Urgent training, stricter regulation, and biomonitoring are critical to mitigate this escalating threat.

5. CONCLUSION

This study unveils a critical intersection of pesticide misuse, health risks, and environmental degradation among Cameroonian vegetable farmers, driven by inadequate knowledge and systemic barriers. The extensive use of hazardous and potentially carcinogenic pesticides, coupled with pervasive malpractices like home storage and frequent applications, poses immediate threats to farmers, particularly women, and long-term risks to ecosystems and food safety. Limited training and assistance, compounded by economic pressures and weak regulatory oversight, distinguish Cameroon from regions with stringent controls, reflecting a broader Sub-Saharan challenge amid rising pesticide reliance. These findings demand urgent, multi-faceted action. Deploying mobile training units through MINADER can deliver Integrated Pest Management and safety education to underserved farmers, while subsidized PPE distribution can address accessibility barriers. Establishing biomonitoring and residue testing, building on existing analytical capacity, is vital to quantify exposure and inform policy. Aligning regulations with African Union standards to phase out the most dangerous compounds offers a pathway to sustainability. Together, these interventions can transform agricultural practices, protecting human health, preserving biodiversity, and ensuring food security—not only in Cameroon but as a blueprint for pesticide-dependent regions globally.

Ethics approval and consent to participate. Not applicable.

Availability of data and materials. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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REFERENCES

Abdulai A N, Konje C N, Achiri T D, Tarla D N and Nsobinenyui D (2019). Pesticide use practices by market gardeners in the Santa Area of the North West Region of Cameroon. *International Journal of Plant & Soil Science* 26, 1–11. https://doi.org/10.9734/ijpss/2018/v26i630060

Ahmed A A and Muhammad R A (2021). A beginner's review of Jamovi statistical software for economic research. *Journal of Economic Research* 6, 1–15.

Atlas des Pesticides (2023). Heinrich-Böll-Stiftung Paris & La Fabrique écologique. Heinrich-Böll-Stiftung, Paris, France, 64 p. https://fr.boell.org/fr/atlas-des-pesticides. Date of consultation: 09/11/2024.

Bagheri A, Emami N, Damalas C A and Allahyari M S (2019). Farmers' knowledge, attitudes, and perceptions of pesticide use in apple farms of northern Iran: Impact on safety behaviour. *Environmental Science and Pollution Research* 26, 5073–5083. https://doi.org/10.1007/s11356-019-04330-y

Bagheri A, Pirmoazen S and Allahyari M S (2021). Assessment of farmers' understanding of the pictograms displayed on pesticide labels. *Environmental Science and Pollution Research* 28, 17812–17825. https://doi.org/10.1007/s11356-020-11821-w

Berenstein G A, Hughes E A, March H, Rojic G, Zalts A and Montserrat J M (2014). Pesticide potential dermal exposure during the manipulation of concentrated mixtures at small horticultural and floricultural production units in Argentina: The formulation effect. *Science of the Total Environment* 472, 509–516. https://doi.org/10.1016/j.scitotenv.2013.11.026

Berg H (2001). Pesticide use in rice and rice–fish farms in the Mekong Delta, Vietnam. *Crop Protection* 20, 897–905. https://doi.org/10.1016/S0261-2194(01)00039-4

Berry C (2020). Glyphosate and cancer: The importance of the whole picture. *Pest Management Science* 76, 2874–2877. https://doi.org/10.1002/ps.5834

Bhandari G, Atreya K, Yang X, Fan L and Geissen V (2018). Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers. *Science of The Total Environment* 631–632, 1560–1571. https://doi.org/10.1016/j.scitotenv.2018.03.144

Boedeker W, Watts M, Clausing P and Marquez E (2020). The global distribution of acute unintentional pesticide poisoning: Estimations based on a systematic review. *BMC Public Health* 20, 1875. https://doi.org/10.1186/s12889-020-09939-0

Bombardi L (2017). Atlas: Geografia do uso de agrotóxicos no Brasil e conexões com a União Européia. FFLCH-USP, São Paulo, Brazil, 296 p.

