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Toward Fraudulent Pesticides in Rural Areas: Do Farmers' Recognition and Purchasing Behaviors Matter?

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Abstract: The growth of fraudulent pesticide trade has become a threat to farmers' health, agrochemical businesses, and agricultural sustainability, as well as to the environment. However, assessment of the levels of farmers' exposure to fraudulent pesticides in the literature is often limited. This paper conducted a quantitative study of farmers' recognition and purchasing behaviors with regard to fraudulent pesticides in the Dakhalia governorate of Egypt. Using a structured questionnaire, data were collected by face-to-face interviews with 368 farmers in three districts of the governorate. The questionnaire included questions on socioeconomic characteristics, risk perception, recognition behavior, and purchasing behavior regarding fraudulent pesticides. The findings indicate that farmers perceived high risks to farmer health and crop yield (a score of 4 out of 5) and a moderate risk to the environment (3.5 out of 5) from fraudulent pesticides. Nonetheless, nearly three-fourths of the farmers had purchased fraudulent pesticides anyway. The statistical analysis suggests that farmers who resist purchasing fraudulent pesticides have higher education, longer experience in farming, and better recognition of fraudulent pesticides. To improve farmers' ability to distinguish and avoid fraudulent pesticides, the paper recommends communication-related anti-counterfeiting measures such as awareness extension programs, as well as distribution measures in cooperation with other stakeholders.

Keywords: pesticides; fraudulent; farmers; behavior; purchase; rural areas; sustainable agriculture

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1. Introduction

Product fraud is a global issue that is increasing in magnitude and scope and adversely affecting different market sectors [1,2]. Pesticides are among the most popular fraudulent products in the agri-food market [3,4]. Although the term "fraud" has been used in the field of international business for a long time [5], it has become something of a buzzword in recent years in the field of pesticides. The advance of globalization and the development of technologies have given rise to a more widely accepted conceptualization of fraudulent pesticides as deliberately mislabeled regarding their source and/or identity; additionally, they may lack the manufacturer's name and address, or are not allowed to be used or sold by national authorities [6]. The term "fraudulent pesticide" describes an array of illicit, illegal, and unauthorized imports or those with counterfeit labeling [7]. For the purposes of this paper, we adopted the classification of Fishel [8], who divided fraudulent pesticides into three main categories, namely, fakes, counterfeits, and illegal parallel imports. Fake pesticides are often sold in simple packs without label information or with minimal labeling about their use and precautions. Such products may contain anything from water or talc to diluted and outdated or obsolete stocks, including restricted or banned materials [6]. Counterfeit pesticides may include products with no active ingredient or a modified product content. These products represent sophisticated copies of genuine products, usually with high-quality packaging and labeling [8]. Finally, illegal parallel imports consist of non-authorized products (not yet registered or mostly banned) or registered products from non-registered distributors [9].

Despite various collaborative and multinational efforts, it is apparent that the problem of fraudulent pesticides is growing. As mentioned in the 2020 status report of the European Union Intellectual Property Office (EUIPO) [10], the sales of legitimate pesticides decreased by an average of 4.2% across the EU due to the presence of counterfeits. This equates to a loss of direct sales of EUR 0.5 billion per year. Adding on its knock-on effects in other sectors, the total loss of sales was estimated to be EUR 1.0 billion. The total employment loss as a result of counterfeit pesticides in this sector across the EU was 3584 jobs annually. In terms of the total yearly government revenue, the total loss was estimated to be EUR 0.1 billion in taxes and social security contributions. In the case of Egypt, a report of the Ministry of Agriculture and Land Reclamation (MALR) showed that counterfeit and illegal pesticides accounted for 15% of the market share of pesticides and agrochemicals in 2019 [11]. In terms of the percentage of counterfeits inspected among other sectors in 2019, this report showed that pesticides ranked fourth after clothing, cosmetics and personal care, and pharmaceuticals. The results included in this report are based on a collaboration between regulatory bodies in the governorates and the MALR in implementing inspection campaigns. The objectives of the campaigns respond to the widespread concern for fraudulent pesticides among farmers by monitoring the outlets of manufacture and the sale of pesticides; monitoring any violations that pose a threat to public health, the environment, agricultural production, and agricultural exports; and taking all necessary measures against violators. The main activities implemented during campaigns include comparing the sales of fraudulent pesticides to those authorized by the MALR based on barcode scanning, in addition to lab testing by taking a random sample of pesticides to ensure their quality.

Farmers play an essential role in combating fraudulent pesticides. This role can be achieved by influencing farmers' behavior regarding the purchase of fraudulent pesticides [12]. Some farmers buy fraudulent pesticides knowingly and intentionally (non-deceptive behavior) or this behavior may be deceptive, when a farmer believes that the package is genuine and he/she is not aware of buying unregistered or illegal products [13]. However, both categories of farmers' purchasing behavior regarding fraudulent pesticides are affected by numerous factors. The intention to purchase can be viewed as a link between attitudes and purchasing behavior [14,15]. According to Haggblade et al. [16], attitudes toward the efficiency and quality of counterfeit pesticides influence the farmers' purchase intentions. Positive attitudes toward purchasing genuine pesticides are expected to increase farmers' likelihood of purchasing these pesticides [17]. The farmer–price relationship should also be taken into consideration. Price is a major factor in the buying decision, and it also influences the choice of product, store, and brand [18–20]. Compared to original pesticides, the low price of fraudulent pesticides may encourage farmers, particularly small-scale farmers, to purchase them [12,21]. Moreover, the perception of risks associated with fraudulent pesticides is also one of the main determinants for farmers in forming a subjective judgment of whether to purchase a particular counterfeit [12]. Farmers should be aware of the adverse consequences of fraudulent pesticides in terms of their crop yield and quality of products [17]. Apart from agricultural risks, the use of counterfeit and illegal pesticides also has health consequences. Such pesticides can negatively affect farmers' health through exposure during application and pose severe health risks to consumers' health due to the residues of unknown and untested substances in foods [22,23]. Furthermore, many active substances and other constituents used in fraudulent pesticides contain highly toxic impurities, which can pose a risk to soil quality, water, and the health of biodiversity [6,24]. Besides this, there are an increasing number of cases of fraudulent pesticides making negative impacts on the plant protection industry (damage to one's reputation, a loss of sales, patent and trademark infringement, and the undermining of industry stewardship activities) [7,25,26] and causing economic damage to governments (job losses, lost taxes and levies from the sale of brands, stifling innovation and competitiveness, and inability to effectively regulate the agro-chemical market) [7,26,27]. Finally, the demographic characteristics of farmers could also be important determinants of their purchasing behavior with regard to fraudulent pesticides [12,28–31]. Practically speaking, even if all of these factors positively motivate farmers not to purchase fraudulent pesticides, recognizing such pesticides is still a dilemma [1,32].

