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Agronomic and Economic Performance of Using Biodegradable Mulches: A Tomato Case Study in Chebika (Tunisia)

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Abstract

The increasing severity of water scarcity underscores the necessity of adopting sustainable agricultural practices to enhance crop productivity and ensure environmental resilience in Tunisia. This study evaluates the agronomic and economic performance of biodegradable mulch as an alternative to traditional methods to traditional methods, through field experiments conducted in Chebika, Tunisia. Agronomic analysis, partial budgeting, and sensitivity analysis are employed to compare the effects of biodegradable mulch versus bare soil in this research. The results demonstrate that biodegradable mulch significantly improves crop growth, accelerates fruit maturation, and enhances yield. Furthermore, its rapid degradation rate (Grade 1 within 185 days) promotes soil health and contributes to environmental sustainability. Economic analysis reveals strong financial viability, showing a net profit increase of 2,847 TND/ha, a benefit-cost ratio of 1.7, and a 70% return on investment compared to no mulching. The sensitivity analysis demonstrates that biodegradable mulch remains profitable, even with a 75% increase in its costs. To facilitate large-scale adoption, this study recommends financial incentives and capacity-building initiatives to support farmer adoption of this sustainable practice.

1. INTRODUCTION

Agricultural innovation is crucial for addressing global food security challenges and promoting efficient natural resource use, especially in water-scarce regions where climate change accelerates soil degradation and threatens agricultural productivity (Malec et al., 2024). With increasing climate variability causing more frequent droughts and extreme weather events, adopting sustainable agronomic practices is essential for enhancing resilience and sustaining food production. Among these innovations, biodegradable mulching has proven effective in conserving soil moisture, suppressing weeds, and regulating soil temperature, thereby improving crop yields and enhancing water-use efficiency (Madin et al., 2024). Polyethylene (PE) mulching, introduced in the early 1950s, has become widespread in agricultural systems due to its effectiveness in enhancing water retention, reducing evaporation, and boosting crop productivity, coupled with the low cost of plastic (Kasirajan and Ngouajio, 2012; Chai et al., 2022). However, the extensive use of PE mulches has raised significant environmental concerns due to their non-biodegradable nature, leading to long-term soil contamination and the accumulation of both macro- and microplastic residues. These plastic residues degrade soil structure, reduce field capacity, and negatively affect microbial diversity. Macroplastic fragments, in particular, cause more severe changes in soil properties compared to smaller particles, accelerating soil degradation. Microplastics absorbed by plants can accumulate within plant tissues, posing potential risks to human health through the food chain. According to Guo et al. (2024), mulch-derived microplastics can significantly disrupt root nodule nitrogen fixation by reducing dinitrogenase activity, altering flavonoid content, and decreasing the abundance of key nitrogen-fixing bacteria such as Bradyrhizobium, thereby impairing nitrogen uptake and plant productivity. Moreover, the leaching of plastic additives into water bodies contributes to further contamination, impairing plant growth and disrupting microbial communities. These consequences not only threaten soil quality and agricultural productivity but also harm ecosystems and biodiversity, creating significant challenges for sustainable farming practices (Qi et al., 2020; Hoang et al., 2024). This underscores the urgent need to explore more sustainable alternatives that align with long-term agricultural sustainability goals.

Biodegradable mulches (BDMs) provide a sustainable alternative to conventional plastic mulches, offering significant agronomic, economic, and ecological benefits that address pressing environmental challenges. Developed since the early 1990s, BDMs are made from aliphatic polyesters such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), and starch–polymer blends, and are gaining recognition for their ability to naturally decompose, thus reducing plastic waste and mitigating soil pollution (Van der Zee, 2021). These materials are broken down by microorganisms, including bacteria and fungi, into natural by-products such as water, carbon dioxide (CO_2), methane (CH_4), and biomass. The degradation rate of BDMs is influenced by various factors, including temperature, moisture, oxygen availability, and microbial activity (Dada et al., 2025). Under optimal conditions, up to 90% of BDMs can degrade within one to two years, depending on local climate and soil characteristics (Griffin-LaHue et al., 2022). This degradation rate is a critical factor in evaluating the environmental impact of BDMs, as it determines how quickly these materials break down into harmless components.