Chuisseu D D P, Domngang C, Boutchouang R P, Njayou N A, Tedong L F M, Manfo T, Simo Nemg B F, Mbiandjeu M, Kouam F A, Galani T B R, Kouamouo J and Ngogang J (2020). Connaissances, attitudes et pratiques des agriculteurs sur les agropesticides et leurs effets sur la santé dans le département du Nde-Cameroun. *African Journal of Integrated Health* 10, 86–94.

Cochran W G (1977). Sampling techniques (3rd ed.). John Wiley & Sons, New York, USA, 428 p.

Crump K (2020). The potential effects of recall bias and selection bias on the epidemiological evidence for the carcinogenicity of glyphosate. *Risk Analysis* 40, 696–704. https://doi.org/10.1111/risa.13440

Dieudonne O, Nguefack J, Dongmo Lekagne J B, Dakole Daboy C, Azah Udom R and Ndonkeu Mangoumou G (2021). The cultivation of sweet pepper (Capsicum annuum) in Foumbot agricultural area, West Region, Cameroon. *Advanced Journal of Social Science* 8, 54–66. https://doi.org/10.21467/ajss.8.1.54-66

Djuidje K, Flora P, Tafokou J, Bernadin R and Vanelle T (2021). Assessing the health and environmental risks of phytosanitary practices used by market gardening in the Yaoundé 7 area (Nkolbisson) in Cameroon. *Journal of Environmental Science and Public Health* 9, 44–50.

Doumbia M and Kwadjo K E (2009). Abstracts-Posters. *Journal of Applied Biosciences* 18, 992–1002 (abstract). https://doi.org/10.1111/acer.13084

Dupont Y (2018). Le goût des pesticides dans le vin. *International Journal of Environmental Studies* 75, 867–869. https://doi.org/10.1080/00207233.2018.1453384

Echodu R, Oedema H, Wokorach G, Zawedde C, Otim G, Luambano N, Miinda E and Asiimwe T (2019). Farmers' practices and their knowledge of biotic constraints to sweetpotato production in East Africa. *Physiological and Molecular Plant Pathology* 105, 3–16. https://doi.org/10.1016/j.pmpp.2018.07.004

Efuetlancha E N (2020). Assessing small-scale farmers' attitudes, practices, and vulnerability to pesticide use in market gardening crops in M'muockngie (South Western Cameroon). *Journal of Advances in Education and Philosophy* 4, 295–305. https://doi.org/10.36348/jaep.2020.v04i06.010

Efuetlancha N E and Kuete M (2020). An assessment of school-going population exposure pathways to agropesticide in the Mungo Corridor of Cameroon. *European Scientific Journal ESJ* 16, 123–144. https://doi.org/10.19044/esj.2020.v16n26p123

FAO (2022). International Code of Conduct on Pesticide Management—Guidance on Good Labelling Practice for Pesticides (2nd rev.). FAO, Rome, Italy, 44 p.

FAOSTAT (2019). Pesticide use data. http://www.fao.org/faostat/fr/#data/QC. Date of consultation: 19/05/2025.

Fontem D A (2003). Effets quantitatifs du mildiou précoce et tardif sur les rendements de la tomate au Cameroun. *Tropicultura* 21, 36–41.

