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Published Version

Kassem, H. S., Mosa, A., Bhattacharya, M. ORCID: https://orcid.org/0000-0002-9328-0317, AbouElnaga, M., Elagamy, M., Atiya, D., Elgamal, B. and Osbahr, H. ORCID: https://orcid.org/0000-0002-0130-2313 (2025) Plastic residues and microplastics in agroecosystems: how Egyptian farmers perceive the risks? Frontiers in Sustainable Food Systems, 9. 1490908. ISSN 2571-581X doi: 10.3389/fsufs.2025.1490908 Available at https://centaur.reading.ac.uk/128952/

To link to this article DOI: http://dx.doi.org/10.3389/fsufs.2025.1490908

Publisher: Frontiers

frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 13 February 2025
DOI 10.3389/fsufs.2025.1490908

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RECEIVED 03 September 2024
ACCEPTED 30 January 2025
PUBLISHED 13 February 2025

CITATION
Kassem HS, Mosa A, Bhattacharya M, AbouElnaga M, Elagamy M, Atiya D, Elgamal B and Osbahr H (2025) Plastic residues and microplastics in agroecosystems: How Egyptian farmers perceive the risks? *Front. Sustain. Food Syst.* 9:1490908. doi: 10.3389/fsufs.2025.1490908

Plastic residues and microplastics in agroecosystems: How Egyptian farmers perceive the risks?

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The widespread presence of microplastic contamination is now recognized as an evolving issue with detrimental effects on agroecosystems. In response, governments and environmental organizations have emphasized the severity of plastic residues and microplastics (MPs) to the public, urging responsible and sustainable plastic use. However, limited research has been conducted to investigate farmers' perceptions of plastic pollution. This study aims to identify the various risks—environmental, economic, health, and social—associated with plastic residues and MPs in three governorates of Egypt. The study found that 48.3% of farmers exhibited a low level of awareness regarding microplastic contamination. Despite this, most farmers perceived MPs as a significant threat to the well-being of their communities. The accumulation of plastic residues has led to aesthetic pollution, identified as one of the most prominent social risks. Among environmental risks, air quality contamination was highly recognized. However, the impacts of MPs on soil and water contamination, agricultural productivity, and animal health remain areas where farmers lack a comprehensive understanding. The findings revealed that farmers' levels of awareness were positively influenced by factors such as plasticulture size, the diversity of plasticulture systems, years of plasticulture utilization, and geographical location (specifically, the Giza governorate). Conversely, satisfaction with plastic quality had a significantly negative effect on farmers' perceptions. These results highlight the urgent need for awareness programs and campaigns targeting farmers to educate them about the hazards associated with plastics and MPs. Additionally, policymakers and other stakeholders in the plastic value chain must collaborate to address and mitigate the problems caused by plastics and MPs in agriculture.

KEYWORDS

plastic residues, perception, sustainable agriculture, farmers, microplastics (MPs)

1 Introduction

Over the past two decades, agricultural innovation in plastic mulch has led to adoption of a diverse range of plastic products to increase the productivity of food crops. These include mulch films, tunnel and greenhouse films and nets, irrigation tubes and driplines, bags and sacks, silage films, bottles, coatings on fertilizers, pesticides, seeds, and plant protectors (Barrowclough et al., 2020). Accordingly, the trade of plastic products has expanded significantly in the last ten years due to the promotion of plastic mulch and the benefits to agricultural operations (Chen Y. et al., 2021). According to the 'Plastic the Facts 2022' report issued by Plastics Europe (2021), the annual worldwide output of plastic has increased rapidly, reaching a total of 390.7 million tons in 2021. In terms of agricultural plastic use, the Food and Agriculture Organization of the United Nations (FAO, 2021) states that agricultural value chains used 12.5 million tonnes of plastic products in plant and animal production in 2019.

However, large-scale management of plastics can generate micropollution due to the accumulation of plastic waste, which degrades to smaller fragments known as particulate plastics. These small pieces can be further categorized as MPs (< 5 mm) and nanoplastics (< 0.1 μm) (Andrady, 2017; Batista et al., 2022). Escalating levels of plastic pollution are indicative of systemic shortcomings throughout the whole plastic life cycle, encompassing manufacture, use, waste disposal, and the secondary markets for recovered material (Hou et al., 2018). In this sense, the 2019 study conducted by the World Wide Fund for Nature (WWF, 2019) examined the present condition of plastic pollution in Mediterranean nations. Based on this data, the Mediterranean area ranks as the fourth largest global manufacturer of plastic items. Their findings revealed an annual influx of 0.57 million tons of plastic into the Mediterranean waterways. Significantly, around 6.6 million tons of plastic waste is improperly handled each year in the Mediterranean region, but mishandling rates differ significantly among nations. Egypt, Turkey, and Italy are primarily responsible for the majority of unmanaged waste in the area, accounting for 42.5, 18.9, and 7.5%, respectively.

Plasticulture systems may have adverse effects on terrestrial and aquatic environments in multiple ways. Plastic residues and MPs at the agricultural production level have a negative impact on species diversity, nutrient availability, and microorganism activities, ultimately leading to a decreased yield (Khalid et al., 2023; Yang et al., 2021). Furthermore, these residues also have significant environmental consequences. Firstly, it leads to soil degradation, hindering the flow of nutrients and moisture penetration, and impeding root development and crop growth (Qi et al., 2023; Rai et al., 2023). Furthermore, it involves the direct introduction of carbon, microbes, and attached compounds into the soil, which indirectly impacts the soil microclimate and atmosphere (Greenfield et al., 2022; Uwamungu et al., 2022). Moreover, waste plastic film causes higher soil temperature and, in turn, may potentially enhance the emission of greenhouse gases by altering the carbon output intensity (Akhtar et al., 2022; Greenfield et al., 2022; Qiang et al., 2023). Studies have also shown that using plastic mulches increases runoff volume and velocity (Han et al., 2022; Nguyen et al., 2023). Aside from plastic residues, runoff may contain post-mulching applications of insecticides, fungicides, or fertilizers. These toxins can infiltrate nearby water sources and cause harmful impacts on the ecological well-being of aquatic organisms (Kumar A. et al., 2023; Kumar V. et al., 2023).

Although plastic mulch offers considerable economic advantages compared to conventional agriculture, such as improved water efficiency, weed management, better crop yields, and off-season growing, it also entails economic hazards. These risks involve the costs of purchasing and disposing of materials and the additional time and work required for laying and removing the mulch, residues, and waste (Arancibia and Motsenbocker, 2008; Battelle, 2019). Moreover, plasticulture has the potential to significantly and adversely affect community health. The leaching of chemicals from plastic mulch might potentially impact health effects in regions where mulch is extensively utilized (Ghosh et al., 2023; Nguyen et al., 2023; Rahman et al., 2021). Similarly, the incineration of mulch has an adverse impact on the air quality, presenting health hazards to nearby residents (Salama and Geyer, 2023; Somanathan et al., 2022; Yao et al., 2022). Regarding animal health, plastic residues and MPs found in agricultural fields and rangelands can potentially enter the rumens of goats, leading to the presence of plastic in their digestive systems. In certain instances, these residues have been linked to the mortality of the animals (Urli et al., 2023; Yuan et al., 2022). The usage of plastic mulch also has social consequences in terms of how the public perceives rural areas. Researchers have established that individuals perceive green landscapes as the most visually pleasing in comparison to regions with plastic mulch, plastic waste, or plastic residues (Yao et al., 2012). Plastic mulches are reported to cause "aesthetic pollution" and can have cultural effects on humans (Battelle, 2019; Picuno et al., 2011).

