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Cochineal Crisis in Tigray: Advances in Management and Control

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Abstract. Cactus pear (*Opuntia ficus-indica*) plays a crucial role in Tigray, Ethiopia, serving as a vital source of food, fodder, and household income. In 2004, the *cochineal insect* (*Dactylopius coccus*) was introduced with the intention of enhancing the economic value of cactus pear. However, the insect quickly became invasive, decimating vast areas of cactus pear and severely impacting the livelihoods of local communities. The rapid spread of the cochineal insect was largely due to a lack of prior knowledge about its biology and the absence of environmental impact assessments before its introduction. Additionally, the out-grower scheme associated with the cochineal trade contributed to the unregulated spread of the pest, both natural and through human activity. Favorable conditions—such as prolonged dry spells, an abundance of cactus pear, and a lack of natural predators—further accelerated the insect's colonization and expansion. Attempts to control the infestation through community mobilization and insecticide applications proved largely ineffective. The suspension of cochineal harvesting is also believed to have worsened the situation. Today, over 75% of the cactus pear cultivation area is affected. Surveys conducted over several years have identified three indigenous predators of the cochineal insect, but their populations remain low. The laboratory evaluations of exotic natural enemies have not shown promising results. Similarly, efforts to find resistance within local cactus pear populations have been unsuccessful. On a more positive note, four introduced cactus pear varieties have demonstrated strong resistance in both laboratory and field conditions. In addition, some farmers have developed effective local management practices for cochineal control. The combined application of resistant cactus pear varieties and these locally developed practices offers a practical pathway to prevent destruction of the crop. Although complete eradication of the cochineal insect may not be feasible, the challenge presents a unique opportunity, producing cochineal under controlled conditions could position Ethiopia as a strong competitor in the global cochineal market. This paper explores the economic and environmental impacts of the cochineal invasion, reviews the responses and lessons learned, and presents recommendations for sustainable pest management.

Keywords: *Beles, Opuntia ficus-indica, Tigray, cochineal (Dactylopius coccus), resistant varieties.*

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Introduction

Agriculture is the cornerstone of livelihoods for over 85% of the population in Tigray, northern Ethiopia (Brutsch, 1997). However, the sector faces significant challenges from both natural factors, such as recurrent droughts, erratic rainfall, and an unstable climate, and human-induced pressures. Annual precipitation in the region ranges from 350 mm to 800 mm (Mondragón and Tegegne, 2006).

Approximately 17% of Tigray is classified as arid, 81.46% as semi-arid, and only 1.6% as dry sub-humid (Haftom *et al.,* 2019). The high temperatures and extended dry seasons further strain agricultural productivity, particularly in the Eastern, Northeastern, and Southeastern zones, which are most vulnerable to food insecurity and environmental degradation (Gebre *et al.,* 2013; De Waal, 2014). The region's rugged terrain and sparse vegetation exacerbate soil erosion, limiting agricultural expansion and productivity (Nyssen *et al.,* 2015). Amid these challenges, cactus pear (*Opuntia ficus-indica*), locally known as Beles, has become a vital crop for Tigray. Its drought tolerance, low water requirements, and ability to thrive in poor soils make it well-suited for the region's arid and semi-arid environments. Cactus pear plays a crucial role in improving food security, providing livestock feed, and supporting environmental conservation (Meaza *et al.,* 2024; Korzan, 2021).

Introduced by Catholic missionaries in the mid-19th century in Erob Woreda (SAERT, 1994a), cactus pear has since become integral to local agriculture, flourishing where other crops fail due to droughts and challenging topography (Welderufael, 2014). The name "Beles" was originally associated with an indigenous plant species related to the edible fig (*Ficus carica* L.), though its current use for cactus pear remains uncertain.