Galani Y J H, Houbraken M, Wumbei A, Djeugap J F, Fotio D, Gong Y Y and Spanoghe P (2021). Contamination of foods from Cameroon with residues of 20 halogenated pesticides and health risk of adult human dietary exposure. *International Journal of Environmental Research and Public Health* 18, 5043. https://doi.org/10.3390/ijerph18095043

Gimou M M, Charrondiere U R, Leblanc J C and Pouillot R (2008). Dietary exposure to pesticide residues in Yaoundé: The Cameroonian total diet study. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment* 25, 458–471. https://doi.org/10.1080/02652030701567475

Gnankiné O, Mouton L, Savadogo A, Martin T, Sanon A, Dabire R K, Vavre F and Fleury F (2013). Biotype status and resistance to neonicotinoids and carbosulfan in Bemisia tabaci (Hemiptera: Aleyrodidae) in Burkina Faso, West Africa. *International Journal of Pest Management* 59, 95–102. https://doi.org/10.1080/09670874.2013.771806

Houbraken M, Bauweraerts I, Fevery D, Van Labeke M-C and Spanoghe P (2016). Pesticide knowledge and practice among horticultural workers in the Lâm Đồng region, Vietnam: A case study of chrysanthemum and strawberries. *Science of the Total Environment* 550, 1001–1009. https://doi.org/10.1016/j.scitotenv.2016.01.183

Kamga A, Kouame C, Tchindjang M, Chagomoka T and Drescher A W (2013). Environmental impacts from overuse of chemical fertilisers and pesticides amongst market gardening in Bamenda, Cameroon. *Revue Scientifique et Technique Forêt et Environnement du Bassin du Congo* 1, 8–24.

Kamsu P N, Tchameni S N, Ayong N A, Moussango M, Youassi O Y, Sameza M L, Michel P and Jazet D (2022). Phytosanitary practices of tomato producers in the western region of Cameroon. *International Journal of Advanced Agricultural Research* 9, 1–9.

Kapeleka J A (2024). Quantification of pesticide dosage and determinants of excessive pesticide use in smallholder vegetable production systems in Tanzania. *Heliyon* 10, e41070. https://doi.org/10.1016/j.heliyon.2024.e41070

Kariathi V, Kassim N and Kimanya M (2016). Pesticide exposure from fresh tomatoes and its relationship with pesticide application practices in Meru district. *Cogent Food & Agriculture* 2, 1196808. https://doi.org/10.1080/23311932.2016.1196808

Kaur G, Kumar B V S, Singh B and Sethi R S (2021). Exposures to 2,4-dichlorophenoxyacetic acid with or without endotoxin upregulate the small cell lung cancer pathway. *Journal of Occupational Medicine and Toxicology* 16, 14. https://doi.org/10.1186/s12995-021-00304-4

Kenko N D B and Kamta N (2021). Human and environmental health implications of pesticide utilisation by market gardeners in the Western Highlands of Cameroon. *Asian Journal of Environment & Ecology* 14, 44–56. https://doi.org/10.9734/ajee/2021/v14i330210

Kenko N D B, Fai A, Ngameni T and Mbida M (2017). Environmental and human health assessment in relation to pesticide use by local farmers and the Cameroon Development Corporation (CDC), Fako Division, South-West Cameroon. *European Scientific Journal ESJ* 13, 454–474. https://doi.org/10.19044/esj.2017.v13n21p454

Khadda Z B, Fagroud M, Karmoudi Y E, Ezrari S, Berni I, Broe M D, Behl T, Bungau S G and Houssaini T S (2021). Farmers' knowledge, attitudes, and perceptions regarding carcinogenic pesticides in the Fez Meknes Region (Morocco). *International Journal of Environmental Research and Public Health* 18, 10879. https://doi.org/10.3390/ijerph182010879

Kim K-H, Kabir E and Jahan S A (2017). Exposure to pesticides and the associated human health effects. *Science of the Total Environment* 575, 525–535. https://doi.org/10.1016/j.scitotenv.2016.09.009

Le Bellec F, Scorbiac M and Sauzier J (2017). Les pratiques phytosanitaires des producteurs de légumes de l'île Maurice: Impacts et perspectives de changement. *Cahiers Agricultures* 26, 55001. https://doi.org/10.1051/cagri/2017038

Le Bellec F, Vélu A, Fournier P, Le Squin S, Michels T, Tendero A and Bockstaller C (2015). Helping farmers to reduce herbicide environmental impacts. *Ecological Indicators* 54, 207–216. https://doi.org/10.1016/j.ecolind.2015.02.010