Farmers have a dual role in managing the risks of plastic pollution; they are exposed to risks and generate them (Mihai et al., 2021; Shah and Wu, 2020). Risk may be broadly defined as the likelihood that conditions may result in outcomes that influence aspects of human values (Siegrist and Árvai, 2020). According to Hansson (2010), risk perception encompasses the subjective evaluation, whether implicit or explicit, of the probability or uncertainty and the desirability or undesirability of unknown outcomes that result in either advantages or disadvantages. Measuring risk perceptions requires a deep understanding of two issues. First, calculating risk perception relies on quantitative risk assessments and qualitative aspects associated with the hazards themselves and the individuals experiencing them (Kortenkamp and Moore, 2010). Second, the nature of environmental risks is distinguished by a significant level of ambiguity and complexity, resulting in intricate cause-and-effect linkages and a multitude of outcomes (Steg et al., 2012). Furthermore, these tendencies arise from the acts of several persons; therefore, addressing them requires the collective efforts of many individuals (Visschers and Siegrist, 2018). Finally, the repercussions of their actions are frequently postponed in time and far-reaching in location (Felipe-Rodriguez et al., 2023). Consequently, it is crucial to understand the social perception to enhance behavioral change towards plastic pollution mitigation, information that is vital to implementing solutions (Janzik et al., 2023). Given the limited number of research on risk perception of MPs, which is still in its early stages, it is challenging to make definitive assertions on the formation of perceptions (Catarino et al., 2021; Felipe-Rodriguez et al., 2023). Undoubtedly, numerous socio-demographic characteristics were mentioned to have an influence on perceptions of risks related to plastics residues and MPs (Catarino et al., 2021; Chen J. et al., 2021; Felipe-Rodriguez et al., 2023; King et al., 2023; Miguel et al., 2024). Moreover, increased degrees of knowledge on this matter are often linked to higher risk assessments (King et al., 2023; Kneel et al., 2023; Miguel et al., 2024; Xue et al., 2021). Additionally, the risk perceptions of individuals are influenced by their worldviews and beliefs (Felipe-Rodriguez et al., 2023).

Even though there has been increasing interest in studying the characterization, sources, and pathways of agricultural plastics residues and MPs in aquatic and terrestrial ecosystems in recent years, there is a significant lack of empirical research focused on farmers' perceptions of the risks associated with plastic pollution and the factors that influence these perceptions. Some studies investigate the perception of agricultural mulch film contamination from the perspectives of

Chinese farmers (Chen J. et al., 2021; Xue et al., 2021) and studies conducted in Ireland examine the manner in which farmers view the environmental impacts of plastic pollution (King et al., 2023; Kneel et al., 2023). The remaining studies focus on assessing the risk perceptions of MPs among the public (Deng et al., 2020; Janzik et al., 2023; Miguel et al., 2024; Wu et al., 2023; Yoon et al., 2021). Few studies have specifically examined the perception of different types of hazards (such as environmental, economic, health, and social impacts) related to the usage of agricultural plastic in farmland. Furthermore, there is a lack of research on this subject within the Egyptian context. Accordingly, the views of Egyptian farmers were analyzed to generate insight into their perceptions. Such findings are critical to assist in the formulation of appropriate policies to regulate and coordinate waste management and promote zero leakage plastic mulch and as a result reduce the amount of plastic pollution that enters Egypt's terrestrial environment. Furthermore, the process of analyzing the factors that influence farmers' perceptions is beneficial in tailoring the awareness and mobilization activities according to the priority interventions' target audience. This, in turn, may effectively address the issue of negative impacts of plastic pollution on agroecosystems. Therefore, this paper aims to address the following objectives: (i) analyze farmers' perception of the risks associated with plastic residues and MPs, and (ii) identify the factors that influence these perceptions.

2 Methodology

2.1 Description of study area

The study was conducted in the Northern East, Central, and Upper regions of Egypt. Three governorates – Dakhalia governorate (from the Northern East Region), Giza governorate (from the Central Region), and the Minya governorate (from the Upper Region) were selected (Figure 1). These governorates were purposively selected according to the number of farmers who own and manage four types of plasticulture systems under investigation, namely plastic mulch in the open field, low polytunnel, high polytunnel, and not houses during the agricultural season 22/2023 (MALR, 2022).

The Minya governorate is geographically divided into nine districts (28.0772° N and 30.0926° E), covering a total land area of 32,279 km². The population was estimated to be over 6,000,000 individuals in 2020 (CAPMAS, 2021). According to meteorological data from 2002 to 2020, January exhibited the lowest recorded temperature of 6.04°C, while the highest recorded temperature of 37.30°C was recorded in August. The governorate experienced an average maximum temperature of 30.36°C, while the average lowest temperature recorded was 15.72°C. The average monthly rainfall exhibits a significantly low value, with the highest recorded monthly rainfall being 3.08 mm (Nour-Eldin et al., 2023). The governorate is recognized as an agricultural region, with around 205,000 hectares of agricultural land. This area accounts for approximately 6.5% of Egypt's total agricultural land. The primary agricultural crops are cotton, wheat, corn, vegetables, sugarcane, grapes, soybeans, watermelons, and bananas (MALR, 2022).

Dakhalia governorate is situated in the northeastern region of Egypt (31.1400° N and 31.2200° E). The overall land area of the governorate is 3,500 km², with agricultural fields accounting for 37% of this governorate. The governorate exhibits a population of approximately 7,000,000 individuals, which is distributed across 22 administrative districts (CAPMAS, 2021). Agricultural activities in Dakhalia governorate predominantly involve crop cultivation, such as vegetables, citrus fruits, rice, wheat, corn, sugar beet, Egyptian clover,

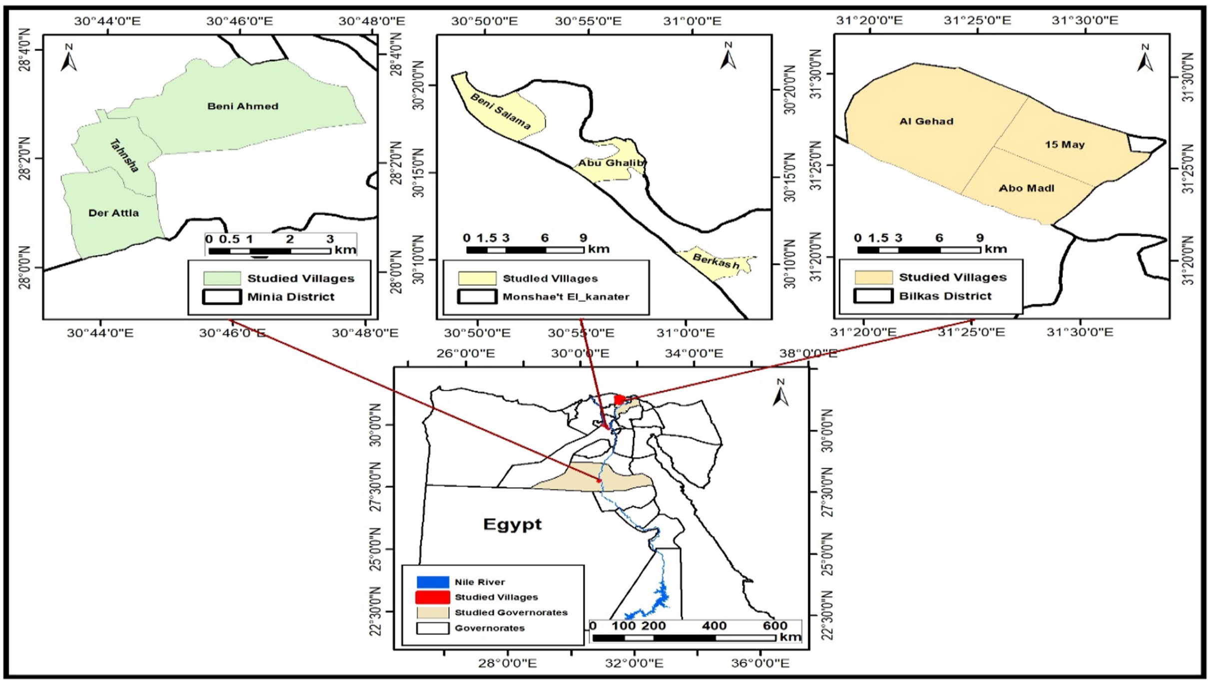

FIGURE 1
Map of the study area.