In fact, farmers might not be able to differentiate between fake and original pesticides due to their availability through legitimate distributors or because of the sophistication of pirate copies [33]. To deter and mitigate the negative impacts from the use of fraudulent pesticides, applying effective formal and informal social control mechanisms in the regulatory, production, and supply chain networks is crucial [34,35]. However, combating this issue not only requires the promotion of the farmers' capacity building in terms of identifying frauds, but also collective action from all stakeholders in the pesticide supply chain [16]. In this context, the United Nations Interregional Crime and Justice Research Institute [7] developed a comprehensive approach to managing this issue among stakeholders that aligns with six general areas, namely, awareness and engagement of authorities and stakeholders, international harmonization and regulatory oversight, supply chain protection and defense activities, enhanced investigation and interdiction capacities, control of financial flows and incentives, and end-user and consumer awareness. In West Africa, Yao's work is one of the most successful examples of collaboration, with a broad array of stakeholders interested in fighting the use fraudulent pesticides [36]. Yao's strategy depends upon four steps: making all stakeholders realize that there is an issue, recognizing fraudulent pesticides, taking proper actions, and lobbying/influencing decision-makers. This strategy is implemented by various activities, including awareness campaigns, training and building capacity programs for all stakeholders, and advocacy toward public authorities. In the same context, Haggblade et al. [21] noted that the prevalence of fraudulent products in the pesticide market requires the simple role of the farmers in terms of making the decision to purchase only products duly registered by the national regulator; likewise, a more aggressive monitoring of pesticide markets and product quality is an urgent need.

Despite the fact that several studies have been undertaken to measure the quality of fraudulent pesticides by conducting laboratory tests [16,21,24,37–39], empirical studies assessing farmers' exposure to fraudulent pesticides and the factors influencing their purchasing behavior have not received enough attention, especially in the context of Egypt. These factors, including the farmers' socio-demographic variables, their perception level of risks associated with fraudulent pesticides, and their recognition level of fraudulent pesticides. Therefore, the current study aimed to (i) explore farmers' risk perception regarding fraudulent pesticides, (ii) identify farmers' exposure to fraudulent pesticides, (iii) identify the level of recognition of fraudulent pesticides among farmers, and (iv) determine the factors influencing the farmers' purchasing behavior.

2. Methodology

2.1. Study Area

The present study was carried out in the Dakhalia governorate, located in the northeast of Egypt (31.1400° N and 31.2200° E). This governorate was selected as it is among the three highest governorates according to the number of fraudulent pesticides inspected in 2019 [11]. The governorate's total area is 3500 km^2, of which 37% is agricultural lands. It has a population of approximately 7,000,000 distributed across 22 districts [40]. The cropping pattern in the Dakhalia governorate mainly includes vegetables, citrus, rice, wheat, corn, sugar beet, and Egyptian clover [41].

2.2. Sampling and Data Collection

A three-stage sampling procedure was applied to select the sample for the survey. In the first stage, the Sherbein, Talkha, and Meet-Ghamr districts were purposely selected, as these have the largest number of registered farmers according to the agricultural directorates' database in the agricultural season (2019/2020). In the second stage, three villages in each district, with a total of nine villages, were randomly selected. The total population in the selected villages was 6489 farmers. In the last stage, simple random sampling was employed to collect data from a total of 377 respondents, using Yamane's [42] sample size determination formula (5% sampling error at a 95% confidence level). The survey was conducted from June 2019 to February 2020. Face-to-face interviews were conducted using a structured questionnaire as a data collection tool in the survey. A total of 368 farmers agreed to participate in the survey and completed the interview, resulting in a response rate of 97.6%.

2.3. Instrument and Variable Measurement

The questionnaire consisted of four sections. Section one included the socioeconomic characteristics of the farmers. Section two focused on the farmers' perception of the risks associated with fraudulent pesticides. The perception of risks was measured on a five-point Likert scale (1 = "strongly disagree", 2 = "disagree", 3 = "neutral", 4 = "agree", and 5 = "strongly agree"). Eight items related to the farmers' exposure to fraudulent pesticides were presented in Section 3. These items consisted of purchasing fraudulent pesticides in the last three years (2017–2019), purchasing fraudulent pesticides considering them genuine, purchasing fraudulent pesticides because of their low price, the type of fraudulent pesticides purchased, the timeliness and method of identifying fraudulent pesticides, the behavior after discovering that the pesticides were fraudulent, the diffusion level of fraudulent pesticides in the last three years (2017–2019), and the information source of the diffusion level of fraudulent pesticides. The farmers were asked to determine their purchase of fraudulent pesticides via a dichotomous question (non-purchased = 1; purchased = 0). Fifteen items related to recognizing counterfeit pesticides were identified according to MALR's regulations for the pesticide market [43] (Section 4). In this section, the farmers were asked to identify their recognition using a five-point Likert scale (5 = "always", 4 = "usually", 3 = "sometimes", 2 = "rarely", and 1 = "never"). A panel of 10 experts from the plant protection and agricultural extension departments at Mansoura University examined the validity of the questionnaire's items based on the study's objectives. Prior to field data collection, pre-testing of the questionnaire was conducted with 30 farmers in the study area to ensure content validity. The Cronbach's alpha of the scales of perception of risks and recognition were 0.89 and 0.86, respectively (>0.7), indicating good internal consistency and high reliability. To understand the level of risk perception and the level of recognition in each item, a total scale score was calculated by summing their ratings for each item. The total score of each item of the scale was divided into three categories based on the percentage of total scores as follows: High level (>75%), medium level (50–75%), and low level (<50%). To ensure the validity of the questionnaire, each item included in the perception and recognition scales was operationalized and measured according to the definitions and explanations provided in previous studies in this field. Additionally, each item was examined based on its study objectives and the relevance of the instrument content by three faculty members with related academic backgrounds at Mansoura University, Egypt. Pre-testing of the instrument with 20 farmers in the study area before data collection also assisted in achieving content validity. Based on the responses and suggestions from the farmers who were involved in the pre-testing, some items were reworded and two items were removed. In terms of reliability, the Cronbach's alpha coefficient was adopted to measure internal consistency [44]. The Cronbach's alpha value of perception and recognition scales were 0.86 and 0.84 respectively, indicating high reliability.