BDMs offer numerous agronomic advantages similar to conventional PE mulches, including enhanced soil temperature regulation, improved moisture retention, effective weed suppression (especially with black films), and better nutrient use efficiency, all of which contribute to increased crop yields. Moreover, BDMs reduce dependence on chemical herbicides by effectively controlling weeds and can play a role in pest and disease management. For example, transparent white films reflect radiation, helping to limit certain insect pests (Mahmoud et al., 2021). In contrast to PE mulches, which persist in the environment due to incomplete degradation, BDMs naturally decompose, preventing long-term plastic accumulation and mitigating environmental pollution. In addition to these environmental benefits, BDMs enhance soil health by improving soil structure, increasing organic matter, and boosting fertility, fostering more sustainable agricultural practices (Xiong et al., 2024). Across various agricultural contexts, BDMs have demonstrated significant environmental and economic advantages. For instance, Chen et al. (2024) highlighted their effectiveness in garlic production in China, where BDMs increased CH_4 absorption, reduced N_2O emissions, and lowered the carbon footprint compared to conventional plastic mulching (PM), while also improving garlic yields and net ecosystem economic benefits (NEEB). Similarly, in Shaanxi, China, Liu et al. (2025) demonstrated that Polybutylene adipate-co-terephthalate (PBAT), a type of BDM, enhanced soil carbon sequestration by increasing particulate organic carbon (POC) and soil organic carbon (SOC) levels. In contrast, polyethylene microplastics (LDPE-Mi) and debris (LDPE-D) suppressed soil respiration and decreased key carbon fractions, such as microbial biomass carbon (MBC) and dissolved organic carbon (DOC), particularly during the flowering and harvesting stages. In Spain, Bandopadhyay et al. (2018) underscored the positive impact of BDMs on soil health by enhancing organic matter and microbial activity, thus providing a more sustainable alternative to plastic mulches. Similarly, Amoroso et al. (2012) demonstrated that BDMs effectively controlled weeds in container-grown 'Red Robin' in Italy, offering an eco-friendly alternative for weed management. In Brazil, Silva (2020) found that BDMs reduced water consumption and improved water use efficiency in pak choi cultivation, further advancing sustainable farming practices. These findings illustrate the potential of BDMs not only as an environmentally friendly alternative to traditional mulches but also as a key component in advancing more sustainable, resource-efficient agricultural systems worldwide.

Although BDMs offer significant environmental benefits, their adoption remains limited, particularly in developing regions, due to higher initial costs, especially for small-scale and resource-constrained farmers. According to Velandia et al. (2020), the cost of a 4 ft × 4,000 ft roll of BDM ranges from approximately 138% to 185% of the price of PE mulch. However, BDM eliminates removal and disposal costs, reducing labor requirements by 8–11 man-hours per acre and avoiding landfill fees. Additionally, unlike PE mulches, BDMs prevent soil contamination from plastic residues, ensuring long-term economic and environmental benefits. These advantages make BDMs a cost-effective solution for sustainable agriculture compared to PE. Moreover, the increasing adoption of non-chemical weed control alternatives, such as BDMs , can lower the overall cost of mulch production by reducing reliance on chemical herbicides, which in turn may decrease production and application costs (Amoroso et al., 2012). According to Marí et al. (2019), financial incentives, such as subsidies of up to 50.1%, could help alleviate the financial burden on farmers, enabling them to cover waste management and recycling costs, making BDMs materials economically viable alternatives to PE mulching , and thus facilitating their wider adoption in open-air pepper production in Spain.

Tunisia faces significant challenges related to groundwater depletion and soil degradation, both of which threaten the sustainability of its agricultural systems and water security (Soula et al., 2021; Thabet et al., 2024). In response to these pressing issues, Chebika region, which is particularly affected by water scarcity, declining soil fertility, and escalating environmental pressures has been selected as pilot site for the introduction of BDMs, a promising yet underutilized solution that could play a crucial role in promoting sustainable agricultural practices. While PE mulching continues to be widely used in Tunisia, its negative environmental impact, particularly the accumulation of plastic waste and the long-term degradation of soil health, has become an undeniable concern. Research by Boughattas et al. (2021) highlights the widespread accumulation of microplastics due to the continued use of PE mulching, which disrupts soil structure, harms microbial diversity, and negatively impacts soil fauna, including earthworms. These findings emphasize the urgent need to explore and implement environmentally sustainable alternatives to PE mulching that align with Tunisia's broader national objectives for water conservation and soil restoration, as articulated in the Water 2050 strategy developed by the Ministry of Agriculture, Water Resources, and Fisheries (MAWRF, 2021).