and grapes (MALR, 2022). The governorate is distinguished by a hot and dry summer climate and relatively low precipitation throughout the winter months. The range of temperatures spans from 15 to 33°C, with an average annual temperature of 20°C. Additionally, the total annual precipitation amounts to 57 mm (Abuzaid et al., 2021). Giza governorate encompasses a land area of 13,184 km^2 distributed across ten administrative districts (29.7618° N, 30.4616° E). The total agricultural area is around 100,000 hectares (CAPMAS, 2021). The average monthly rainfall is 20 mm, and the average annual temperature is 22.1°C (Climate Data, 2023). The predominant agricultural produce in this governorate is wheat, fava beans, onion, vegetables, corn, sesame, and peanuts (MALR, 2022).

2.2 Sampling and data collection

A two-stage random sampling technique was employed in order to choose the farmers who would participate in the survey, ensuring that the sample accurately represents the three governorates. The study selected one district in each governorate that demonstrates widespread utilization of plasticulture systems in farming activities. Minya, Bilkas, and Monshae't El Kanater districts were chosen in the governorates of Minya, Dakhalia, and Giza, respectively (see Figure 1). Three villages were randomly selected within each district, following recommendations from agricultural development officers at the district level. Therefore, the following locations were chosen for our study: Beni Ahmed, Tahnasha, and Der Attia from the Minya district; Al Gehad, Abo Madi, and 15 May from the Bilkas district; and Abu Ghalib, Berkash, and Beni Salama from the Monshae't El Kanater district. The study's population comprises all farmers in the nine villages that own and operate the four plasticulture systems throughout the agricultural season of 22/2023, with a total of 2,883 farmers. The data collection process involved the utilization of stratified proportional random sampling based on farm size. Farmers were classified into four categories: small (2 hectares or less), semi-medium (> 2–4 hectares), medium (> 4–10 hectares), and high (> 10 hectares). The number of farmers in each category was calculated in every village. A total of 351 respondents were included in the study using Yamane's (Adam, 2020) sample size determination formula, with data collected from thirty-nine farmers in each village. The survey was performed during April 2023 and July 2023 and employed face-to-face interviews as a means of data gathering, utilizing a structured questionnaire as the primary instrument. In total, 300 farmers consented to participate and successfully finished the interview, obtaining a response rate of 85.5%.

2.3 Instrument and variable measurement

The data collection tool comprised three sections. Section one involved the demographic characteristics of the farmers, including age, farm size, farming experience, and cooperative membership. Section two included questions to describe plasticulture characteristics in terms of types of plasticulture systems adopted in the last year, experience in owning plasticulture systems, percentage of plasticulture systems size to total farm size in the last year, use of plastic mulch in the last year, and satisfaction with the plastic quality used in plasticulture systems. The third section focused on the farmers' perception of the risks associated with microplastic contamination. In this section, eighteen items related to the risks of MPs were identified according to the review of the literature (Battelle, 2019; Khan et al., 2023; Okeke et al., 2022; Tian et al., 2022; Yu et al., 2022).

The perception of risks was measured on a five-point Likert scale (5 = "strongly agree," 4 = "agree," 3 = "neutral," 2 = "disagree," and 1 = "strongly disagree"). In order to establish face validity, the questionnaire underwent a pilot study with ten farmers within the study area, whereby possible shortcomings were identified, and the clarity and comprehensibility of the questions were tested. The input was thoroughly examined and considered throughout the development of the final version of the questionnaire to enhance the instrument's reliability and validity. Cronbach's alpha formula was employed to assess the reliability of the perception scale. The Cronbach's alpha coefficient for the measure of perception was found to be 0.88, suggesting strong internal consistency and high reliability. During the presentation of the questionnaire, the researchers provided a comprehensive explanation of the study's objectives and emphasized the guarantee of anonymity for the obtained data. Participants were provided with a hard copy of the questionnaire and information sheet. The act of participation was completely voluntary, and those involved did not receive any form of remuneration. Written consent was obtained from all respondents who can read and write. Verbal consent was taken from illiterate farmers involved in the study using smart phone's voice recorder. The informed consent procedures were prepared and approved by the ethical criteria established by the University of Reading (Ref# APD 1911D).

The Min-Max Normalization technique, as applied by Ngarava et al. (2020), was utilized to standardize farmers' perceptions regarding the risks associated with microplastic pollution. On the one hand, this method scales data into a fixed range (e.g., [0, 1] or [−1, 1]), ensuring consistent feature ranges, which improves model convergence. Furthermore, it maintains the relative relationships between data points and performs well with uniform distributions (Aggarwal, 2015). On the other hand, this method is highly sensitive to outliers. In addition, the variability of the data may be reduced, and important patterns may be obscured by compressing all data to a fixed range [0,1] (or another interval). Using a specific range of responses (e.g., Likert scale) is useful in reducing the weaknesses of this method by making extreme outliers less influential. Furthermore, all responses are forced into discrete ordinal categories, reducing variability caused by extreme values and compressing skewed distributions' effects (Maimon and Rokach, 2005).

The Min-Max Normalization technique was employed to generate a numerical value that ranged from 0 to 1, utilizing the below calculation.

$$PI_{qi} = \frac{P_{qi}(\text{obs}) - P_{qi}(\text{min})}{P_{qi}(\text{max}) - P_{qi}(\text{min})}$$

The Perceptive Index of question I is denoted as PI_{qi}. The observed value of perceptive question i, abbreviated as P_{qi} (obs), global maximum value of question i (=5), represented as P_{qi} (max), the global minimum value of question i (=1), denoted as Pqi(min). The overall PI_{qi} for each respondent is calculated by the following formula:

$$PI_{overall(j)} = \frac{\sum_{i=1}^{n} PI_{qi}}{n}$$

where n is the number of perception questions (=18).

The overall perception of farmers was divided into five levels of 0.20 points each (totaling 1), following the five-point scale model of Ko (2005), as below: Very high: 0.81–1.00; High: 0.61–0.80; intermediate: 0.41–0.60; Low: 0.21–0.40; Very low: 0.00–0.20.