2.4. Data Analysis

Data were processed and analyzed using Statistical Package for Social Sciences (IBM SPSS, ver. 25.0, IBM Corp, Armonk, NY, USA). The frequencies, percentages, means, and standard deviations were applied as descriptive statistical tools. Moreover, binary logistic regression analysis was used to examine the determinants associated with the purchasing behavior regarding fraudulent pesticides. Binary logistic regression is a powerful statistical way of modeling the dependent variable (dichotomous) and the predictors tend to a linear relationship. There are two main advantages of using logistic regression. First, it provides a quantified value for the strength of the association while adjusting for other variables (removes confounding effects). The exponential of coefficients corresponds to the odds ratios of the given factor. Second, more than one explanatory variable, be it continuous, dichotomous, or ordinal, can be included in the model [45]. Nine explanatory variables were included in the model: Farm size, education level, age, farming experience, off-farm income, extension as a source of information in pesticides, training experience in pesticides, perception of risks associated with fraudulent pesticides, and recognition of fraudulent pesticides. Based on previous studies, the variable measurement and the direction of impact on farmers' decision making with regard to purchasing fraudulent pesticides were predicted, as shown in Table 1.

Table 1. Description and measurement of variables of the purchasing behavior model.

Variable	Description and Measurement	Expected Outcome (+/−)
Age	Years of age. Continuous variable.	−
Education level	Education status of farmer. Dummy variable (1 if the farmer had at least basic education; 0 otherwise).	+
Farming experience	Years of farming experience. Continuous variable.	+
Off-farm income	Income gained from off-farm activities. Dichotomous variable (no = 0; yes = 1).	+
Training experience in pesticides	Dichotomous variable (no = 0; yes = 1).	+
Farm size	Number of cultivated areas owned in hectares. Continuous variable.	+
Extension as a source of information	Dichotomous variable (no = 0; yes = 1).	+
Perception of risks	Percentage of risk perception of farmer. Continuous variable.	+
Recognition	Percentage of recognizing behavior of farmer. Continuous variable.	+
Purchasing behavior regarding fraudulent pesticides	Dependent variable. Dichotomous variable (non-purchased = 1; purchased = 0).	

(+/−) indicate a positive or negative relationship with the dependent variable.

3. Results

3.1. Socioeconomic Profile of the Respondents

The findings regarding the socioeconomic characteristics of the respondents (Table 2) showed that the mean age of the respondents was 56.23 years, and most farmers (63.2%) were aged between 45 and 60 years. The majority of the farmers (74.1%) had no formal education, a small proportion (7.7%) had primary education, 11.1% had secondary education, and 17.1% had a university degree. More than one-half of the farmers (55.8%) had a farm smaller than 1 ha, while less than one-quarter (21.6%) had more than 3 ha; the average farm size was 2.61 ha. Regarding farming experience, approximately one-half (51.1%) had between 16 and 30 years of farming experience, with an average farming experience of 25.72 years. Crops were the main farming activity, being managed by 48.1% of farmers, followed by fruits (34.8%) and vegetables (17.1%). In terms of information sources of pesticides, the majority of farmers (70.3%) retrieved their information from pesticides retailers, whereas 42.1% stated that they obtained their information from other farmers, and extension services ranked third, with a percentage of 39.1%. In total, the vast majority of the respondents (82.5%) had not received even a single training session on pesticides.

Table 2. Socioeconomic profile of the respondents.

Variable	Frequency (*n* = 468)	%
Age (min. = 30; max. = 79; mean = 56.23; SD = 9.04)		
<45 years	33	7.1
45–60 years	296	63.2
>60 years	139	29.7
Education		
Illiterate	163	34.8
Read and write	137	29.3
Basic education	36	7.7
Secondary school	52	11.1
University	80	17.1
Farm size (min. = 0.4; max. =8; mean = 2.61; SD = 1.73)		
<1 hectare	261	55.8
1–3 hectares	106	22.6
>3 hectares	101	21.6
Off-farm income		
Yes	266	56.8
No	202	43.2
Farming experience (min. = 5; max. = 55; mean = 25.72; SD = 10.51)		
<16 years	101	21.6
16–30 years	239	51.1
>30 years	128	27.4
Type of agricultural production		
Crops	225	48.1
Vegetables	80	17.1
Fruits	163	34.8
Information sources on pesticides *		
Other farmers	197	42.1
Extension	183	39.1
Input dealers	329	70.3
TV and social media	133	28.4
Private companies	119	25.4
Pesticide's label	97	20.7
Training experience in pesticides		
Yes	82	17.5
No	386	82.5

* More than one answer was allowed; percentages of the categories do not sum up to 100%.

