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Willingness to adopt biodegradable mulch among farmers in Saudi Arabia: implications for agricultural extension

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Biodegradable mulch (BDMs) films are ecologically safe substitutes for polyethylene mulches (PEMs) in agricultural systems. However, since it is an innovative technology on the market, it is not easy for farmers to adopt it. Understanding farmers' familiarity with BDM and their willingness to adopt it in the future could play a crucial role in the design and implementation of effective agricultural interventions for promoting the adoption of BDM to reduce environmental pollution. Therefore, a study was undertaken to assess farmers' familiarity with BDM and their willingness to adopt it in the future. Data were collected from fruit and vegetable growers located in Al-Kharj, Saudi Arabia, using a simple random sampling approach with the help of a pre-tested paper-based questionnaire. The findings revealed that most of the farmers were not familiar with BDM. Despite the lack of awareness, a considerable portion indicated their willingness to adopt BDM in the future. The farmers' education level, farm size, and membership in agricultural cooperatives significantly influenced their familiarity with BDM. Education level, farming experience, and membership in agricultural cooperatives also showed significant relationships with their willingness to adopt BDM in the future. Moreover, the farmers were not aware of the potential benefits of this new innovation. The study recommends that extension education programs through the active involvement of agricultural cooperatives should be implemented to make farmers aware of the advantages of BDM over PEM. In addition, the government should facilitate the adoption of this promising innovation by enhancing its availability on the market and affordability to farmers.

KEYWORDS

adoption, biodegradable mulch, familiarity, willingness, Saudi Arabia

1 Introduction

Agricultural innovations are significant drivers of improved agricultural productivity, self-sufficiency, competitiveness, and profitability (Pigford et al., 2018). Among various other agriculture innovations, plasticulture is an important agro-innovation that was put into practice during the 1930's (Mormile et al., 2017). Olericulture refers to the use of plastic materials in various agricultural activities, including irrigation, greenhouse or tunnel covering, soil fumigation, mulching, the packaging of agricultural products, and the protection of harvests from precipitation

(Bhattacharya et al., 2018). Plastic mulching involves the application of plastic films to cover the soil with holes that allow plants to grow. This technique was commercially adopted on a wide scale during the 1960's (Haapala et al., 2014).

Across the globe, polyethylene mulching is prevalent in agricultural practices, as it offers numerous benefits. It improves water-use efficiency, and helps prevent erosion, enhances product quality, and offers protection against insect pests, birds, and weeds (Ferdous et al., 2017; Lamont, 2017; Shan et al., 2022). Furthermore, it is an effective adaptive strategy to mitigate the effects of drought and desertification in arid and semi-arid regions (Rodan et al., 2020). It also protects crops against severe weather, such as freezing temperatures, hail, and flooding (Koundinya et al., 2018).

However, residual plastic films may also contaminate agricultural lands, posing a serious environmental threat. Previous studies have shown that mulching film, in particular, is prone to deterioration into tiny pieces of plastic (microplastics) in the soil, which may have adverse effects both on the environment and agricultural production in a variety of ways by: (1) reducing soil microbial activity and species diversity, negatively affecting crop growth (Zhang et al., 2021); (2) damaging soil structure, which in turn affects moisture penetration and nutrient movement (Zhou et al., 2021); (3) indirectly influencing soil microclimate and directly adding adherent chemicals to the soil (Khalid et al., 2020); and (4) changing the produced carbon strength due to the residual film, which consequently influences greenhouse gas emissions (Ren et al., 2020). Besides, recycling plastic mulches is an enormous challenge. After their use in the field, plastic mulch is burned or buried in landfills due to recycling difficulties (Shah and Wu, 2020). Consequently, such practices cause air pollution and seriously threaten environmental sustainability and wildlife (Divya and Sarkar, 2019). Despite these associated problems, farmers frequently employ plastic mulch, polyethylene mulch (PEM) film, because of its high accessibility, affordability, and physical properties like flexibility and durability, which facilitate its application on a commercial scale (Miles et al., 2018).