The Tobit model employed in this study was formulated in the following manner (Barros et al., 2018):

$$PI_i^* = x_i'\beta + \varepsilon_i, \varepsilon_i \sim N\left(0, \sigma^2\right)$$

$$PI_i^* = \begin{cases} PI_i^*, \text{if } PI_i^* > 0 \\ 0, \text{if } PI_i^* \leq 0 \end{cases}$$

The latent variable, PI_i^*, is only observable when its values exceed zero. The explanatory variables are denoted as x_i, with a vector β representing their coefficients, and ε_i representing the error term, which follows a normal distribution. The log-likelihood function L was optimized by the estimation of β and σ.

$$\max_{\beta,\sigma} \ln L = \sum_{PI_i > 0} \frac{1}{\sigma} \rho\left(\frac{PI_i - x_i'\beta}{\sigma}\right) + \sum_{PI_i = 0} \ln\left[1 - \tau\left(\frac{x_i'\beta}{\sigma}\right)\right]$$

The symbol ö represents the standard normal cumulative distribution function, whereas ñ represents the corresponding density function.

The Tobit model was employed in this study, where the dependent variable is censored at a single limit or both extremities. This is optimal when the observed values are truncated, and the true values outside the limit are unknown (e.g., right-censoring at a maximal threshold or left-censoring at 0). In contrast, ordinal regression is not suitable for continuous outcomes with censoring, as it is predicated on discrete ordered categories (Wooldridge, 2010). Moreover, The Tobit model treats the dependent variable as continuous before censoring occurs, preserving the complete information about the variable's distribution. Alternatives like ordinal regression classify data into ordered categories, leading to a potential loss of precision and statistical power (Amemiya, 1984).

Eleven explanatory variables were included in the Tobit model (Table 1), including age, education, farming experience, cooperative membership, plasticulture size, satisfaction with the plastic quality, multiplicity of plasticulture systems, years of plasticulture utilization, utilization of plastic mulch, Minya governorate, and Dakhalia governorate. These variables were selected based on a analysis of current literature, an assessment of local agricultural circumstances, and an investigation of commonly used approaches in managing plasticulture systems.

2.4 Data analysis

The data analysis and reliability testing procedures were conducted using Stata (v.16.1, StataCorp LLC, College Station, TX). Summary statistics and frequency distributions were employed as analytical tools to provide a description and interpretation of the data. The Tobit regression model was employed to analyze the factors that influence farmers' perceptions on the risks associated with microplastic contamination. The predetermined level of significance was chosen to be $p < 0.1$.

3 Results

3.1 Descriptive results of the socio-economic characteristics and the farming context

The demographic characteristics of farmers are presented in Table 2. The results show that age ranged from 20 to 85 years, with a mean age of 46.98 years. More than one-third of farmers (34.3%) were between 36 and 46 years old. Less than half of farmers (44%) had obtained secondary school, while 14% held higher education degrees. The average farm size was 5.29 hectares. However, it is worth noting that 35.8% of the respondents were classified as smallholders with land holdings of two hectares or less, while a small percentage (15.7%) had more than ten hectares. The findings also disclosed that 39% had a farming experience of between 26 and 35 years, with 30.7% 25 and 36 years; the average was 24.89 years. Moreover, the majority of the respondents (71.7%) were members of agricultural cooperatives, while 17.8% were not. Details of the demographic characteristics of the respondents at the governorate level are presented in Appendix Table A1.

A number of plasticulture systems adopted by farmers are depicted in Figure 2, where it can be noted that farmers owned and managed more than one type of plasticulture system within their farms. The primary cultivation system employed by the vast majority of farmers (94.3%) was the installation of low polytunnels. This is followed by the adoption of high polytunnels (12%), plastic mulch in open fields (11.7%), and net house systems (11%). Less than half of farmers (44.3%) had 8–16 years of plasticulture experience (Figure 3), with a mean of 17.26 years. As to the size of plasticulture systems as a percentage of total farm size (Figure 4), in the largest group (58.7%), plasticulture systems accounted for more than 75% of total farm size. For only 9.7% of farmers, it accounted for less than 26% of total farm size. Furthermore, 48% of farmers employ plastic mulch in their agricultural practices either as a standalone cultivation method or in conjunction with other plasticulture methods. In terms of farmers' satisfaction with the quality of plastic, the results in Figure 5 illustrate that most farmers (54.3%) expressed that the plastic material utilized as a plastic cover in plasticulture systems or as mulch is of an inferior quality. In contrast, it was found that 23.3% of farmers were highly satisfied with the quality of plastic. The foregoing plasticulture characteristics were measured at the governorate level, as shown in (Appendix Figures A1–A5).

3.2 Farmers' perception of microplastic pollution risks

Farmers' perceptions of the hazards associated with microplastic contamination in the three governorates are presented in Figure 6. Farmers residing in Giza governorate had a greater degree of perceptiveness (high and very high), with a percentage of 55%. In contrast, farmers in Minya governorate and Dakhalia governorate

TABLE 1 Description and measurement of variables used in Tobit regression model.

Variable	Explanation	Description and measurement	Expected sign
Independent			
AGE	Age	Years of age. Continuous variable.	–
EDU	Education	Education status of farmer. Dummy variable (1 if the farmer had at least secondary education; 0 otherwise).	+
FEP	Farming experience	Years of farming experience. Continuous variable.	+
COOM	Cooperative membership	Membership of agricultural cooperative. Dichotomous variable (no = 0; yes = 1).	+
PLS	Plasticulture size (%)	The percentage of plasticulture size to total farm size. Continuous variable.	+
PPQ	Satisfaction with the plastic quality	Farmers opinions toward the quality of plastic materials used in plasticulture systems. Dummy variable (1 if the farmer had at least high perceptions; 0 otherwise).	+/–
MPS	Multiplicity of plasticulture systems	Number of plasticulture system adopted by the farmers in the last year. Dummy variable (1 if the farmer had adopted more than one; 0 otherwise).	+
YPU	Years of plasticulture utilization	Average years of farming experience in manging plasticulture systems. Continuous variable.	+
UPM	Utilization of plastic mulch in last year	Applying plastic mulch either as a standalone cultivation method or in conjunction with other plasticulture methods. Dummy variable (1 if yes; 0 otherwise).	+
MGV	Minya governorate	Farmers who are surveyed in Minya governorate. Dummy variable (1 if the farmer residing in Minya governorate; 0 otherwise).	+/–
DGV	Dakhalia governorate	Farmers who are surveyed in Dakhalia governorate. Dummy variable (1 if the farmer residing in Dakhalia governorate; 0 otherwise).	+/–
Dependent			
PI	Perceptive index	Truncated: 0 (low)–1 (high)	

showed lower high and very high levels of perception, with percentages of 29.3 and 28%, respectively. Overall, most farmers (48.3%) exhibited a low level of perceived risks (low and very low) regarding microplastic contamination. A moderate level of perception was observed in 22.3% of farmers, while 29.3% were categorized as having a high and very high levels of perception. Details of each item regarding the risks associated with microplastic pollution are illustrated in Figure 7.

Farmers expressed concerns regarding the health and social issues linked to microplastic pollution, as seen in Figure 7. The findings in Figure 7 depicted that a majority of farmers (85% combined agreement) held the belief that MPs provide a substantial risk to the overall well-being of their communities. Specifically, 59% of farmers agree, while an additional 26% expressed total agreement. Furthermore, it is worth noting that a high proportion of farmers (62% agree and 23% fully agree) perceived agri-plastics and MPs as contributors to aesthetic pollution. Additionally, farmers (41% agree and 24% completely agree) held the belief that these plastics pose a hazardous threat to livestock. The deposition of MPs in soil has been identified as a factor that amplifies economic concerns. Farmers (44% in agreement and 18% in complete agreement) acknowledge the escalating expenses associated with the mitigation of microplastic pollution in the environment. In the same context, farmers voiced their apprehensions over potential environmental hazards. The following list presents the top five affected aspects that are widely perceived as environmental risks, arranged in descending order: contamination of air quality, with 63% of respondents agreeing and 29% completely agreeing; contamination of groundwater, with 48% agreeing and 20% completely agreeing; reduction in root growth, with 44% agreeing and 20% completely agreeing; degradation of soil structure and quality, with 45% agreeing and 18% completely agreeing; and increase in greenhouse gas emissions, with 37% agreeing and 24% completely agreeing. It is noteworthy to acknowledge that the impact of MPs on agricultural productivity remains a subject where farmers have not yet developed a comprehensive consensus. The survey conducted among farmers revealed that 20% agreed with the notion, while 33% expressed complete disagreement. Likewise, regarding the impact of MPs on animal health, 24% strongly agreed, and 33% strongly disagreed.