This study aims to assess the agronomic and economic performance of BDMs in Tunisia through field experiments and economic analysis, comparing them to bare soil. The analysis will include partial budgeting and sensitivity analyses, providing key insights for policymakers, agricultural extension services, and private-sector stakeholders. Ultimately, this research will demonstrate the potential of BDMs to address critical agricultural and environmental challenges while contributing to the development of resilient, sustainable food production systems in Tunisia. The findings will be essential in shaping the future of resource-efficient farming in the country.

2. MATERIALS AND METHODS

2.1 Study Site and Experimental Design

The BDM films used in this study were supplied by Novamont, a leading Italian company in the development of biodegradable plastic technologies. This collaboration focused on developing and evaluating mulch films tailored to the unique climatic conditions of African and Mediterranean agricultural systems, addressing the pressing environmental and agricultural challenges faced by these regions. The research was conducted in Chebika region (Kairouan Governorate) located in central Tunisia. The region experience hot, dry summers, limited rainfall, and increasing environmental pressures on agricultural systems. Chebika research station (35° 33′ 35.3″ N, 9° 52′ 42.4″ E) (Fig. 1) is particularly vulnerable to soil degradation and escalating water scarcity, which makes it an ideal case study for evaluating the effectiveness of BDMs as a climate-resilient agricultural strategy. Field trials were conducted to compare the performance of BDMs against bare soil, with a specific focus on tomato cultivation. Two open-field trials were carried out, one from February to July 2022 and another from February to July 2024. The study aimed to evaluate the potential of BDMs to improve soil moisture retention, reduce evaporation losses, and enhance crop resilience and yields under semi-arid conditions. The findings of this research are intended to provide valuable insights into sustainable agricultural practices, contributing to long-term food security and environmental sustainability in Tunisian regions facing water scarcity.

2.2. Agronomic and Economic Evaluation

The agronomic performance of BDM was evaluated by examining several key factors, including weed suppression, plant growth, total yield, fruit quality, and soil health. Following the methodologies outlined by Abou Chehade et al. (2019) and Morra et al. (2021), weed biomass was measured to assess the level of weed