Lombardi C, Thompson S, Ritz B, Cockburn M and Heck J E (2021). Residential proximity to pesticide application as a risk factor for childhood central nervous system tumours. *Environmental Research* 197, 111078. https://doi.org/10.1016/j.envres.2021.111078

López-Dávila E, Torres L, Houbraken M and Laing G (2020). Knowledge and practical use of pesticides in Cuba. *Environmental Management and Sustainability* 21, 1–12. https://doi.org/10.1186/s40550-018-0066-1

Marete G, Lalah J, Mputhia J and Wekesa V (2021). Pesticide usage practices as sources of occupational exposure and health impacts on horticultural farmers in Meru County, Kenya. *Heliyon* 7, e05906. https://doi.org/10.1016/j.heliyon.2021.e05906

MINADER (2021). Liste des pesticides homologués au Cameroun au 04 Mars 2021. Commission Nationale d'Homologation des Pesticides à Usage Agricole; Ministère de l'Agriculture et du Développement Rural (MINADER), Yaoundé, Cameroon, 12 p.

Miyittah K M, Kwadzo M, Gyamfua A P and Dodor D E (2020). Health risk factors associated with pesticide use by watermelon farmers in the Central region, Ghana. *Environmental Systems Research* 9, 10. https://doi.org/10.1186/s40068-020-00170-9

Mubushar M, Aldosari F O, Baig M B, Alotaibi B M and Khan A (2019). Assessment of farmers on their knowledge regarding pesticide usage and biosafety. *Saudi Journal of Biological Sciences* 26, 1903–1910. https://doi.org/10.1016/j.sjbs.2019.03.001

Negatu B, Kromhout H, Mekonnen Y and Vermeulen R (2016). Use of chemical pesticides in Ethiopia: A cross-sectional comparative study on knowledge, attitude, and practice of farmers and farm workers in three farming systems. *Annals of Occupational Hygiene* 60, 551–566. https://doi.org/10.1093/annhyg/mew004

Ngowi A V F (2003). A study of farmers' knowledge, attitude, and experience in the use of pesticides in coffee farming. *Tropical Pesticides Research Institute Journal* 13, 62–64.

Njukeng J N, Nkembi L, Forghab N E and Nji A D (2021). Agroforestry practices and food security in the Mount Bamboutos landscape, Western Highlands of Cameroon. *World Journal of Advanced Research and Reviews* 11, 203–211. https://doi.org/10.30574/wjarr.2021.11.1.0311

Nkembi L, Mubeteneh T C, Nji A D, Forghab N E and Nkengafac N J (2023). Farmland management strategies by smallholder farmers in the Mount Bamboutos landscape in Cameroon. In: Nishi M & Subramanian S M (Eds.), Ecosystem Restoration through Managing Socio-Ecological Production Landscapes and Seascapes (SEPLS), Springer Nature Singapore, Singapore, pp. 97–116. https://doi.org/10.1007/978-981-99-1292-6_6

Ntsoli P G, Boat B, Marie A, Baleba C C, Tchatcho N S F, Djoko K I, Titti R W, Etame K G M and Yaouba A (2024). Postharvest practices, perceptions, and knowledge of mycotoxins among groundnut farmers in the Adamawa, Centre, and North regions of Cameroon. *Scientifica* 2024, 5596036. https://doi.org/10.1155/2024/5596036

Okolle N J, Afari-Sefa V, Bidogeza J C, Tata P I and Ngome F A (2016). An evaluation of smallholder farmers' knowledge, perceptions, choices, and gender perspectives in vegetable pests and diseases control practices in the humid tropics of Cameroon. *International Journal of Pest Management* 62, 165–174. https://doi.org/10.1080/09670874.2016.1184772

ONACC (2023). Bulletin de prévisions des paramètres climatiques des mois de décembre, janvier et février 2022-2023.http://onsp.minsante.cm/sites/default/files/publications/319/Bulletin_N°21_de_Déc_2022_à_Fév_2023%2C_version_du_05-12-2022.pdf. Date of consultation: 09/10/2024.