In order to determine the interrelations between variables included in the Tobit model, a correlation matrix for the variables investigated was performed, as shown in Table 3. In descending order, significant and positive associations were observed between the perceived risk and the following variables: utilization of plastic mulch ($r = 0.328$), plasticulture size ($r = 0.307$), years of plasticulture utilization ($r = 0.279$), cooperative membership ($r = 0.257$), multiplicity of plasticulture systems ($r = 0.255$), and farming experience ($r = 0.232$). In contrast, there was a negative relationship between the risk perception of MPs and the perceived quality of plastic. However, no significant relationship was found between farmers' risk perception of MPs and their age and education.

3.3 Econmetric model

Table 4 presents an overview of the variables that influence farmers' perception of microplastic contamination within the study area. The findings of the study reveal a set of factors that consistently differentiated between those farmers who had high perceptions and those who had not, where the Chi-square for the goodness of fit model

TABLE 2 Socio-economic profile of the respondents.

Variable	Category	Frequency (n = 300)	Percentage
Age (Years)	< 36	50	16.7
	36–46	103	34.3
	47–58	95	31.7
	> 58	52	17.3
Min	20		
Max	85		
Mean	46.98		
SD	11.42		
Education	Illiterate	45	15
	Primary school	81	27
	Secondary school	132	44
	University	42	14
Farm size (Hectares)	<= 2	106	35.3
	> 2–4	63	21
	4–10	84	28
	> 10	47	15.7
Min	0.27		
Max	30		
Mean	5.29		
SD	5.93		
Farming experience (years)	< 13	39	13
	13–24	117	39
	25–36	92	30.7
	> 36	52	17.3
Min	2		
Max	55		
Mean	24.89		
SD	11.92		
Cooperative membership	Yes	215	71.7
	No	85	28.3

is significant at the 0.01 level (chi-square = 127.10, $p < 0.01$, df = 11), justifying the use of a Trobit model for analysis. The findings indicate that many factors, including plasticulture size, years of plasticulture utilization, and location (specifically, Minya governorate and Dakhalia governorate), were shown to have a significant impact on individuals' perception of the hazards associated with microplastic contamination at 0.01 level. Additionally, the perception of plastic quality was also identified as a significant determinant, albeit at a lower significance level of 10%. The findings in Table 4 indicate that an increase in the size of plasticulture systems is associated with an increase in perceptions toward the risks associated with microplastic contamination. Likewise, if farmers have a longer farming experience in owning and managing plasticulture systems, they are likely to have a higher perception of the risks of microplastic pollution. However, an increase in the perception of plastic as being high quality was associated with a decrease in the perceptions toward the risks associated with microplastic pollution. The location results indicate that farmers from Minya and Dakhalia governorates are associated with low perceptions. In contrast, an increase in the number of farmers in Giza governorate increases the level of perceptions.

4 Discussion

Given the growing concern about agricultural plastic residues and microplastics (MPs), this study examines farmers' perceptions of the risks associated with MPs and explores how these perceptions vary based on socio-economic profiles and farming characteristics. The study addresses perceived risk across four dimensions: environmental, economic, health, and social. These insights contribute to the existing literature on farmers' perceptions of MPs and provide guidelines for designing awareness campaigns and extension programs tailored for farmers. Notably, this study is among the first to document farmers' perceptions of risks linked to plastic residues and MPs in Egypt. The findings align with Egypt's 2030 vision, which aims to establish a proactive framework for managing plastic waste in agriculture (MALR, 2016).

The findings have theoretical implications. Within the framework of Protection Motivation Theory (PMT), farmers with larger plasticulture systems, greater farming experience, and longer durations of plasticulture utilization are more likely to adopt preventive risk-avoidance measures. According to PMT, these farmers exhibit higher levels of risk perception, enhancing their risk appraisal. Their extensive use of plasticulture likely heightens their awareness of the adverse effects of plastic residues and MPs, motivating protective behaviors. Furthermore, dissatisfaction with plastic quality may encourage these farmers to adopt preventive measures, such as selecting higher-quality materials or managing plastic waste more effectively. Conversely, farmers from governorates with lower perception levels (e.g., Minya and Dakhalia) are less likely to engage in such behaviors, likely due to limited awareness or inadequate coping strategies. This underscores the need to strengthen both risk appraisal and coping appraisal—key components of PMT—through targeted education and interventions. By enhancing self-efficacy and response efficacy, such programs can bridge behavioral gaps and encourage the broader adoption of risk-avoidance practices.

One of the primary results of this research is that risk perception of MPs residues is highly perceived by only 29.3% of farmers in the study area. This means that farmers face difficulties in understanding the risks associated with agricultural plastics. This result might be due to several interconnected factors. Limited knowledge of the sources, pathways, and impacts of MPs on agricultural productivity, water quality, and soil health hinders farmers' awareness. In addition, the complexity of MP pollution, encompassing health, economic, and environmental dimensions, makes it challenging for farmers to understand its broader implications. This knowledge gap is further exacerbated by insufficient awareness and education programs tailored to address MP-related issues. Furthermore, farmers often prioritize immediate agricultural concerns over long-term environmental risks. This focus limits their capacity to recognize the multifaceted dimensions of MPs issue, as their attention is directed toward short-term and tangible challenges such as pest control, crop yield, or market demand. Accordingly, farmers may view MPs as a less urgent issue, perceiving their impacts as irrelevant or distant from their

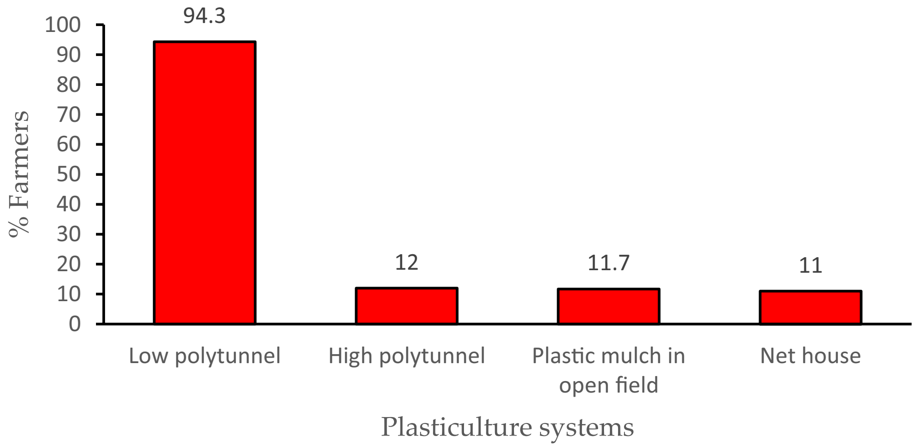

FIGURE 2
Types of plasticulture systems adopted by farmers.