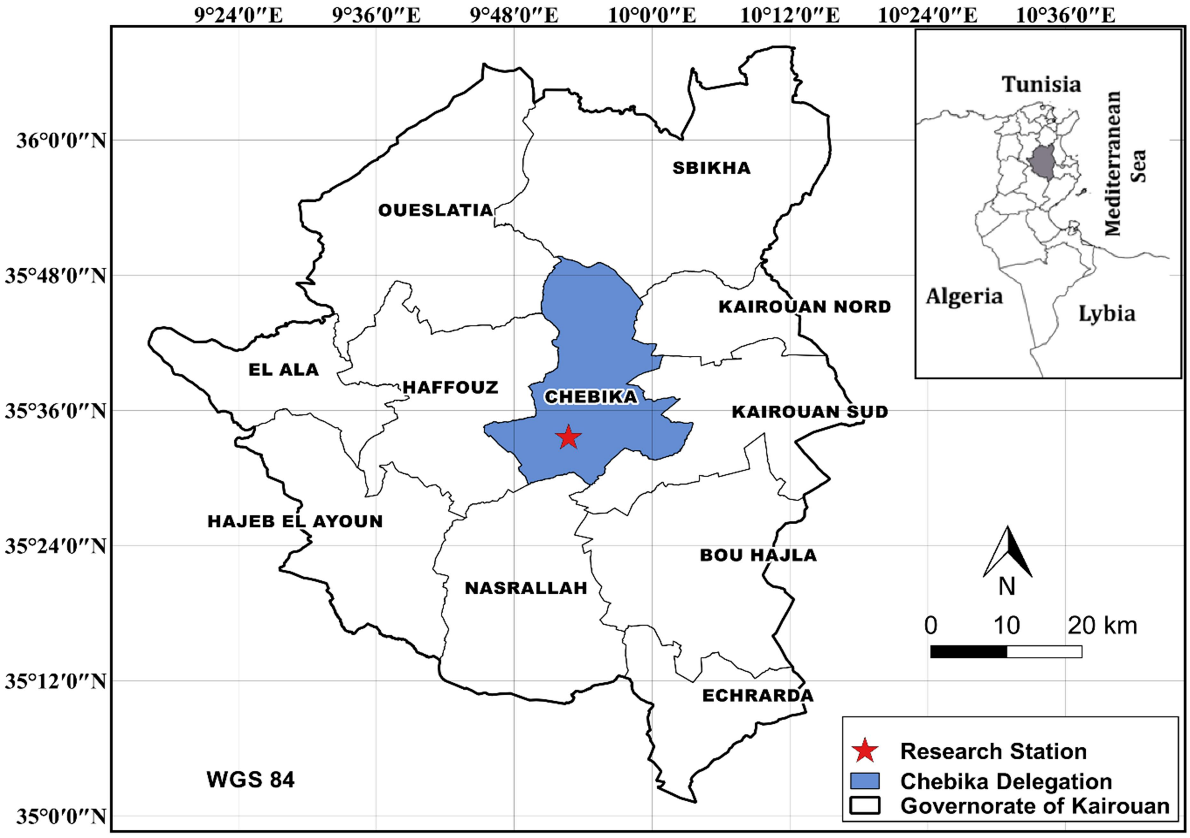

Fig.1. Location of the research station

Fig 2. Installation of the mulching film in Chebika

competition. Plant growth was evaluated by monitoring both height and biomass accumulation, including fresh and dry aboveground biomass (fruits and stems). Total yield was determined by harvesting and weighing marketable fruits, with weight serving as the primary indicator of quality and productivity. According to Liu et al. (2025), the decomposition duration of BDM is a critical factor influencing soil health, as it directly affects nutrient cycling and microbial activity. To assess this, BDM films were applied using standard mulching techniques, and their degradation was monitored at three key intervals: 80, 115, and 185 days post-transplanting. These time points were chosen to capture the critical stages of mulch decomposition, providing valuable insights into its temporal dynamics and impact on soil health. The evaluation followed the European Standard EN 17033:2018, which mandates that BDM films must achieve 90% CO_2 conversion within 24 months under soil conditions (European Bioplastics, 2017; Novamont , 2018). Economic performance was evaluated using the following indicators: additional costs and revenue of BDM versus conventional (open field) practices, benefit-cost ratio (B/C), and return on investment (ROI).

2.3. Partial budgeting and sensitivity analysis

Economic viability is assessed using partial budgeting, a key tool in agricultural management that serves as a planning and decision-making framework, allowing producers to evaluate the financial implications of specific operational changes. Partial budgeting involves assessing both negative effects (i.e., additional costs and reduced revenues) and positive effects (i.e., additional revenue and reduced costs) (Fig. 3). By focusing on incremental costs and benefits, this method isolates the net economic impact of proposed modifications in production practices, providing an accurate assessment of profitability and risk (Alimi and Manyong, 2000). To enhance the effectiveness of partial budgeting, it is essential to integrate sensitivity analysis, a powerful tool for evaluating how fluctuations in input costs affect profitability (Wei et al., 2020).

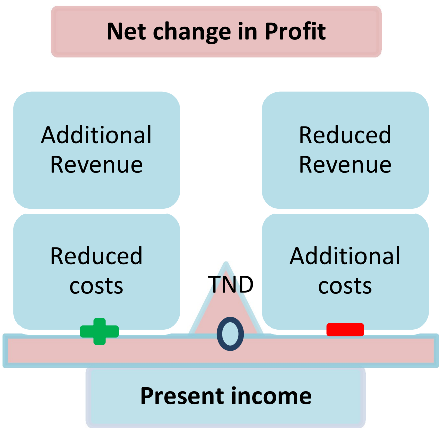

Fig. 3. Conceptual Framework of Partial Budgeting (Lessley et al., 1991)