However, potential environmental impacts and post-application problems have triggered the scientific community to find more sustainable alternatives to PEM for farmers (Hou et al., 2019). During the 1990's, Biodegradable Plastic Mulch (BDM) was developed as a sustainable alternative to PEM to address environmental hazards caused by it. This new form of mulch can be incorporated into soil after harvesting crops (Hayes et al., 2019). The different types of BDM include paper-based BDM, like oil- and wax-coated paper, and films and fabrics made from biodegradable polyesters. These polyesters encompass polyhydroxyalkanoates (PHA), polyhydroxybutyrate (PHB), polylactic acid (PLA), polybutylene adipate/terephthalate (PBAT) polylactides, and starch-polyester blends (e.g., Mater-Bi; Wortman et al., 2015).

The long-term impacts of the BDMs are still under investigation, however they offer a promising approach to minimizing plastic pollution caused by agricultural activities (Serrano-Ruiz et al., 2021). Several studies reported (Waterer, 2010; Miles and Marsh, 2012; Velandia et al., 2020a,b) that BDM reduced labor costs. Adoption of BDMs have the potential to improve environmental sustainability by reducing soil, water, and air pollution in the surrounding environment and could contribute to improving food security (Filippi et al., 2011; Saraiva et al., 2012; Benincasa et al., 2014). As this is a new innovation, there are very few studies that have attempted to study farmers' awareness and familiarity with it as well as its adoption at the farm level and different barriers that can hamper its adoption. A previous study conducted in USA (Goldberger et al., 2015) found that American farmers had high familiarity with BDM. Another study reported that farmers' familiarity with BDM promoted their willingness to adopt this new technology (Velandia et al., 2019). Regarding barriers, Goldberger et al. (2015) found that lack of information, low availability in the market, high purchase and installation costs, difficulty in mechanical harvesting, lack of trust, agronomic performance, rapid degradation of biodegradable films were major barriers to the adoption of BDM. In most of the countries, agricultural extension department of the ministry of agriculture is responsible for making farmers aware about latest innovations in agricultural production. The department is also responsible for educating farming communities about these innovations in order to promote their adoption at the farm level for enhancing agricultural productivity and farm incomes.

In Saudi Arabia, greenhouse agriculture and tunnel farming is common for growing vegetables and other horticultural crops. These forms of agriculture commonly employ plastic mulches in large proportions and hence pose serious environmental hazards. In the country, the government is encouraging farmers to adopt more sustainable agricultural practices that has the potential to reduce associated environmental problems. BDM could be an effective alternative to PEMs due to its lower negative environmental impacts. However, large-scale adoption of this new practice would require that the farming community is familiar with it and shows willingness to adopt it. Understanding farmers' familiarity with BDM and their willingness to adopt it is critical in assessing their preparedness to implement this new agricultural innovation on their farms and is also vital for designing relevant extension initiatives (Ingman et al., 2015). Moreover, analyzing different barriers to the adoption of BDM could also help inform the relevant agricultural institutions and policymakers in designing effective programs for farmers to facilitate the adoption of BDM at a large scale (Canali et al., 2017). There is no previous study that documented farmers' familiarity with BDM and their willingness to adopt it. Saudi Arabia is planning to reduce its agricultural plastic waste. Therefore, the present study was designed to achieve the following research objectives:

- To investigate farmers' familiarity with BDM and their willingness to adopt this innovation in the future.
- To analyze key barriers to the adoption of BDM in Saudi Arabia.

2 Materials and methods

2.1 Description of the study area

The Al-Kharj governorate was selected as the study area because of its agricultural importance. It is located about 80 km southeast of Riyadh, the capital of Saudi Arabia (SA) and has