3.2. Farmers' Perception of the Risks Associated with Fraudulent Pesticides

Table 3 shows the perception level of the health and environmental risks associated with fraudulent pesticides. Overall, the farmers had a high perception level of health risks, with a mean of 3.91. The assessment of the items pertaining to the adverse impacts of fraudulent pesticides on farmers, consumers, and animals shows that the farmers considered their perception level as being high. In terms of environmental risk, however, particularly regarding the importance of the environmental consequences of fraudulent pesticides, the farmers had a moderate perception level (mean = 3.51; SD = 0.74). For all four items assessed (Table 3), the perception levels ranged from moderate to high. The farmers rated "loss or damage to the crop due to the poor effect on pests" as having the highest level of perception (mean = 3.97; SD = 0.81), while "subsequent consequences of the environmental contamination on all wildlife, animals, and humans" had the lowest level of perception (mean = 3.07; SD = 0.59). To sum up, the results presented in Table 3 show that the majority of the farmers had a good level of perception regarding the health and environmental risks of fraudulent pesticides.

Table 3. Perception of the risks associated with fraudulent pesticides from the farmers' point of view.

Statements	Mean	SD
Health risk (mean = 3.91; SD = 0.62)		
I believe that fraudulent pesticides can be dangerous to farmers' health.	4.05	0.60
I believe that fraudulent pesticides can be dangerous to consumers' health.	3.92	0.62
I believe that the subsequent consequences of fraudulent pesticides hurt all wildlife and animals.	3.78	0.65
Environmental risk (mean = 3.51; SD = 0.74).		
Loss or damage to crops due to poor effect on pests.	3.97	0.81
Loss or damage to crops due to adverse physical effects of the product.	3.88	0.85
Environmental contamination of soil and water from the unknown toxic effects of the product.	3.15	0.71
Subsequent consequences of the environmental contamination on all wildlife, animals, and humans.	3.07	0.59

3.3. Farmers' Exposure to Fraudulent Pesticides

3.3.1. Diffusion Level of Fraudulent Pesticides

Table 4 depicts the diffusion level of fraudulent pesticides in the study area in the last three years from the farmers' perspectives; it can be observed that the majority of the respondents claimed that the number of fraudulent pesticides increased compared to previous years. The findings also revealed that the farmers obtained their information about the diffusion level of fraudulent pesticides from various sources. These sources can be ranked in descending order as follows: Pesticide supplier (85%), personal experience (59.8%), complaints from other farmers (55.1%), and mass media (46.4%).

Table 4. The diffusion level of fraudulent pesticides from the farmers' perspectives.

Variable	Frequency (*n* = 468)	%
Diffusion level of fraudulent pesticides in the last three years		
Increased	389	83.1
Decreased	7	1.5
Similar to previous years	50	10.7
I do not know	22	4.7
Information sources of the diffusion level of fraudulent pesticides *		
Personal experience	280	59.8
Pesticide supplier	398	85
Mass media	217	46.4
Extension	132	28.2
Complaints from other farmers	258	55.1

* More than one answer was allowed; percentages of the categories do not sum up to 100%.

3.3.2. Farmers' Purchasing Behavior Regarding Fraudulent Pesticides

Our analysis of purchasing behavior regarding fraudulent pesticides in the last three years (Table 5) indicate that the majority of the farmers (73.9%) purchased fraudulent pesticides. Among these farmers, the vast majority of them (98.8%) purchased fraudulent pesticides as genuine products. The findings also showed that almost one-third (32.7%) purchased fraudulent pesticides because of the low price.

Table 5. Farmers' purchasing behavior regarding fraudulent pesticides.

Variable	Frequency (*n* = 468)	%
Purchasing fraudulent pesticides in the last three years		
Yes	346	73.9
No	122	26.1
Purchasing fraudulent pesticides considering them genuine *		
Yes	342	98.8
No	4	1.2
Purchasing fraudulent because of the low price *		
Yes	113	32.7
No	229	66.2

* Farmers who purchased fraudulent pesticides.

3.3.3. Type of Fraudulent Pesticides Purchased

The findings indicate that farmers purchased various types of fraudulent pesticides (Table 6). Fake pesticides were the most frequent type purchased by the respondents, and the majority of the respondents (81.2%) purchased fake pesticides. Counterfeit pesticides were the next type mostly purchased by farmers, with a percentage of 71.7%. The third type most frequently purchased by the respondents was illegal parallel imports, although this type was purchased by less than one-third of the respondents (30.6%).

Table 6. Type of fraudulent pesticides purchased.

Variable	Frequency (*n* = 346) *	%
Type of fraudulent pesticides purchased **		
Fake pesticides	281	81.2
Counterfeit of genuine branded pesticides	248	71.7
Illegal parallel imports	106	30.6
I do not know	17	4.9

* Farmers who purchased fraudulent pesticides. ** More than one answer was allowed; percentages of the categories do not sum up to 100%.

3.3.4. Timeliness and Method of Identifying Fraud

In terms of the timeliness and method of identifying fraudulent pesticides, as shown in Figure 1, the findings indicate that farmers used various detection methods. However, inaccuracies upon visual inspection was considered by most farmers as a way to detect fraudulent pesticides. Nevertheless, a lack of pest control efficiency was the most popular method for detecting fraudulent pesticides among the farmers (76%). The next most popular factor for detecting fraud among the farmers was while opening a pesticide's package (33.8%). Besides these, detecting fraud during pesticide handling (loading, mixing, or applying) was also mentioned by 29.2% of the farmers. Interestingly, accurate methods for detecting fraud were applied by only a small proportion of the farmers, by means of lab testing (1.2%) and sniffer dogs (0.6%) in particular.