Partial budgeting is a widely used tool for evaluating the economic impacts of various agricultural practices. It has been applied to assess pest management strategies (William et al., 2015; Rwegasira et al., 2020), nutrient management plans (El-Deep, 2014; Melese et al., 2018; Medel-Jiménez et al., 2021), and modifications in farm operations, such as reducing corn acreage and replacing it with soybeans (Lessley et al., 1991). Additionally, partial budgeting has been employed to analyze changes in input usage, the adoption of organic practices, and the implementation of direct marketing strategies (Clark et al., 2014). The tool has also been used to evaluate the economic effects of practices such as organic mulching and intercropping in maize cultivation (Anane et al., 2020), as well as the financial implications of transitioning from PE mulch to BDM in pie pumpkin production (Velandia et al., 2019).

This study employs partial budget analysis and sensitivity testing to assess the economic feasibility and profitability of BDM compared to non-mulching practices in tomato cultivation. By integrating these methods, the study provides a comprehensive evaluation of BDM's cost-effectiveness and financial sustainability across different economic scenarios. The additional costs of BDM include its higher material price and increased labor requirements for installation and harvesting. However, these may be offset by reduced expenditures on herbicides and fertilizers, as BDM suppresses weeds and enhances soil fertility. Its moisture-retention properties also contribute to lower irrigation costs, improving water-use efficiency. Moreover, BDM may generate additional revenue through higher yields and improved crop quality, which could command premium market prices. To evaluate the impact of varying BDM mulch costs on profitability, a sensitivity analysis was conducted, modeling cost increases of 25%, 50%, 75%, and 100%.

3. RESULTS

3.1. Agronomic performance

The findings demonstrate that BDM enhances vegetation intensity, accelerates fruit maturity, and improves fruit size. In Chebika, tomato yield increased significantly from 2.5 kg/plant in bare soil to 4 kg/plant in mulched crops. The efficiency of BDM in Chebika can be attributed to tomato varieties ("Dorra") and soil properties (sandy soil). Mulched crops exhibited vigorous vegetation, an earlier crop cycle, advanced fruit maturity, and larger fruit size, leading to significantly higher yields than bare soil (Fig. 4). These findings underscore the importance of site-specific factors in determining the effectiveness of BDM in enhancing tomato quality and productivity.

The experiments demonstrated that soil moisture retention was significantly higher in mulched plots compared to bare soil, leading to a substantial reduction in irrigation requirements. Additionally, the BDM degraded consistently under varying climatic conditions, breaking down completely within four months (Fig. 5). Table 1 illustrates the degradation status of the mulch, using a scale from 1 to 9, where 1 represents nearly complete degradation and 9 indicates no degradation. At Day 0, the site was graded 9, indicating no degradation. By Day 80,

Fig. 4. Comparison of vegetation between bare soil (C) and biodegradable mulched crops (D) in Chebika food hub.

Fig.5 . State of the film degradation at 80 days (E), 115 days (F) and 185 days (G) after transplanting.

Table 1. Degradation State of BDM (Grade1: Nearly complete degradation to 9: No degradation)

Days after mulching installation	0	80	115	185
Chebika region	9	9	6	1

the degradation grade remained at 9. However, after Day 115, the degradation rate accelerated, with a grade of 6. By Day 185, it reached a grade of 1. These findings suggest that while degradation was initially slow, it significantly accelerated after Day 115. Chebika exhibited a high degradation rate due to soil type and local climatic conditions.

3.2. Economic Feasibility and Sensitivity Analysis

The partial budget analysis for seasonal tomato cultivation in Chebika (Table 2) highlights the strong financial advantages of BDM. The additional costs (4160) include Rolls of mulch (3500), labor cost to install the mulch (60) and labor cost of harvesting (600). The total reduced costs (water, fertilizer, and pesticide use) are approximately 1247, and the additional revenue from higher yields and improved market prices is approximately 5760, resulting in a net profit gain of 2,847 TND/ha (Table 2). The benefit-cost ratio (B/C) is 1.7, and the return on investment (ROI) is 70%, further demonstrating BDM's financial viability. The substantial net profit highlights the effectiveness of BDM as a sustainable agricultural practice. These findings strongly support the adoption of BDM, particularly in water-scarce regions, as a viable alternative to conventional practices.