an arid climate and desert landscape. The Riyadh region covers approximately 17% of the total area of KSA. It encompasses 19 governorates: Al-Diriyah, Al-Kharj, Al-Dwadmy, Al-Quway'iyah, Wadi Al-Dawaser, Al-Aflaj, Al-Zulfi, Shaqra, Hotat Bani Tameem, Afeef, Al-Saleel, Dharma, Al-Muzahmeya, Rammah, Thadig, Hraymla, Al-Hareeq, and Al-Ghat (GAS, 2019). Several crops are cultivated in the Riyadh region: barley (27.1%), fodder crops (35.3%), winter potatoes (45%), greenhouse tomatoes (47%), and palm trees (25%; GAS, 2018). Approximately 68% of the area is mainly irrigated using groundwater resources (Baig et al., 2020). Of these governorates, the Al-Kharj governorate is a growing agricultural oasis for cultivating fruits, vegetables, dates, and cereals (Feng et al., 2021). It is characterized by low annual rainfall (mean 67 mm/year) and high temperatures (from 22.9 to 45.5°C), while the monthly mean relative humidity ranges from 15.7 to 45.1%. During the early 1980's, the government of Saudi Arabia endeavored to boost agricultural production in the region and achieved self-sufficiency in dairy and livestock products (Algahtani et al., 2015). This region also serves as an experimental site for implementing governmental initiatives. To promote agriculture in the region, the government offered free land, interest-free loans as well as guaranteed purchase of their agricultural products. Because of excessive governmental support, the region witnesses substantial agricultural developments (Al-Farraj et al., 2013; Algahtani et al., 2015). Currently, farmers extensively grow vegetables and fruits in greenhouses using PEM (Algahtani et al., 2015).

2.2 Research design

The rural areas of two cities in the Al-Kharj governorate, namely Al-Dabiyia and A-Hayathem, were selected purposively because of their widespread use of plastic mulch in agriculture (Feng et al., 2021). The simple random sampling technique was used to select 200 farmers from these areas. Data were collected with the help of a paper-based structured questionnaire. The questionnaire was distributed to the farmers in their native Arabic language. They were informed about the aim of the study and were assured that the collected data would be utilized only for academic and research purposes. Out of the 200 farmers, 141 (71%) returned the completed questionnaires, which was used for the final data analysis. Data collection was completed in 4 months: January–March 2024. The study was approved by the Research Ethics Committee of the Deanship of Graduate Studies at King Saud University (KSU-HE-22602).

2.3 Research instrument

The questionnaire was reviewed by a group of agricultural experts and researchers in the College of Food and Agriculture Sciences at King Saud University. The survey questionnaire consisted of different sections. In the first section, age, education level, farming experience, access to loans, membership in agricultural cooperatives, information from the Agricultural Extension Department, farm size, and the use of BDM in the past were included. Agricultural extension department of the Ministry of Environment, Water and Agriculture (MEWA) is responsible for the dissemination of agricultural innovations to the farmers as well as their technical capacity building in Saudi Arabia. Farmers were asked to provide information about whether they have access to extension services provided by the extension department or not using a nominal scale (yes and no). Questions about membership in agricultural cooperatives, access to loans, and information from the Agricultural Extension Department were measured using a nominal scale (0 = no; 1 = yes). The farmers' education and experience (1 = low; 2 = high) and farm size (1 = small landholders; 2 = large landholders) were computed as new nominal variables, using their raw scores. The respondents with school education were classified as having a low level of education, whereas respondents with college and university education were classified as having a high level of education. The respondents with 5–8 years of farming experience were classified as having a low level of farming experience, whereas the respondents with more than 8 years of farming experience were classified as having a high level of farming experience. The respondents with 10 to 20 acres of farmland were classified as small landholders, whereas the respondents with more than 20 acres of farmland were classified as large landholders.

The second section measured the farmers' familiarity with BDM using a 5-point Likert type scale (1 = not familiar at all; 2 = slightly familiar; 3 = moderately familiar; 4 = familiar; 5 = highly familiar). In the third section, there were questions regarding the farmers' willingness to adopt BDM in the future. Their willingness to adopt BDM was also measured using a 5-point Likert type scale (1 = not willing at all; 2 = slightly willing; 3 = moderately willing; 4 = willing; 5 = highly willing). The last section of the questionnaire contained questions about different barriers to the adoption of BDM in Saudi Arabia. This variable was measured using a 3-point Likert type scale (1 = disagree; 2 = I do not know; 3 = Agree). The instruments items and variables were adapted from previous research studies (Goldberger et al., 2015, 2019; Scaringelli et al., 2016, 2017; Velandia et al., 2020a,b,c; Yang et al., 2023) with certain modifications as per local circumstances. In most of the studies, age is measured at interval scale. However, according to the local circumstances, we measured it in age groups. Moreover, farm size was also adjusted keeping in view the average farm size in Saudi Arabia.