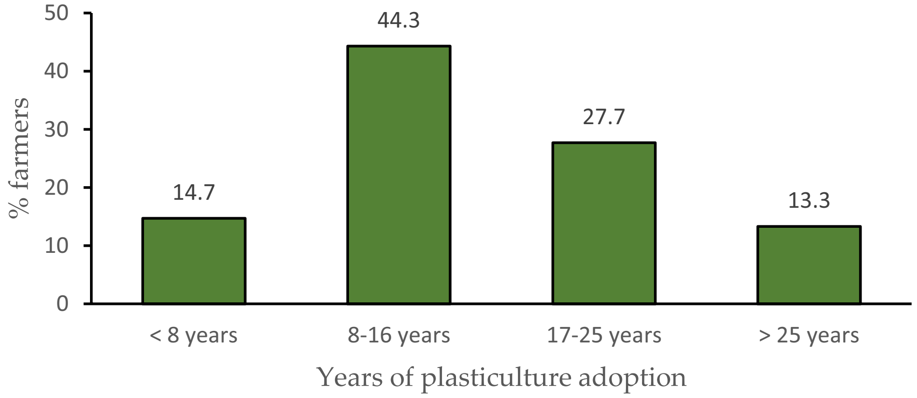

FIGURE 3
Farmers' experience in owning plasticulture systems.

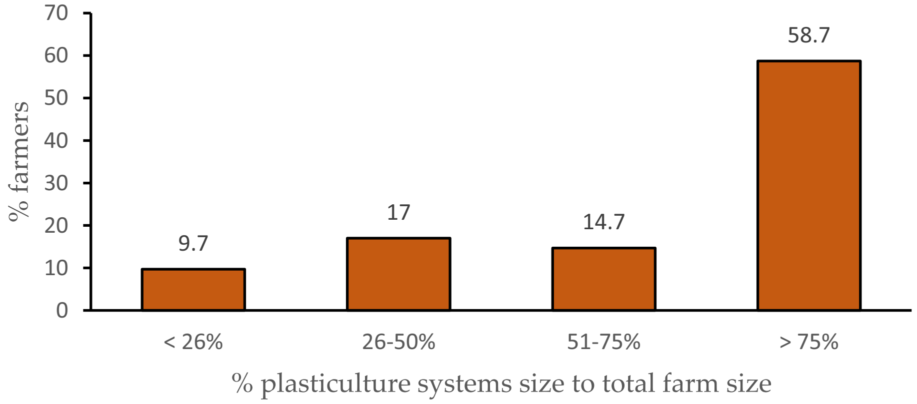

FIGURE 4
Percentage of plasticulture systems size to total farm size.

immediate agricultural practices. This mindset diminishes their motivation to adopt preventive measures against MPs pollution or seek information about this issue. In this regard, it is essential to note that the survey's dependence on self-reported perceptions introduces the possibility of recall bias, such as social desirability, which could potentially affect the accuracy of the results. Farmers may either

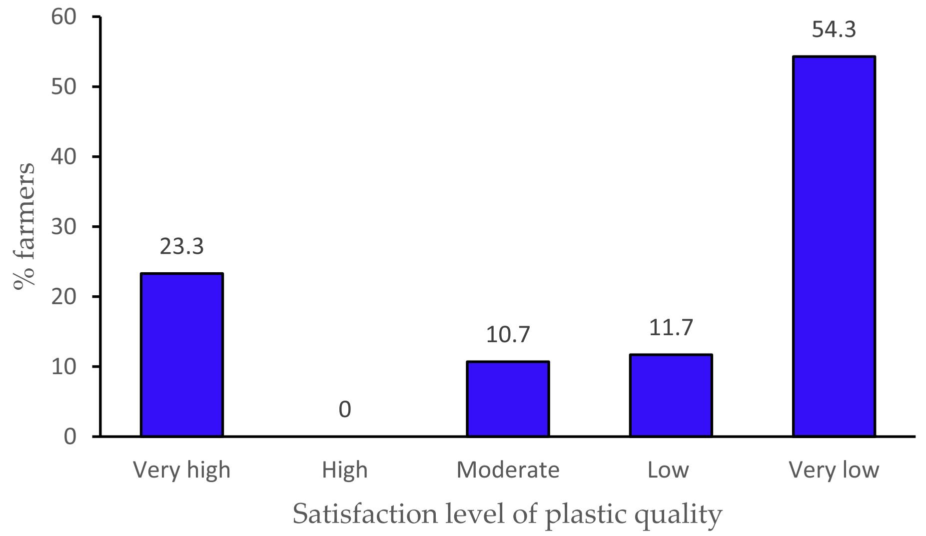

FIGURE 5
Farmers' satisfaction of plastic quality.

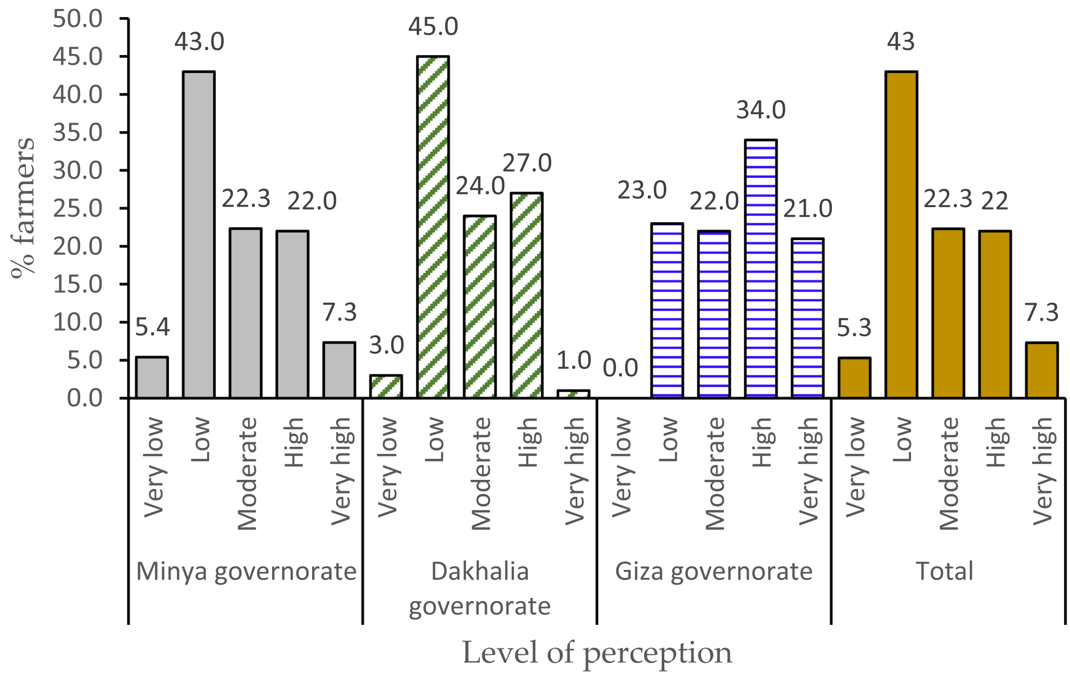

FIGURE 6
Farmers' perception of microplastic pollution risks.

struggle to avoid investigating their awareness of the risks of malpractices they undertook or overstate their views to align with perceived societal expectations.