Pan Y, Ren Y and Luning P A (2021). Factors influencing Chinese farmers' proper pesticide application in agricultural products—a review. *Food Control* 122, 107788. https://doi.org/10.1016/j.foodcont.2020.107788

Pesticide Action Network Europe (2022). EU pesticide atlas 2022. PAN Europe, Brussels, Belgium, 48 p.

PPDB (2022). PPDB: Pesticide Properties DataBase. University of Hertfordshire. http://sitem.herts.ac.uk/aeru/ppdb/en/search.htm. Date of consultation: 19/08/2024.

Samsel A and Seneff S (2015). Glyphosate, pathways to modern diseases III: Manganese, neurological diseases, and associated pathologies. *Surgical Neurology International* 6, 45. https://doi.org/10.4103/2152-7806.153876

Sapbamrer R (2018). Pesticide use, poisoning, and knowledge about pesticide management among farmers in Northern Thailand. *Journal of Occupational Health* 60, 10–25. https://doi.org/10.1539/joh.17-0152-OA

Schiffers B and Mar A (2011). Sécurité des opérateurs et bonnes pratiques phytosanitaires. COLEACP/PIP Press, Brussels, Belgium, 120 p.

Sharafi K, Pirsaheb M, Maleki S, Arfaeinia H, Karimyan K, Moradi M and Safari Y (2018). Knowledge, attitude, and practices of farmers about pesticide use, risks, and wastes; a cross-sectional study (Kermanshah, Iran). *Science of The Total Environment* 645, 509–517. https://doi.org/10.1016/j.scitotenv.2018.07.132

Siqueira H A A, Guedes R N C and Picanço M C (2000). Insecticide resistance in populations of Tuta absoluta (Lepidoptera: Gelechiidae). *Agricultural and Forest Entomology* 2, 147–153. https://doi.org/10.1046/j.1461-9563.2000.00062.x

Smith A M, Smith M T, La Merrill M A, Liaw J and Steinmaus C (2017). 2,4-Dichlorophenoxyacetic acid (2,4-D) and risk of non-Hodgkin lymphoma: A meta-analysis accounting for exposure levels. *Annals of Epidemiology* 27, 281–289. https://doi.org/10.1016/j.annepidem.2017.03.003

Sonchieu J, Fointama E, Akono N and Serri B (2019). Farmers' knowledge, attitude, and practices on pesticide safety: A case study of vegetable farmers in Mount-Bamboutos agricultural area, Cameroon. *Agricultural Sciences* 10, 1039–1055. https://doi.org/10.4236/as.2019.108079

Sonchieu J, Ngassoum B M, Akono E N and Laxman P S (2017). Pesticide applications on some vegetables cultivated and health implications in Santa, North West-Cameroon. *International Journal of Agriculture & Environmental Science* 4, 1–8. https://doi.org/10.14445/23942568/ijaes-v4i2p108

Sopkoutie G N K, Djeugap J F, Wumbei A, Spanoghe P and Galani Y J H (2024). Assessment of pesticide usage, phytosanitary practices and risks associated with pesticide use by farmers in Cameroon: A comprehensive literature review. *Cameroon Journal of Biological and Biochemical Sciences* 32, 82–109.

Sopkoutie N G K, Abdulai A N, Tarla D N, Djeugap F, Galani Y J H, Ekengoue C, Tabang W, Nya E and Payne V (2021). Phytosanitary practices and evaluation of 17 pesticide residues in tomatoes fruits produced in Foumbot District, Western Highland-Cameroon. *European Scientific Journal ESJ* 17, 30–50. https://doi.org/10.19044/esj.2021.v17n3p30

Soudani N, Boukhalfa H H, Toumi K and Soudani A (2024). Human health and environmental risk perceptions related to pesticide use in Algerian market gardening. *Agriculturae Conspectus Scientificus* 89, 391–403.