2.4 Validity and reliability

A group of researchers at King Saud University reviewed and validated the questionnaire in terms of its content validity. A pilot study was also conducted in order to test the reliability of the questionnaire. Data were collected from 30 farmers, and Cronbach's alpha was calculated to determine the reliability of the Likert scale (Croasmun and Ostrom, 2011; Warmbrod, 2014; Wadkar et al., 2016). The value of the Cronbach's alpha was estimated to be 0.81. After these procedures, we started the field survey, to achieve the study goals.

2.5 Data analysis

Both descriptive and inferential statistics were used for summarizing and analyzing the collected data. The personal demographics of the farmers were summarized using frequencies and percentages. The barriers to the adoption of BDMs were summarized using frequencies, mean, and standard deviation. To determine differences in the farmers' familiarity with BDM and their willingness to adopt BDM in the future due to their personal demographics, parametric statistics were used. For the nominal variables with two categories (education level, farming experience, access to loans, membership in agricultural cooperatives, source of information, and farm size), the independent *T*-test was used. The Statistical Package for Social Sciences (IBM SPSS, version 28.0) was used for running the data analysis.

3 Results

3.1 Farmers' personal demographics

The demographic characteristics of the respondents regarding age, education, farming experience, access to loans, membership in agricultural cooperatives, information from the Agricultural Extension Department, farm size, and the use of BMD in the past are presented in Table 1. Regarding age, the majority of the respondents (46%) belonged to the age group of 36–40 years; about 35% fell within the age range of 31–35 years. Only 11.3 and 7.8% of the respondents belonged to the age groups of more than 40 years and under 30 years, respectively. Regarding education level, the majority of the respondents (60%) had a high level of education. About two-fifth (40%) of them possessed low educational level. The results also showed that the majority of the respondents (56%) had a low level of farming experience, while 44% of them reported having high farming experience. About 44% of the respondents had access to loans, whereas 56% indicated no access to loans. In terms of agricultural cooperatives' membership, the majority (78%) of the respondents were not the members. Just over one-fifth (22%) of them reported that they had memberships in the agricultural cooperatives. In addition, around half of the respondents received information services from the Agricultural Extension Department, with the remaining half received no such services. Regarding landholdings, about 57% of the respondents had small land area. The remaining 43% possessed large landholdings. A significant proportion (64%) of the respondents were involved in the cultivation of vegetables in greenhouse. Over one-third (36%) cultivated fruits in greenhouses at their farms. The vast majority (96%) of the respondents used black polyethylene plastic mulches in the greenhouses. None of the respondents ever used BDM in the past.

TABLE 1 Demographic characteristics of the farmers.

Variables	*F*	%
Age		
Lower than 30	11	7.8
31–35	49	34.8
36–40	65	46.1
Higher than 40	16	11.3
Education level		
Low	57	40.4
High	84	59.6
Farming experience		
Low	79	56
High	62	44
Access to loans		
No	79	56
Yes	62	44
Membership in agricultural cooperatives		
No	110	78.0
Yes	31	22.0
Information from the Agricultural Extension Department		
No	70	49.6
Yes	71	50.4
Farm size		
Small	81	57.4
Large	60	42.6
Cultivated crops in a greenhouse		
Vegetables	90	63.8
Fruits	51	36.2
Mulch color		
Black	135	95.7
Other colors	6	4.3
Use of biodegradable mulch in the past		
Yes	0	0.00
No	141	100

3.2 Farmers' familiarity with BDM and their willingness to adopt it in the future

The findings of the study showed that about two-fifth (40%) of the farmers were not familiar with BDM (Figure 1). Simultaneously, over one-third (36%) of them were either familiar with or highly familiar with BDM. About 12% indicated slight familiarity, whereas ~11% of them were moderately familiar with BDM.

Figure 2 shows the farmers' willingness to adopt BDM in the future. About 45% of the farmers were highly willing to adopt BDM. In contrast, around 29% of the farmers expressed no willingness for the adoption of BDM in the future. Nearly one-fifth (19%) showed slight willingness in this regard.