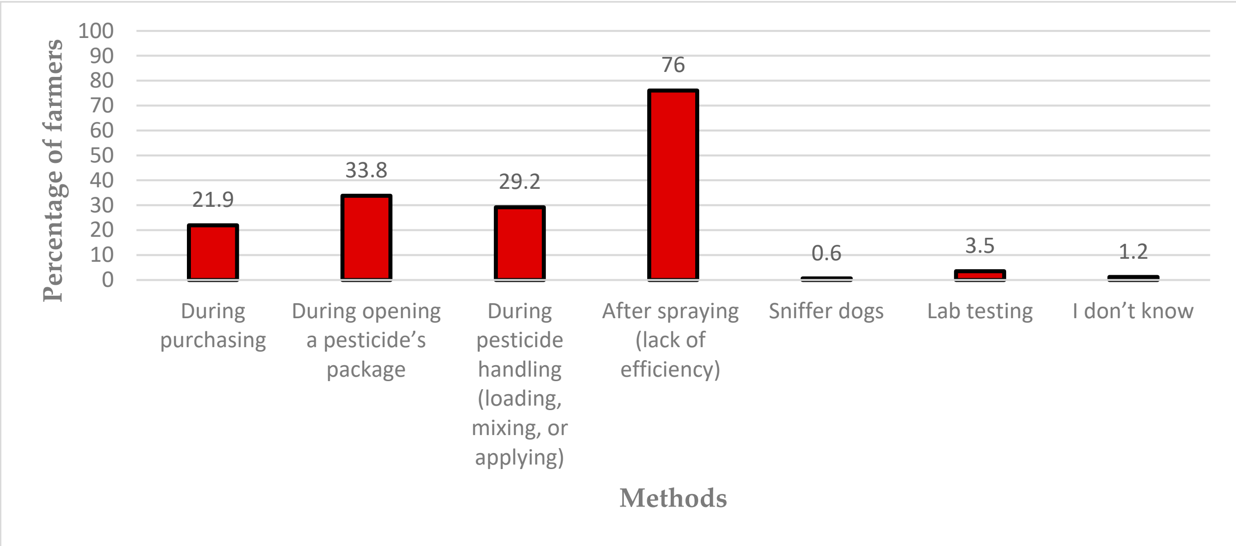

Figure 1. Timeliness and method of identifying fraudulent pesticides (by the farmers who purchased fraudulent pesticides).

3.3.5. Farmers' Behavior after Discovering Fraudulent Pesticides

As part of the analysis of exposure to fraudulent pesticides, the farmers were asked to identify their behavior after discovering fraudulent pesticides, as shown in Figure 2. The findings indicate that some of the farmers applied more than one option. Approximately 67% of the respondents purchased an alternative pesticide, whereas 55.5% of the respondents went to their pesticide supplier/company to complain and ask for a replacement, and 24.3% of them complained to regulatory agencies. Meanwhile, more than one-quarter (26.6%) related no specific behavior after discovering fraudulent pesticides.

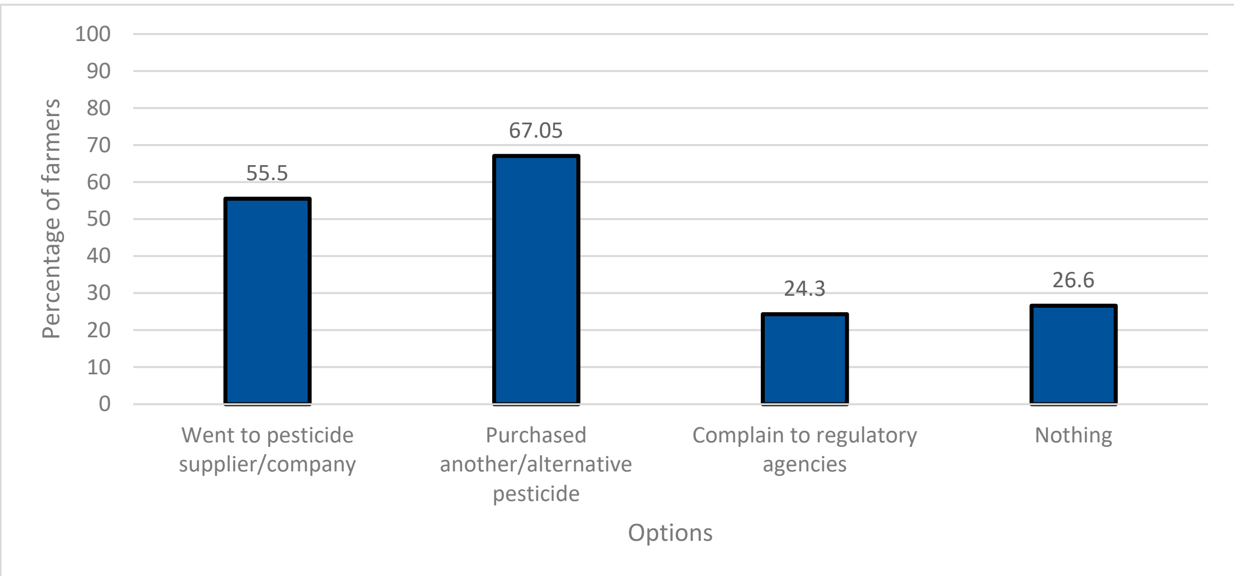

Figure 2. Behavior after discovering fraudulent pesticides (by the farmers who purchased fraudulent pesticides).

3.4. Farmers' Recognition of Fraudulent Pesticides

During the purchase of fraudulent pesticides, for all 15 items being assessed (Table 7), the recognition level of fraudulent pesticides ranged from low to moderate. The farmers rated "Be sure of the period until the expiry date" as having the highest level of recognition (mean = 2.81; SD = 0.86), while "If a product appears suspicious, contact your supplier or manufacturer's representative" as having the lowest level of recognition (mean = 1.97;

SD = 0.85). Overall, the findings in Figure 3 show that most of the farmers (55.8%) had insufficient knowledge in terms of recognizing fraudulent pesticides during their purchase, while less than a third (30.7%) had moderate recognition, and only 13.5% had a high level of recognition of fraudulent pesticides.

Table 7. Farmers' recognition of fraudulent pesticides.