The sensitivity analysis confirms that BDM remains a profitable investment, even with a 75% cost increase (Fig. 6). Although profitability decreases as costs rise, net returns remain positive up to a mulch cost of 6,347 TND/ha, demonstrating its economic resilience. These findings highlight the importance of targeted

Table 2. Partial budget for the introduction of BDM in seasonal tomato cultivation

DEBIT (TND/ha)*		CREDIT (TND/ha)*	
1.Additional costs	**4160**	**3.Reduced Costs**	**1247**
Rolls of mulch	3500	Irrigation water	700
Labor cost to install the mulch	60	Fertilizers	187
Labor cost of harvesting	600	Pesticides	360
2.Reduced revenue	**0**	**4.Additional revenue**	**5760**
Nil	0	Increased yield	4800
		Increased price	960
A.Total additional costs and reduced revenue = 1+2	**4160**	**B. Total reduced costs and additional revenue = 3+4**	**7007**
Net change in profit = (B-A)= 7007-4160= 2847 TND/ha			

**TND: Tunisian National Dinar (1 Euro = 3.3 TND)*

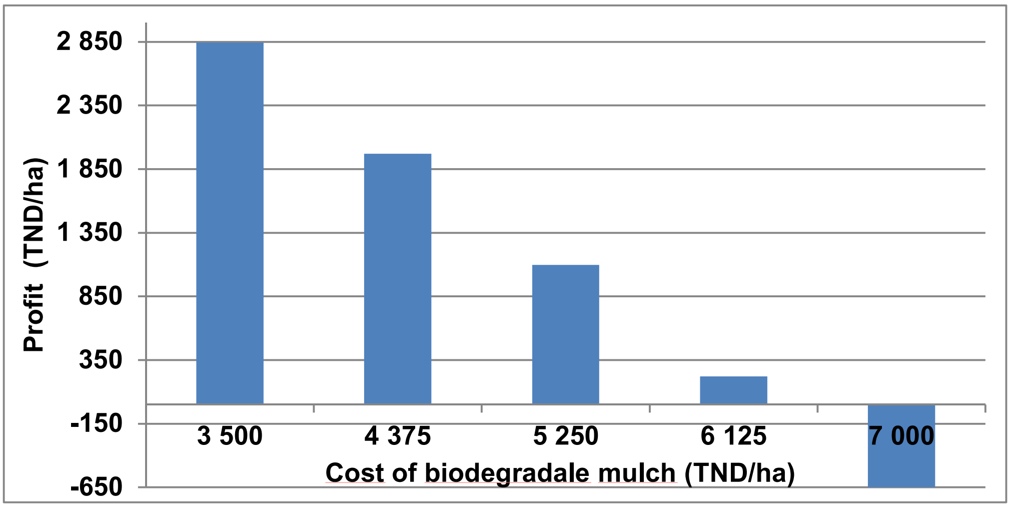

Fig. 6. Sensitivity analysis of increased BDM costs

policy interventions to support adoption, with financial incentives, such as subsidies and tax reductions, playing a crucial role in lowering installation costs and promoting large-scale implementation.