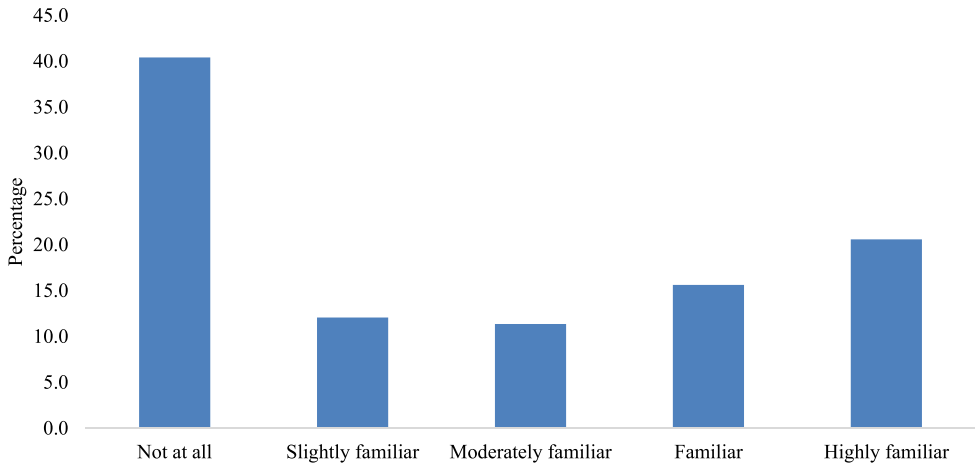

FIGURE 1
Farmers' familiarity with BDM.

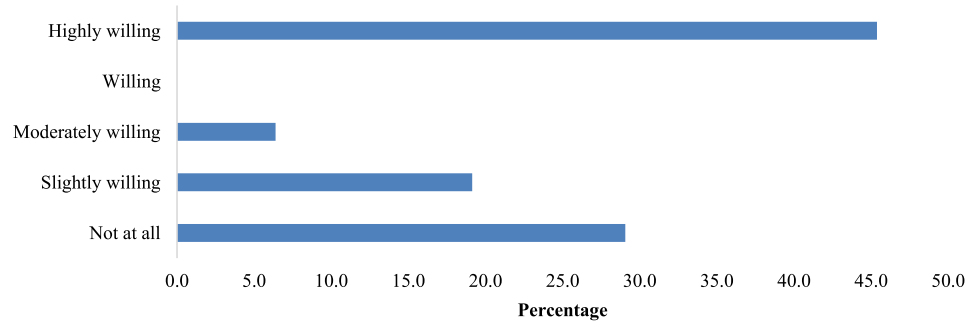

FIGURE 2
Farmers' willingness to adopt BDM in the future.

3.3 Differences in the farmers' familiarity with BDM and their willingness to adopt it in the future according to their demographic characteristics

Table 2 shows the results of the independent samples *t*-test that was run in order to find differences in farmers' familiarity with BDM. The results revealed significant differences in the farmers' familiarity with the BDM based on their level of education ($t = -11.13$; $p = 0.000$), membership in an agricultural cooperative ($t = -3.57$; $p = 0.000$) and farm size ($t = -2.10$; $p = 0.037$). In order to measure the strength of the relationship, the effect size was computed using Cohen's *d* (Lakens, 2013; Goulet-Pelletier and Cousineau, 2018). The highly educated farmers showed relatively higher familiarity with the BDM than the farmers with a low level of education. Regarding education, the difference in the means represented a large effect (Cohen's $d = 2.05$). Similarly, the farmers who had memberships in agricultural cooperatives showed higher relatively familiarity with the BDM than those who had no membership of the agricultural cooperatives. The difference in the means also demonstrated a large effect (Cohen's $d = 0.72$). Moreover, the farmers who owned large agricultural land showed higher familiarity with the BDM than those who owned small agricultural land area. Regarding farm size, the difference in the means represented a small effect (Cohen's $d = 0.35$).

Regarding farmer's willingness to adopt BDM in the future, there were also significant differences based on their education level ($t = -17.95$; $p = 0.000$), farming experience ($t = -2.69$; $p = 0.008$), and cooperative membership ($t = -4.90$; $p = 0.000$). The farmers with a higher level of education were more willing to adopt BDM in the future than who had lower educational qualifications. The difference in the means represented a large effect (Cohen's $d = 3.23$). The experienced farmers were also more willing to adopt BDM than with less farming experience. However, the effect was moderate (Cohen's $d = 0.64$). The farmers who had memberships in the agricultural cooperatives expressed higher willingness to adopt BDM than those who had no memberships. The computed effect was also large (Cohen's $d = 1.09$).