Sougnabe S P, Yandia A, Aicheleke J, Brévault T, Vaissayre M and Ngartoubam L T (2010). Pratiques phytosanitaires paysannes dans les savanes d'Afrique centrale. In: Savanes africaines en développement: Innover pour durer, Prasac, N'Djaména, Tchad; Cirad, Montpellier, France, pp. 1–13.

Tarla D N, Manu I N, Tamedjouong Z T, Kamga A and Fontem D A (2015). Plight of pesticide applicators in Cameroon: Case of tomato (Lycopersicon esculentum Mill.) farmers in Foumbot. *Journal of Agriculture and Environmental Sciences* 4, 87–98. https://doi.org/10.15640/jaes.v4n2a10

Tarla D N, Meutchieye F, Assako V A, Fontem D A and Kome J J A (2013). Exposure of market gardeners during pesticide application in the Western Highlands of Cameroon. *Scholarly Journal of Agricultural Science* 3, 172–177.

Tarla D N, Tchamba N M, Baleguel N P, Fontem D A, Baleguel P D and Hans D (2014). Inventory of obsolete pesticide stockpiles in Cameroon. *Scholarly Journal of Agricultural Science* 4, 43–50.

Tolera S (2020). Systematic review on adverse effects of pesticides on top ten importers of African countries. *Journal of Applied Sciences and Environmental Management* 24, 1607–1616. https://doi.org/10.4314/jasem.v24i9.9

Tudi M, Daniel R, Wang L, Lyu J, Sadler R, Connell D, Chu C and Phung D (2021). Agriculture development, pesticide application, and its impact on the environment. *International Journal of Environmental Research and Public Health* 18, 1112. https://doi.org/10.3390/ijerph18031112

Wang Y, Huo X and Zhu Y (2015). Why are some restricted pesticides still chosen by some farmers in China? Empirical evidence from a survey of vegetable and apple growers. *Food Control* 51, 417–424. https://doi.org/10.1016/j.foodcont.2014.12.002

Wang Z, Kottawatta K S A, Kodithuwakku S P, Fernando T S, Lee Y-L, Ng E H Y, Yeung W S B and Lee K-F (2021). The fungicide mancozeb reduces spheroid attachment onto endometrial epithelial cells through downregulation of oestrogen receptor β and integrin β3 in Ishikawa cells. *Ecotoxicology and Environmental Safety* 208, 111606. https://doi.org/10.1016/j.ecoenv.2020.111606

Weis G C C, Assmann C E, Cadoná F C, Bonadiman B da S R, Alves A de O, Machado A K, Duarte M M M F, Cruz I B M da and Costabeber I H (2019). Immunomodulatory effect of mancozeb, chlorothalonil, and thiophanate methyl pesticides on macrophage cells. *Ecotoxicology and Environmental Safety* 182, 109420. https://doi.org/10.1016/j.ecoenv.2019.109420

World Health Organization (2009). Pesticide residues in food – 2008: Toxicological evaluations. WHO Press, Geneva, Switzerland, 448 p.

World Health Organization (2021). IARC Monographs on the Identification of Carcinogenic Hazards to Humans. https://monographs.iarc.who.int/list-of-classifications. Date of consultation: 22/06/2024.

Wumbei A, Houbraken M and Spanoghe P (2019). Pesticide use and exposure among yam farmers in the Nanumba traditional area of Ghana. *Environmental Monitoring and Assessment* 191, 307. https://doi.org/10.1007/s10661-019-7449-5

Zyoud S H, Sawalha A F, Sweileh W M, Awang R, Al-Khalil S I, Al-Jabi S W and Bsharat N M (2010). Knowledge and practices of pesticide use among farm workers in the West Bank, Palestine: Safety implications. *Environmental Health and Preventive Medicine* 15, 252–261. https://doi.org/10.1007/s12199-010-0136-3