4. DISCUSSION

Numerous studies worldwide have demonstrated that BDM films significantly enhance the agronomic performance of crops, including tomatoes, by improving crop biomass, yield, soil properties, and water use efficiency, while also exhibiting a high degradation rate (Dewi et al., 2024). Deng et al. (2019) found that in China, crops such as maize and cotton experienced substantial yield increases of 69.4–76.2% and 65.2–71.9%, respectively, compared to bare soil controls. Similarly, Wang et al. (2024) reported that polybutylene adipate terephthalate (PBAT) biodegradable mulching films increased chewing cane yield by 13.46%, doubled root biomass, and enhanced plant weight by 26.25%. These improvements were associated with better nutrient uptake, elevated soil and root enzymatic activities, and shifts in fungal community composition. BDM films also effectively enhanced water use efficiency by 64.5–73.1% and demonstrated a high degradation rate, reaching grade 4 (characterized by evenly distributed, network-like cracks) within 140 days. Similarly, Wufuer et al. (2023) reported that while tomato yield under BDM was 3.14% lower than under PE, it remained 68.6% higher than that of bare soil. Additionally, 60.9% of the BDMs degraded within 100 days, reinforcing its environmental advantages. Martin-Closas et al. (2008), Sekara et al. (2019), and Di Mola et al. (2023), among others, have also demonstrated that organic tomatoes grown with BDM and PE exhibited superior early fruit development, higher overall yield, improved fruit quality, and greater marketable fruit weight per plant compared to bare soil. Moreover, integrating BDM with climate-resilient farming techniques and integrated pest management (IPM) can significantly enhance water conservation and soil health (UNEP DTU Partnership, 2021). BDM films not only improve soil moisture retention but also provide a protective barrier against weed germination and mitigate the impacts of extreme weather, thereby fostering a more resilient and sustainable farming system. These findings highlight the potential of BDM as a viable alternative to conventional plastic mulch, offering both agronomic and environmental benefits while supporting the sustainable development of agricultural systems. However, as noted by Campanale et al. (2024), the use of BDMs must be carefully evaluated due to potential risks associated with incomplete biodegradation. Residual micro-bioplastics, nano-bioparticles, and additives may persist in the soil, potentially affecting soil properties and biological activity. These residues can also act as carriers for a wide range of chemical substances, raising concerns about long-term environmental impacts. Importantly, the actual rate and completeness of biodegradation are influenced by the physical and chemical characteristics of the soil and local climate conditions. Xue et al. (2023) found that although BDM films significantly reduce environmental pollution, their continuous use for more than three years may lead to a decline in fungal necromass carbon, potentially affecting soil carbon storage. Alterations in microbial community composition, along with a reduction in dissolved organic carbon, suggest that BDMs could disrupt soil carbon sequestration processes. Therefore, while BDMs offer clear agronomic and environmental advantages over conventional plastic films, their use should be accompanied by site-specific assessments and long-term monitoring to ensure they contribute effectively to sustainable agricultural practices. Moreover, several studies have employed partial budget analysis to assess the economic viability of mulches, including biodegradable options. Tyagi and Kulmi (2018) conducted a field experiment in India and found that plastic mulching significantly enhanced tomato growth and yield. Their results showed a higher cost-benefit ratio of 2.8 with mulch compared to 2.01 without, demonstrating its financial advantage. Similarly, Galinato et al. (2020) and Velandia et al. (2020b) evaluated the feasibility of BDM as an alternative to PE mulch. They reported a positive net change in profit due to labor and disposal savings in pumpkin production. Their studies also conducted sensitivity analysis based on varying BDM prices, disposal fees, hourly wage rates, pumpkin price discounts, labor cost changes, and marketable yields. However, these findings cannot be universally applied, as production costs and revenues vary across regions, crops, and management practices. Additionally, the main limitation of these analyses is their focus on short-term changes in profits, neglecting the long-term benefits related to BDM, such as improvements in soil health.

Our findings demonstrate that using BDM provided by Novamont in tomato cultivation increases yield by 60% (from 2.5 kg to 4 kg per plant) and significantly enhances net returns compared to bare soil, even with a 75% increase in BDM costs. Additionally, the mulch exhibited a rapid degradation rate, breaking down almost entirely within 185 days. The increased net returns can be attributed to lower production costs, primarily due to reduced expenses for manual weeding, herbicides, fertilizers, and irrigation, as well as higher income from selling the harvested fruit. Notably, mulched tomato crops in Chebika achieved higher yields and net returns than those without mulch. This can be explained by the performance of BDMs being influenced by factors such as differences in tomato varieties, local soil characteristics (including temperature and moisture), regional climatic conditions, and the type of mulch used, including its color and composition, as noted by Adamczewska-Sowińska et al. (2025). Our findings from the Chebika region align with previous research demonstrating the positive effects of BDMs on tomato cultivation. Burato et al. (2025) reported similar benefits in Parma, Italy, where BDMs , such as those produced by Novamont, improved tomato yield, water productivity, fruit quality, and marginal net returns compared to non-mulching systems. Their study found that BDMs provided by Novamont increased total yield by 15–31%, boosted marketable yield by up to 30%, and enhanced water productivity by up to 36%. Additionally, no film residues were detected in the soil after two years.