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TABLE 2 The *t*-test comparison for differences in farmers' familiarity with BDM and their willingness to adopt it in the future with regard to socio-economic characteristics.

Variables	Farmer's familiarity with BDM					Farmer's willingness to adopt BDM				
	Mean	SD	*t*	*p*-value		Mean	SD	*t*		*p*-value
Education										
Low ($n = 57$)	1.30	0.49	−11.13	0.000**	*Cohen's d* = 2.05	1.33	0.66	−17.95	*Cohen's d* =3.23	0.000**
High ($n = 84$)	3.55	1.46				4.36	1.14			
Farming experience										
Low ($n = 79$)	2.46	1.67	−1.52	0.130		2.78	1.70	−2.69	*Cohen's d*= 0.64	0.008**
High ($n = 62$)	2.87	1.52				3.58	1.78			
Cooperative membership										
Yes ($n = 31$)	3.52	1.54	−3.57	0.000**	*Cohen's d* = 0.72	4.42	1.20	−4.90	*Cohen's d* =1.09	0.000**
No ($n = 110$)	2.39	1.55				2.77	1.75			
Farm size										
Small ($n = 81$)	2.40	1.44	−2.10	0.037*	*Cohen's d* = 0.35	2.96	1.66	−1.33		0.184
Large ($n = 60$)	2.97	1.77				3.37	1.92			
Access to loan										
Yes ($n = 62$)	2.65	1.67	−0.04	0.965		3.23	1.72	−0.53		0.593
No ($n = 79$)	2.63	1.57				3.06	1.83			
Information from agricultural extension department										
Yes ($n = 71$)	2.70	1.66	−0.48	0.627		3.14	1.76	−0.04		0.968
No ($n = 70$)	2.57	1.56				3.13	1.80			

*Significant at the 0.05 level.
**Significant at the 0.01 level.

3.4 Barriers to the adoption of BDM in Saudi Arabia

Table 3 depicts the results about different barriers to the adoption of BDM in Saudi Arabia among the farming community. Over half (54%) of the farmers believed that there is a lack of proper information about BDM. The vast majority (94%) thought that BDM has high disposal cost. More than half (53%) expressed that BDM is not available in the market, whereas about 48% said that they are not aware of its market presence. The vast majority (87%) also expressed that BDM may have negative impacts on soil and believed that it may reduce organic matter content in the soil (84%). About one-third (34%) of the farmers indicated that BDM may decrease crop production. However, two-thirds (66%) of them were undecided about this negative role. Around 63% of the farmers were neutral whether BDM breaks down quickly or not. Over two-thirds (67%) were convinced that BDM may not control weeds. About 34% believed that other farmers are not using BDM at their farms, whereas most of the farmers (66%) were neutral about it. Nearly two-fifths (40%) believed that BDM is expensive, while about 60% were neutral about the cost of BDM.

4 Discussion

The present study explores farmers' familiarity with BDM, their willingness to adopt it in the future, and perceived barriers to the adoption of BDM in Saudi Arabia. The analysis of the responses revealed that the majority of the farmers were not familiar with BDM in the study area. It may be because BDM is a relatively new agricultural innovation that has been proposed as a potential solution to minimize environmental problems posed by PEM. Several other studies (Velandia et al., 2020c; Arpana Kamboj and Singh, 2022) also reported that only a small proportion of the farmers were familiar with BDM.

Although a considerable proportion of the farmers have expressed their willingness to adopt BDM in the future, some farmers reported that they are not willing to adopt this innovation as a replacement of PEM. It may be attributed to their poor awareness of and knowledge about the potential benefits of BDM over PEM. Similar findings were reported by Velandia et al. (2020a), who found low adoption of BDM among Tennessee fruit and vegetable farmers. The reasons behind the low adoption among growers were the scant information about BDM, uncertainty about the advantages of BDM and its long-term effects on the soil, the high price as compared with plastic mulch, low availability on the

TABLE 3 Perceived barriers to the adoption of BDM.