Deng et al. (2020) pointed out that MPs may still be unfamiliar to the public. On the one hand, the low level of awareness contributes to a lack of motivation to engage in emission reduction efforts for MPs (Deng et al., 2020). On the other hand, such a situation prevents people from using appropriate strategies to mitigate microplastic contamination (Henderson and Green, 2020). This result supports the arguments of Henderson and Green (2020) and Pahl and Wyles (2017) that knowledge is crucial in altering people's perceptions and promoting environmentally conscious behavior. However, it is important to emphasize that knowledge is not only the determinant for forming perception. According to the theory of risk perception (Syberg et al., 2018), risk perception has eight drivers, including voluntariness, control, knowledge, timing, severity, benefits, novelty, and tangibility. In other words, the risk is perceived as more severe if a risk is

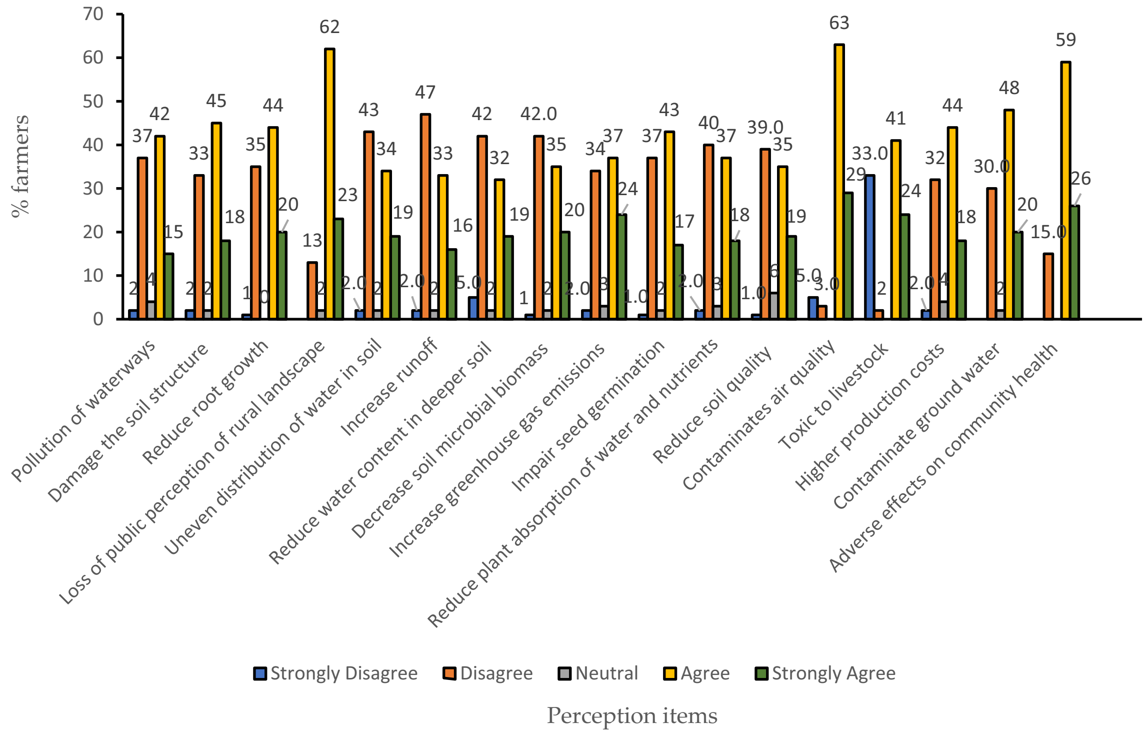

FIGURE 7
Distribution of farmers according to their view about risks associated with agricultural plastic.

imposed; is perceived to be uncontrollable; unknown; has instant and disastrous potential; affects high number of the population; without any obvious advantage; is associated with new technologies and novel entities, and is more tangible.

Assessment of perception levels enables an analysis of the extent to which respondents viewed the various risks associated with plastic pollution. In the current study, a medium variation in the farmers' perception of the adverse effects of plastic use in agriculture was observed. Specifically, farmers' perception was relatively high regarding the risks of MPs on community health, loss of public perception of rural areas, and air quality. However, the impact of MPs on soil and water contamination, agricultural productivity, and animal health remains a subject where farmers have not yet developed a comprehensive understanding. These findings suggest that farmers do not fully understand the complete picture of MPs consequences. This result confirms what was concluded previously regarding the effect of knowledge on perception. Additionally, socio-economic profile of farmers may play a vital role in interpreting the varying level of perception among farmers, and this will be clarified later. This variation in perception levels was highlighted in previous studies. In this context, a study conducted by King et al. (2023) found that many Irish farmers believed they had a better understanding of plastic pollution than microplastic contamination and its impact on aquatic ecosystems. Another study conducted in China by Xue et al. (2021) found that 53.78% of respondents believe that agricultural mulch film has the potential to contaminate farmland, while 33.98% hold the view that it does not produce pollution. Additionally, 12.25% of participants expressed uncertainty about the impact of agricultural mulch film on farmland pollution. A study conducted in Portugal found that the general public were more concerned about MPs in land and marine environments than the air (Miguel et al., 2024). Wu et al. (2023) observed the same trend for concerns, where microplastic contamination in aquatic ecosystems and human health-related issues are gaining more public attention.

The findings also highlight that years of plasticulture utilization positively influence farmers' perceptions, which means that more-experienced farmers were found to have higher perceptions of risk. A possible explanation for this result is that the lengthy period of using plasticulture systems has facilitated farmers' acquisition of expertise in aspects of plastic management in agricultural operations, enabling them to recognize the adverse consequences of plastic residues on the environment and society. Likewise, our study found that farm size positively affected perceptions. Specifically, increasing the size of the farm was associated with higher perceptions of the risk regarding the use of agricultural plastics. Large-scale farmers employ plastic on a broader scope, enhancing their expertise in both the advantages and disadvantages of utilizing plastic systems more extensively than small-scale farmers. Moreover, as noted by Komarek et al. (2020), significant economic losses are usually associated with larger farm sizes if crops are damaged, leading larger-scale farmers to purchase high-quality plastic inputs. This result is in line with those of previous studies in the field of environmental risk (Ahmad et al., 2020). Our finding supports the argument of Ahmad et al. (2020) that farming experience and farm size play a vital role in changing individuals' perceptions of environmental risks. Surprisingly, our findings did not support a link between education and farmers' perception of MPs risks. The results are inconsistent with a study

TABLE 3 **Correlation matrix of independent variables investigated and risk perception of microplastics.**

Variables	Age	Education	Farming experience	Cooperative membership	Perception of plastic quality	Years of plasticulture utilization	Utilization of plastic mulch	Multiplicity of plasticulture systems	Plasticulture size	Risk perception
Age	1.000									
Education	0.304**	1.000								
Farming experience	0.733**	−0.338**	1.000							
Cooperative membership	0.210**	0.019	0.314**	1.000						
Perception of plastic quality	−0.060	0.034	−0.192**	−0.270**	1.000					
Years of plasticulture utilization	0.415**	−0.019	0.532**	0.251**	−0.149**	1.000				
Utilization of plastic mulch	0.087	−0.034	0.189**	0.264**	−0.546**	0.024	1.000			
Multiplicity of plasticulture systems	0.126*	0.015	0.173**	0.165**	−0.167**	0.118*	0.444**	1.000		
Plasticulture size	−0.097	0.110	−0.026	−0.045	−0.254**	0.030	0.344**	0.189**	1.000	
Risk perception	0.096	0.031	0.232**	0.257**	−0.288**	0.279**	0.328**	0.255**	0.307**	1.000

** denotes significant differences at a p value of < 0.01; * denotes significant differences at a p value of < 0.05.

TABLE 4 Factors affecting perceptions towards microplastic pollution in farm fields.