Statements	Mean	SD
The label must contain information on the product registration number from the Ministry of Agriculture.	2.57	0.99
Buy only from authorized distributors or retailers.	2.86	1.10
The label must include information about the manufacturer, importer, directions for use, safety, and first aid.	2.61	0.91
Be sure of the period until the expiry date. Most genuine pesticides have a shelf life of 2–3 years, while fraudulent pesticides may have an expiry date of up to 5 years.	2.81	0.86
Ask the seller to provide a proper invoice with the trademarked product.	2.19	0.83
Be wary of very low prices compared to genuine pesticides.	2.40	0.92
If a product appears suspicious, contact your supplier or manufacturer's representative.	1.97	0.85
If you purchased a fraudulent pesticide or if you suspect that someone is producing or selling such goods, report the seller to trading standards or for fraud.	2.09	0.86
Holograms do not exist or are different from the original.	2.44	0.76
The label is not badly stuck onto the container and is not easily removed.	2.72	0.82
The cap of the container is similar to the original and is properly sealed.	2.71	0.83
Ensure that the logo/trademark on the container or label looks similar to the original.	2.57	1.15
Be sure that the shape of the container is similar to the original (quality of materials, color, etc.).	2.64	1.08
Be sure that the format of the pictograms is in correct order and distributed as the original.	2.64	0.85
Avoid partial or incomplete labels, which is a common sign of an illegal product. The label must be written in Arabic.	2.52	0.90

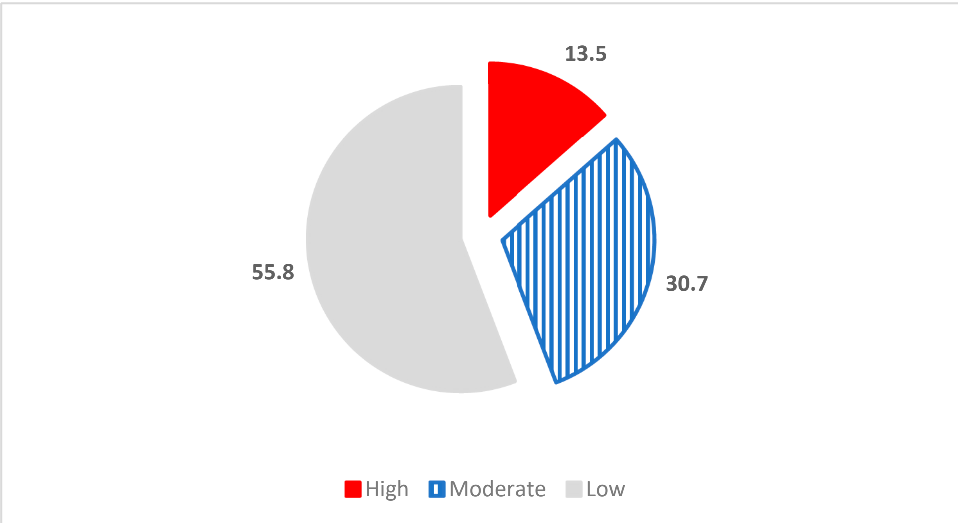

Figure 3. Level of the farmers' recognition regarding fraudulent pesticides.

3.5. Factors Influencing the Farmers' Purchasing Behavior Regarding Fraudulent Pesticides

To determine the factors that influence the farmers' purchasing behavior regarding legal versus fraudulent pesticides, a binary logistic regression model was specified and estimated (Table 8). The results indicate a set of predictors that reliably distinguished between those farmers who had purchased fraudulent pesticides and those who had not (Chi-square = 423.84, $p < 0.01$, df = 9). Nagelkerke's R^2 of 0.873 indicates a strong relationship between the dependent and independent variables. The overall prediction success was 95.7% (96.8% for not purchased and 92.6% for purchased). The results indicate that education level ($p = 0.00$), farming experience ($p = 0.001$), and recognition of fraudulent pesticides ($p = 0.00$) were the main variables that had a significant influence on the purchasing behavior regarding fraudulent pesticides in the study area. On the contrary, the other independent variables included in the model were not significant predictors of farmers' purchasing behavior regarding fraudulent pesticides.

Table 8. Factors influencing the purchasing of fraudulent pesticides.

Variable	Coefficients	Odds Ratio	Std. Err.	z	$p > z$
Constant	–25.734	0.000	0.000	36.384	0.000
Age	–0.315	0.730	0.572	0.320	0.572
Farm size	–0.004	0.996	0.088	2.916	0.088
Farming experience	0.116 **	0.891	0.001	11.741	0.001
Recognition	0.468 **	1.597	0.000	56.556	0.000
Off-farm income	–1.222	0.295	0.060	3.541	0.060
Education level	0.191 **	1.211	0.000	23.218	0.000
Extension as a source of information	0.083	1.087	0.887	0.020	0.887
Pesticide training experience	0.782	2.186	0.492	0.473	0.492
Perception of risks	–0.040	0.961	0.032	1.511	0.219
Chi-square (9) = 423.84 **; Nagelkerke's R^2 = 0.873; Log likelihood = 113.26					

** means statistically significant at 1%.

4. Discussion

Combating the production and distribution of fraudulent pesticides is a continuous concern for all actors of the pesticide supply chain in order to reduce their adverse impacts on the industry, farmers, and the environment. The present study assessed the current level of farmers' perceptions, purchasing, and recognition regarding fraudulent pesticides. Furthermore, this study assessed how farmers with behavioral heterogeneity and different socioeconomic characteristics purchase fraudulent pesticides in the study area. The insights into farmers' behaviors regarding fraudulent pesticides from this assessment enrich existing literature in the field, which are mainly based on measuring the quality of these pesticides as compared to authentic products. Additionally, the study provides a series of guidelines for designing extension programs and advisory services to raise awareness among farmers. While farmers' actual purchasing rates of fraudulent pesticides have not previously been documented in Egypt, these results are consistent with the country's 2030 vision of developing an active framework for tackling counterfeit and illegal pesticides on the agricultural market [46].