Perceived barriers	Disagree	Neither agree nor disagree	Agree	Mean	SD
	%	%	%		
Lack of proper information	44.0	2.1	53.9	2.09	0.987
Low interest	21.3	67.7	12.1	1.90	0.571
High disposal cost	0.00	5.7	94.3	2.94	0.232
It is not available in the market	0.00	47.5	52.5	2.52	0.501
It may have negative impacts on soil	0.00	13.5	86.5	2.86	0.342
It may decrease crop production	0.00	66.0	34.0	2.34	0.475
It may break down quickly	0.00	63.1	36.9	2.36	0.484
It may not control weeds	0.00	32.6	67.4	2.67	0.470
Other farmers are not using it	0.00	66.0	34.0	2.34	0.475
It may reduce organic matter in the soil	0.00	15.6	84.4	2.84	0.364
It cannot be used for next season	0.00	66.7	33.3	2.33	0.473
It is expensive	0.00	60.3	39.7	2.39	0.491

market, and farmers' bad experiences with mulch products that were wrongly labeled as BDM (Goldberger et al., 2015).

Inferential statistical analysis revealed that certain demographic factors significantly influence farmers' familiarity with BDM and their willingness to adopt it in the future. These factors include: level of education and membership of agricultural cooperatives. Farmers having higher level of formal education had a higher level of familiarity with BDM than the farmers with low level of formal education. Highly educated growers may have easy access to various sources of agricultural information (Velandia et al., 2020c), that in turn may improve their awareness about latest farming innovations. Education can also enable farmers to better evaluate the potential economic and environmental advantages of using BDM in place of PEM than their less-educated peers (Dumbrell et al., 2016; Scaringelli et al., 2016; Miles et al., 2018; Dentzman and Goldberger, 2020; Yang et al., 2023), and therefore they may have higher motivation for the adoption of BDM. Concerning farmers' prior experience, the surveyed highly educated respondents stated that they had experienced difficulties in removing and disposing of plastic mulch. Moreover, they agreed that the high labor cost, the time-consuming work, and the increase in environmental and plastic pollution stimulated them to learn about BDM. Highly educated farmers may struggle to find cost-effective and innovative solutions to counter difficulties such as high labor cost, environmental pollution, and time-intensive activities.

Membership in agricultural cooperatives has also significant relationship with the farmers' familiarity with BDM and their willingness to adopt it. Several studies (Chagwiza et al., 2016; Ma and Abdulai, 2017; Getahun and Muleta, 2021; Uneze and Onuoha, 2021; Muddassir and Alotaibi, 2023) have highlighted the importance of education and extension services for accelerating the adoption of agricultural innovations and sustainable agricultural practices and positive impacts on farm income and food security. Extension activities are commonly considered as an important pathway for the dissemination of innovative knowledge and information (Alzahrani et al., 2023). Agricultural cooperatives conduct programs and field-based demonstrations to enhance farmers knowledge and skills and also provide a platform for interaction with the farming community to exchange ideas, raising their awareness about latest agricultural innovations (Mccraw and Motes, 2007). Khan et al. (2015) found that training sessions delivered by agricultural cooperatives improved farmers' familiarity with innovative agricultural technologies and motivated them to replace conventional practices with modern practices. This may explain why the member farmers are more familiar with BDM than non-members.

Furthermore, Hayes et al. (2019) suggested that government regulators should extend educational programs to farming communities to enhance awareness about the advantages of replacing PEM with BDM. Based on their findings, Velandia et al. (2020a) also suggested that Tennessee fruit and vegetable manufacturers and universities should educate farmers about BDM. Yang et al. (2023) found that farmers who obtained training on mulching technology delivered by the government or industry showed a high willingness to adopt BDMs. During such trainings, experts can directly share information about innovative technologies, and growers can share information with other farmers, and this enhances their confidence in adopting new practices (Baird et al., 2016; Goldberger et al., 2019). The Ministry of the Environment, Water, and Agriculture (MEWA) is also focusing on sustainable development and environmental conservation in Saudi Arabia. In the past year, the Saudi Green Initiative made a commitment to reduce environmental issues in Saudi Arabia. The Council of Economic and Development Affairs reported that the lack of environmental compliance, lack of environmental awareness, and wide adoption of improper

practices have degraded the environment, vegetation, and wildlife (Alotaibi et al., 2020). The Saudi Green Initiative may encourage agricultural cooperatives to train farmers about environmental-friendly techniques such as BDM. Active participation in training may increase the awareness of the advantages of BDM among members of agricultural cooperatives. More awareness may lead to willingness among farmers to adopt BDM in the future.