Variable	Coefficient	SE	*t*	*p* > |t|	Confidence interval (95%)	
Age	−0.002	0.001	−1.40	0.162	−0.00437	0.0010
Education	0.006	0.023	0.30	0.767	−0.03862	0.0529
Farming experience	0.002	0.001	1.37	0.172	−0.0011	0.0046
Cooperative membership	0.024	0.026	0.92	0.358	−0.0306	0.07517
Plasticulture size (%)	0.001 ***	0.004	2.48	0.014	0.0002	0.0017
Perception of plastic quality	−0.043 *	0.026	−1.67	0.096	−0.0064	0.0966
Multiplicity of plasticulture systems	0.001	0.029	0.59	0.557	−0.0388	0.0778
Years of plasticulture utilization	0.004 ***	0.001	3.01	0.003	0.0015	0.0069
Utilization of plastic mulch	−0.056	0.034	−1.65	0.101	−0.1244	0.0109
Minya governorate	−0.243 ***	0.038	−6.29	0.000	−0.1977	−0.0708
Dakhalia governorate	−0.110 ***	0.028	−3.93	0.000	0.0561	0.1666
Giza governorate	0.209 ***	0.031	2.98	0.000	0.0623	0.1458
constant	0.474	0.073	5.60	0.000	0.2330	0.4899
Summary statistics						
Sigma	0.179	0.007			0.1648	0.1940
χ^2	127.10					
$p > \chi^2$	0.000					
Log likelihood	83.357					
Pseudo R^2	0.3203					

*$p < 0.1$, ***$p < 0.01$, SE = standard error.

conducted by Deng et al. (2020) in China to examine perceptions of MPs and their influencing factors, which concluded that people with higher education were not concerned about MPs, while people with lower education had greater levels of concern about MPs. However, Henderson and Green (2020) revealed that individuals with increased environmental awareness exhibit greater levels of concern and have a more extensive knowledge of MPs.

The satisfaction with plastic quality significantly and negatively influenced the risk perceptions. A low level of satisfaction was associated with farmers being more likely to have high perceptions compared to the group of high-satisfied farmers. This may be attributed to the fact that the frequent use of poor-quality plastics results in an increase in plastic residues and MPs, which can be observed by farmers season after season; that is why farmers who use such materials, or are not satisfied with them, perceive the adverse effects of agricultural plastics more than others. Farmers who dissatisfied with plastic quality often develop a stronger sense of the risks posed by MPs because they directly see the problems caused by low quality materials. Substandard plastics break down more quickly, leaving visible residues and microplastics in the soil—something these farmers observe and worry about. They may also face additional costs for replacing these plastics and deal with lower crop yields due to inefficiencies, which only adds to their frustrations. These personal experiences make the risks of microplastics more tangible to them, as they recognize how it affects their soil, productivity, and even the environment around them. This hands-on exposure naturally leads them to be more concerned about the broader impacts of MPs.

The results of the Tobit regression model also indicated that farmers in the Giza governorate exhibited positive perceptions of satisfaction compared to farmers in other governorates. The result may be attributed to the fact that farmers in the Giza governorate are more experienced farmers in plasticulture utilization have larger farm sizes, and adopt multiple types of plasticulture systems (Appendix 1), and those variables were found to have a significant positive influence on farmers' risk perceptions. Unexpectedly, despite there being a significant association between the use of plastic mulch and the higher occurrence of MPs in terrestrial environments (Huang et al., 2020; Khalid et al., 2023; Qiang et al., 2023; Zhang et al., 2022), the findings show that the utilization of plastic mulch was found to not have an influence on farmers' perception of risk. This result may be attributed to a more comprehensive understanding of MPs among farmers, leading to an increased awareness and concern about MPs, regardless of their use of plastic mulch. In addition, it is worth noting that plastic mulch utilization was measured based on the last agricultural season (2022–23). This means that respondents may have used plastic mulch in previous years, contributing to an enhanced perception of its adverse environmental effects.

However, certain limitations should be considered when interpreting the findings. As the study is limited to three governorates in Egypt, the results may not be generalizable to other regions or global contexts. This emphasizes the need for future research in diverse geographical, cultural, and economic settings. Additionally, the study employed a Likert scale to evaluate perception levels, relying on farmers' self-reported beliefs, which may introduce bias. Despite efforts to enhance sample inclusivity by categorizing farms based on size, other factors—such as variations in plastic use (types of systems, quantity, and quality), education, and media usage—should be considered in future sampling approaches. Complementary methods, such as experimental approaches or direct observation, could mitigate bias and validate self-reported data. A mixed-methods approach would strengthen the robustness of conclusions. Moreover, integrating longitudinal data or conducting comparative studies across countries would address the issue of limited investigation and provide valuable insights in diverse contexts.

5 Conclusion

This paper analyzes the current level of farmers' perceptions of risks associated with microplastics (MPs) and the factors influencing these perceptions in rural Egypt. Given the limited attention this topic has received in existing literature, this study contributes to the scientific understanding of how farmers perceive the environmental, economic, social, and health risks associated with plastic pollution and how these perceptions vary across socio-economic attributes and farming characteristics. Four key conclusions are drawn from the empirical investigation conducted in this study. First, farmers demonstrate relatively low awareness of MP-related risks but show greater concern for health and social issues. Among environmental risks, air quality pollution caused by burning plastic waste is of particular concern to farmers. Second, the perception of risks associated with plastic pollution is influenced by the context of plastic use, particularly farm size and farming experience. Third, perceptions of MP-related risks vary significantly across regions within Egypt. Fourth, the quality of plastic materials used in manufacturing plasticulture systems plays a critical role in shaping farmers' risk perceptions of plastic pollution. The study provides practical recommendations for mitigating microplastic pollution. Policymakers should promote sustainable alternatives, such as biodegradable plastics, and enforce proper waste management systems with incentives for compliance. Raising awareness through digital platforms and social media is crucial, along with stricter regulations on plastic quality and disposal. Regional and context-specific interventions should address disparities in perception, such as those observed in governorates like Minya and Dakhalia. Furthermore, increased funding for research and innovation in alternatives and recycling technologies can offer long-term solutions. Encouraging stakeholder collaboration by fostering partnerships among farmers, manufacturers, policymakers, and environmental organizations is also essential. Given the scarcity of research on farmers' perceptions of MP-related risks in agriculture, future studies should assess the effectiveness of interventions, such as awareness campaigns, in improving understanding of these risks. Investigating indigenous knowledge through qualitative research and evaluating its feasibility using scientific principles may also provide valuable insights. Furthermore, additional research is needed to explore the interplay between microplastic pollution and broader climate change impacts on agriculture.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics approval was obtained (Ref# APD 1911D) from the Ethics Committee of Reading University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

HK: Conceptualization, Formal analysis, Methodology, Writing – original draft. AM: Funding acquisition, Investigation, Supervision, Writing – review & editing. MB: Conceptualization, Data curation, Formal analysis, Resources, Validation, Writing – review & editing. MA: Data curation, Investigation, Writing – review & editing. ME: Data curation, Validation, Writing – review & editing. DA: Data curation, Validation, Writing – review & editing. BE: Data curation, Validation, Writing – review & editing. HO: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The authors extend their appreciation to the UK Global Research Challenges Fund and the Natural Environment Research Council (GCRF, project NE/V005871/1).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1490908/full#supplementary-material

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