A growing number of purchases of fraudulent pesticides was observed in the study area. Our findings highlight that an overwhelming number of farmers have suffered from non-deceptive purchasing. The results are consistent with those of Kassem and Alotaibi [12], who found that 73.5% of farmers have purchased fraudulent pesticides in Saudi Arabia. In Uganda, a study conducted by Ashour et al. [17] found that 41% of farmers believe that local herbicides are counterfeit. This study also showed that among a large sample of herbicides collected, 30% contained less than 75% of the active ingredient advertised. Furthermore, another study conducted a market survey of fraudulent pesticides in Mali and found that counterfeit and illegal pesticides accounted for approximately 26% of all pesticide volumes sold [16]. Another market survey conducted in Egypt to monitor the counterfeit situation for a pesticide widely used in Egypt (abamectin) [39] showed that among the samples collected, 42.86% were not registered through the Egyptian Agricultural Pesticides Committee. Additionally, the percentage of the active ingredient in 71.4% of the samples was less than the acceptable limit, while 14.3% of the samples did not contain any abamectin. This result might be due to the fact that more than half of the farmers did not have good education (Table 2). Less-educated farmers do not have the capability of increasing their knowledge about the efficiency of counterfeits or reading label information, or, consequently, differentiating between original and fake products. Moreover, this result might also be because the majority of farmers rely on pesticide retailers as the main source of information about pesticides (Table 2). Pesticide dealers may not be considered as a trusted source for information in some cases. As indicated by Lekei et al. [47], some pesticide retailers, particularly unauthorized shops, may deceive farmers about the performance and effectiveness of pesticides in order to guide them toward certain products in pursuit of profit and as a kind of product advertisement. Meanwhile, as noticed during the field study, some dealers offer pesticides to farmers on a credit basis. This method may build trust-based relationships. The findings also highlighted that among those farmers who purchased fraudulent pesticides, the majority of them expressed that they had purchased such pesticides due to their low price. This might be a result of those farmers purchasing these pesticides for their price advantage in the belief that their quality is satisfactory. This result is consistent with the results of [28], who confirmed that the financial and accessibility criteria ranked second after the performance and effectiveness criteria in terms of importance when farmers select and use pesticides. Therefore, pesticide companies should adopt price-related anti-counterfeiting measures by implementing two mechanisms: first, by introducing lower-price product entry lines to reduce price gaps; second, by reviewing and reducing market, transaction, and production costs to minimize the risk of others undercutting the cost of the product [48–50].

However, the use of visual inspection for detecting fraudulent products is the first step in an overall strategy against fraudulent pesticides, even though this approach is not reliable for detecting counterfeits in most cases. In this context, our findings show that most farmers identify fraudulent pesticides based on their low efficiency, which may indicate that there is resistance to it. This means that farmers face difficulties in accurately identifying fraudulent pesticides during phase of the cycle from purchasing to spraying. This might be because farmers lack sufficient knowledge of the different methods of counterfeiting. Furthermore, we doubt that a farmer would go through a list of chemicals to check that everything was legal. According to Figure 3 in this paper, most farmers do not know how to clearly detect frauds through a visual assessment of the product label and packaging. Furthermore, according to Figure 1, over three-fourths of farmers make their assessment after spraying in their fields, based on the poor results obtained. But many other factors affect spraying efficacy—including time of day, wind speed, and nozzle settings. Poor application methods rather than fraud are possibly to blame for poor pest control results. Ashour et al. [17], for example, found only a weak relationship between farmer assessment of fraud levels and the actual quality of the herbicide glyphosate found in the local market. In fact, distinguishing counterfeits is even more difficult and, in most cases, requires dogs or lab testing, unless the fake is so poor. This conclusion was confirmed by the survey work conducted in Mali on this issue by Haggblade et al. [16], who took suspected counterfeits to the local registered importers for assessment. The results showed that importers could not tell, in some cases, whether the products were counterfeit or authentic from the label alone. To really know, they had to pull a sample from the bottle and test the chemical signature—not necessarily of the active ingredient, but of all of the co-formulants as well. Their labs could distinguish counterfeits readily from the spectrometry. However, simple visual inspection of the label is not always reliable, even for authorized importers. Besides lab testing methods such as biological and physiological indicators, there are chemical signatures, breakdown spectroscopy, and near-infrared spectroscopy [51,52]. Over the past few decades, a variety of digital anti-counterfeiting measures have been developed, from barcodes to holograms, radio frequency identification tags, and invisible pigments, inks, and infrared markers, and more recently, embedded nanotechnology-based solutions to ensure the full traceability and accurate detection of fraudulent products [9,53–55]. However, such techniques could be stand-alone systems that do not encourage collaboration among stakeholders in overcoming challenges such as developing a uniform protocol for inspection, surveillance, and monitoring, and using a platform to register pesticides [54,56,57].

To protect agribusiness against fraudulent pesticides, farmers are strongly advised by authorities to follow the recommended precautions to minimize the risks of buying and using these pesticides. Examining recognition level enabled an assessment of the extent to which respondents were practicing precaution recommendations. In particular, a medium variation in the respondents' recognition of fraudulent pesticides was observed in the present study. Specifically, farmers' recognition level had fallen to a low or moderate level for all of the practices investigated. This might be attributed to the farmers' lack of knowledge about the importance of anti-counterfeiting measures as the main component of combating counterfeit and illegal pesticides on the market. Other possible explanations for this result could be due to the farmers' inability to visually distinguish a legitimate product from a sophisticated fake copy due to the continuous improvement of counterfeit technology. The findings are in agreement with those of Zimba and Zimudzi [58], who argued that 22.7% of Zimbabwean farmers stated that they could distinguish between counterfeit and genuine pesticides to a large extent. Gharib [59] emphasized the need for awareness-raising and education activities for farmers on how to identify high-quality genuine agricultural inputs. Such programs may be particularly valuable for helping farmers make informed purchasing decisions when fraudulent pesticides exist on the market [26]. This education should also include a clear indication of who to contact for further information or a recommendation to report any suspicions in relation to fraudulent pesticides [60]. Globally, several industry-led initiatives have been piloted to address counterfeiting. The end-user authentication initiative conducted in Ghana is one example of verifying brand schemes [23]. In this initiative, CropLife (funded by Bayer) piloted the use of "Holospots" on Confidor, an insecticide for cocoa. Each container was marked with a hologram, which was verified by viewing under direct light and tilting the label. The user then texts in the numerical code shown to assess the authenticity of the product results.