Despite the numerous agronomic and economic benefits of BDM, its widespread adoption faces several challenges. The primary obstacle is the higher initial investment compared to traditionalPE mulching , which poses a significant barrier for farmers in developing countries with limited financial resources. Additionally, a lack of awareness among farmers and limited access to BDM products further restrict its use. The absence of clear standards and regulations creates uncertainty regarding the quality, performance, and safety of these products. Furthermore, insufficient research and development efforts impede advancements in biodegradability, durability, functionality, and product diversity, thereby slowing innovation in the field of BDM (Ramadhani et al., 2024).

Addressing these challenges requires robust government interventions and well-structured economic policy incentives, including targeted subsidies to support both farmers and manufacturers (Hao et al., 2024), as well as tax reductions for companies producing BDM (Chutipat et al., 2023). As highlighted by the Bangkok Post (2023), Thailand has implemented a program offering a 25% corporate income tax reduction for businesses purchasing biodegradable plastic products between 2022 and 2024. This initiative is a key component of the government's bio-circular-green (BCG) economic model, which not only encourages sustainable practices and aims to reduce plastic waste but also supports market expansion by incentivizing businesses to adopt sustainable practices. Moreover, as explained by Yang et al. (2023) and Muddassir et al. (2024), many farmers are not familiar with BDM. Several factors influence familiarity with this technology, including higher education, farming experience, farm size, and membership in agricultural cooperatives. Education, in particular, is a crucial determinant of both farmers' adoption of and willingness to pay for BDM. Therefore, comprehensive training programs in Tunisia are essential to raise awareness, enhance technical knowledge among stakeholders, and equip farmers with the information and skills necessary for the effective adoption of BDMs.

5. CONCLUSION

This study highlights the potential of biodegradable mulch as a transformative agricultural innovation in Tunisia, demonstrating both its economic viability and environmental benefits. Field trials, conducted in collaboration with farmers, show that the mulch biodegrades rapidly, with near-complete decomposition occurring within 185 days. This process reduces essential agricultural inputs, such as water, fertilizers, and pesticides, thereby enhancing resource efficiency. These agronomic advantages result in improved yields, higher produce quality, and faster harvest timelines, making biodegradable mulch a promising alternative to non-mulching practices. Economically, this technology proves both profitable and resilient to cost fluctuations, remaining viable even with a 75% increase in biodegradable mulch costs. A comprehensive partial budget analysis, which accounts for savings from reduced irrigation, fertilizer, and herbicide usage, alongside increased yields and higher crop market prices, effectively covers additional costs such as the higher initial investment and increased labor costs, providing a clear evaluation of short-term financial returns. Long term, this technology fosters sustainability by mitigating water depletion and enhancing soil health. It also reduces plastic waste accumulation, offering significant environmental benefits. However, further research is needed to assess the long-term impacts of biodegradable mulch on soil and water quality, microbial biodiversity, and its overall carbon footprint. Additionally, a more detailed evaluation is essential to understand the long-term economic effects and how biodegradable mulch can mitigate environmental externalities, contributing to sustainable agricultural practices. Moreover, understanding farmers' perceptions and their willingness to adopt biodegradable mulch is crucial for large-scale implementation, ensuring the widespread and lasting impact of this innovation.

Policy interventions should combine financial incentives, such as targeted subsidies and microcredit programs, with initiatives to build technical expertise and support the transition to sustainable agricultural practices, promoting the adoption of biodegradable mulching. Integrating this practice into broader climate-smart strategies can enhance resilience to climate change and boost food security, especially in regions facing severe water scarcity. While this study focuses on tomato crops, its findings may be applicable to other summer horticultural systems cultivated under similar open-field conditions. This suggests that the benefits of biodegradable mulching could be extended through its availability by encouraging entrepreneurship in biodegradable mulch. Farmers and extension officers training on biodegradable mulching technology, financial support for biodegradable mulch films, and incentives to farmers' associations in order to improve their market access of vegetables produced with biodegradable mulch are also recommended.

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