The sustainable agronomic advantages of BDM and farmers' interest in learning about this innovation may enhance their willingness to adopt BDM in the future. According to the researchers' observations, farmers in the current study area were willing to adopt BDM as an innovative mulch technology and were ready to perform trials in their fields. Therefore, it is suggested that demonstrations of BDM in the study area should be conducted and that in turn may enhance farmers' willingness to adopt BDM in the future. As a reference point, a demonstration of BDM was conducted at Washington State University Northwestern Washington Research and Extension Center in Mount Vernon. Because of the excellent sustainable agronomic performance and environmental advantages of BDM, farmers expressed willingness to adopt BDM in the future (Cowan et al., 2015).

Farm size is also significantly related to the farmers' familiarity with BDM. Farmers who owned large agricultural land might be more worried about end of the season cost saving. It is understandable that large farm size generally implies greater overall farming cost. More labor hours in removing and disposal of plastic mulch are associated with farm size (Velandia et al., 2020a). Farmers with large farm size may be constantly looking for efficient alternatives for the proper removal and disposal of PEM. Farmers having higher farming experience are also more likely to adopt BDM. This finding is in line with the findings of Scaringelli et al. (2017), who found that the willingness to adopt BDM is higher among farmers who have more experience in using mulching techniques. Moreover, the experience of using BDM may also motivate farmers to adopt it in the long run once they realize its benefits (Goldberger et al., 2019).

The high disposal cost of BDM was identified as a major obstacle to the adoption of BDM. However, from an economic perspective, BDM can be tilled into the soil at the end of the season, reducing disposal, labor, and environmental costs. Considering these factors, we could say that BDM could be an effective alternative than PEM (Waterer, 2010; Miles and Marsh, 2012; Velandia et al., 2020a,b). Therefore, the farmers seem to have wrong perceptions about the disposal cost of BDM. In this context, we suggest that extension department should particularly focus on properly educating farmers about the potential economic and environmental benefits of BDM, especially through field demonstrations of burying BDM into soil after harvesting. The lack of knowledge about the economic advantage of BDM may prevent farmers from its large-scale adoption.

5 Conclusions

This study assesses farmers' familiarity with BDM, their willingness to adopt it in the future, and perceived barriers to its adoption in Saudi Arabia. The findings suggest that most of the farmers were not familiar with BDM. Although some of them were aware of it, but none of the farmers were using this new innovation on their farms. Farmers' higher education, large farm size, and membership in agricultural cooperatives improve their familiarity with BDM. Moreover, a significant proportion of the farmers were willing to adopt BDM in the future. The willingness to adopt BDM was also higher among farmers having higher educational qualifications, more farming experience and memberships in agricultural cooperatives. Most of the farmers were uncertain about the potential advantages of BDM, particularly disposal cost, impacts on soil and overall agricultural productivity.

The findings of the study may have several policy implications. First, it is imperative that policymakers understand the major barriers to farmers' awareness and adoption of BDM. The significant role of the agricultural cooperatives in raising farmers' awareness about BDM and promoting the willingness to its adoption suggests that the government could effectively utilize this institution to achieve the national agricultural development and environmental sustainability goals. The farming community can be educated about the potential benefits of BDM as a sustainable alternative to PEM using this institution. Improved awareness and knowledge about BDM may also improve their willingness to adopt it in the future. Moreover, the government should make serious efforts to make this technology available in the market at a highly affordable cost as one key limitation that discourages its adoption is its high cost. Overall, the adoption of BDM by the famers would be beneficial for both the farming community as well as the government, as this promising innovation has the potential to enhance agricultural productivity and minimize plastic pollution.

Note that the current study selected fruit and vegetable growers only from the Al-Kharj governorate. The findings of the study may not be generalizable to farmers of other geographical regions. It is therefore suggested that a similar study should be conducted in other regions of Saudi Arabia that are more prone to plastic-borne pollution.

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 study was approved by the Research Ethics Committee of the Deanship of Graduate Studies at King Saud University (KSU-HE-22602). 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

MM: Writing – original draft, Data curation, Formal analysis, Methodology, Software, Writing – review & editing. BA: Writing – original draft, Conceptualization, Project administration, Supervision, Validation. MA: Conceptualization, Visualization, Writing – original draft.

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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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