The results of the binary logistic regression model indicated that the farming experience variable holding all other things constant is an important factor that influences farmers' purchasing behavior regarding fraudulent pesticides. The variable of farming experience positively influenced their purchasing behavior and was statistically significant at the 1% significance level ($p = 0.001$). The coefficient of the farming experience of the farmers was positively associated with their purchasing behavior regarding fraudulent pesticides, which indicates the orientation toward non-purchasing among the more experienced farmers. An additional year in the farming experience of the farmers increased the log odds of not purchasing fraudulent pesticides (versus purchasing) by approximately 0.891 times (odds ratio = 891). Again, the farmers who had purchased fraudulent pesticides had a lower mean level of farming experience when compared to those who had not. A probable explanation for this finding is that more experienced farmers are more concerned about the health effects of fraudulent pesticides, as well as more aware of authorized and trusted pesticide shops compared to less experienced farmers. Previous studies have examined farmers' pesticide use and safety behavior, providing similar evidence to our findings [61–64].

The variable of the education significantly and positively influenced the purchasing behavior regarding fraudulent pesticides. A higher level of education was associated with farmers being more likely not to purchase fraudulent pesticides, in comparison to the group of less-educated farmers. When an additional year of education was attained by the farmers, the results showed that such farmers were approximately 1.2 time (odds ratio = 1.121) more likely not to purchase fraudulent pesticides (statistically significant at the 1% significance level ($p = 0.00$). Education is a helpful tool for farmers in analyzing the risks associated with the use of fraudulent pesticides, following the features and methods of recognition (visual inspection and analytical methods, as possible), and making decisions about the best options to purchase [17,60]. These results are in line with other studies that examined farmers' behavior in pesticide use in general, such as the works by [29,31,65,66].

The results showed that the variable of farmers' recognition of fraudulent pesticides was positively related to the likelihood of a farmer not purchasing such pesticides. The results in Table 8 show that those farmers who had higher recognition levels were more likely not to purchase fraudulent pesticides by approximately 1.795 times (odds ratio = 1.795) (statistically significant at the 1% level ($p = 0.00$) compared to farmers who had lower recognition levels. This shows that in terms of the non-purchase of fraudulent pesticides, as farmers' recognition level changed in a positive way, they were more likely not to purchase such pesticides. These results confirm the findings of [12,16], who found that farmers' adoption of recommended precautions during the purchase of pesticides had an effect on their fight against counterfeit and illegal pesticides on the market, suggesting that farmers' recognition could be linked to their avoidance of the purchase of fraudulent pesticides.

This study has certain limitations that should be taken into account. First is the inclusion of data only from a random sample of farmers from one governorate, which means that the study cannot be generalized to a national level or to other countries. Second, we analyzed their purchasing behavior using a dichotomous question (yes/no). This approach did not allow us to accurately measure the continuity of purchasing. In other words, we were unable to differentiate between a farmer who purchased fraudulent pesticides many times and a farmer who had purchased them only once. Therefore, future studies should include the intensity of purchasing during a specific period. Third, this study relied mainly on self-reports of farmers' recognition levels. This led to an inability to assess whether farmers were able to correctly detect fraudulent pesticides. Thus, future studies should examine the relationship between farmers' recognition level and the measured quality. Finally, many more factors such as subjective norms, beliefs and values, costs and benefits, behavioral control, and government policy are also worth investigating.

5. Conclusions

To the best of our knowledge, this study is one of the first to examine farmers' recognition and purchasing behaviors regarding fraudulent pesticides. Our findings highlight that despite Egyptian farmers having a high perception of the health and environmental risks associated with fraudulent pesticides, the percentage of farmers who have experienced the purchase of such pesticides is high. Some of the key reasons for the use of non-genuine pesticides are difficulty in differentiating between genuine and non-genuine pesticides, the influencing power of distributors/retailers, and the low price of non-genuine pesticides. However, an in-depth examination of the influence of independent variables on farmers' purchasing behavior indicated that farmers with more experience in recognizing fraudulent pesticides were more likely not to purchase these pesticides. In the same sense, non-purchasing behavior was positively associated with age and farming experience. In a practical sense, this study provides insights into the role that should be followed by farmers to tackle fraudulent pesticides, particularly during the purchasing stage. The policy implications of this study are multifold. Given that most farmers rely on pesticide retailers for information on pesticides, the government, along with different stakeholders, should organize training programs for the recognition of fraudulent pesticides. Moreover, developing an up-to-date list of all legally registered pesticides as well as implementing random inspection over pesticide distribution enterprises should be carried out. For farmers, awareness campaigns using new information technologies are required. These programs should aim to enhance knowledge among farmers about the negative consequences of using fraudulent pesticides, the main types of fraudulent pesticides, the features and methods of recognition, the authentication of the genuineness of pesticides through mobile phones, and how farmers can notify authorities of suspicious pesticides or activity. Due to the scarcity of research on farmers' behavior with regard to fraudulent pesticides, more research in this area is needed to bring more diverse perspectives from different countries. This study shows the need for more comprehensive empirical research to estimate the amount of fraudulent pesticides in circulation rather than relying on a simple yes/no variable, by conducting a quantitative assessment to estimate the levels of fraud and disaggregating the results by active ingredient. Finally, suggesting an intervention framework for combating fraudulent pesticides in the context of agricultural knowledge and innovation systems could also be an interesting topic to consider.

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