Beyond its role as a food source, cactus pear offers agricultural, ecological, and economic benefits. Its ability to grow in degraded soils, where conventional crops struggle, makes it an essential alternative in the face of persistent drought and declining farmland productivity. Its dense root system helps prevent soil erosion, mitigates desertification, and aids in land conservation (Mondragón-Jacobo and Tegegne, 2006). Economically, cactus pear serves as a staple food, livestock feed, fuel wood, and an income source, enhancing the financial stability of smallholder farmers. As land fragmentation and soil degradation continue, communities in Tigray increasingly rely on cactus pear to safeguard food security and reduce agricultural risks (Hagos, 1997).

The survival of this highly valued crop, however, has been threatened by the introduction of the cochineal insect (*Dactylopius coccus* Costa) in 2004. The insect was originally introduced for dye production, but it quickly became invasive, devastating cactus plantations across the region and exacerbating agricultural and economic challenges in the region (Meaza *et al.,* 2024).

The cochineal industry was initially intended to generate income, create youth employment, and boost foreign currency earnings. However, due to the unrestrained form of management, the infestation decimated cactus pear plantations on both private and communal lands, leading to feed shortages, reduced livestock productivity, and decreased income. There followed strong opposition from local communities due to the severe damage inflicted on cactus pear crops.

Consequently, the project was terminated in 2010, but by that time, the cochineal insect had already spread across thousands of hectares of cactus pear, and the infestation continued to threaten agricultural sustainability and rural livelihoods. The spread of the infestation has exacerbated food insecurity, loss of livestock feed, and economic instability, leaving many communities grappling with diminished agricultural productivity. The infestation persists, posing a long-term threat to the survival of cactus pear in the region.

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Debate continues over whether sustained harvesting of cochineal could have mitigated its destructive impact while preserving both the cactus pear crop and the economic benefits of the insect. Some suggest that controlled harvesting could have balanced cochineal exploitation with cactus pear conservation. Others call for a complete ban on the collection and sale of cochineal, fearing intentional spread by those involved in the trade. A third perspective proposes regulated harvesting with strict measures to prevent further spread, aiming to leverage the insect's economic potential while mitigating environmental damage. Despite these differing viewpoints, no clear policy or strategy has been implemented regarding the fate of the invasive cochineal insect. Current efforts primarily focus on minimizing damage to cactus pear vegetation and restoring affected landscapes.

This paper explores the multifaceted economic and environmental impacts of the cochineal insect's invasion in Tigray, examining the damage inflicted on cactus pear cultivation, a cornerstone of local agriculture and livelihoods.

In addition to analyzing the impacts, this paper highlights the experiences and lessons learned by local farmers, government authorities, and agricultural organizations in combating the pest. It examines the successes and challenges encountered in managing the infestation, including controlled harvesting, community resistance, and debates over balancing the insect's economic potential with cactus pear conservation.

The paper offers recommendations for the sustainable management of the cochineal insect in the region. These strategies aim to balance economic gain with ecological preservation, including regulated harvesting and policies to curb the pest's spread while preserving cactus pear's vital role in local agriculture. The goal is to provide a framework that helps mitigate current damage and ensures the long-term sustainability of cactus pear cultivation, a critical resource for Tigray's agricultural landscape and rural economy.

Material and Methods

Both primary and secondary data sources were utilized to gather comprehensive information. Key sources included annual reports from the Tigray Region Bureau of Agriculture and Rural Development, workshop reports, and planning documents from the Regional Cochineal Management Steering Committee. As an active member of this committee, the author conducted multiple field visits to cochineal-infested areas, directly engaging in affected communities to collect firsthand accounts. Additionally, the author played a significant role in regional initiatives aimed at controlling cochineal infestation, contributing valuable insights and observations to the management efforts.

The spread and significance of cactus pear in Tigray: Historical context and current challenges

Cactus pear is believed to have been introduced to Tigray through Erob, a district in the northeastern part of the region, from where it gradually spread southward. According to a 2024 assessment, cactus pear is now cultivated across 32 districts in Tigray (Fig. 1). While intentional planting in homesteads for food, fodder, and live fencing has contributed to its spread over the years, natural dissemination by birds, wild animals, and humans has played a predominant role. This has enabled cactus pears to cover vast areas, including hillsides, escarpments, mountains, and private and communal lands (Fig. 2).

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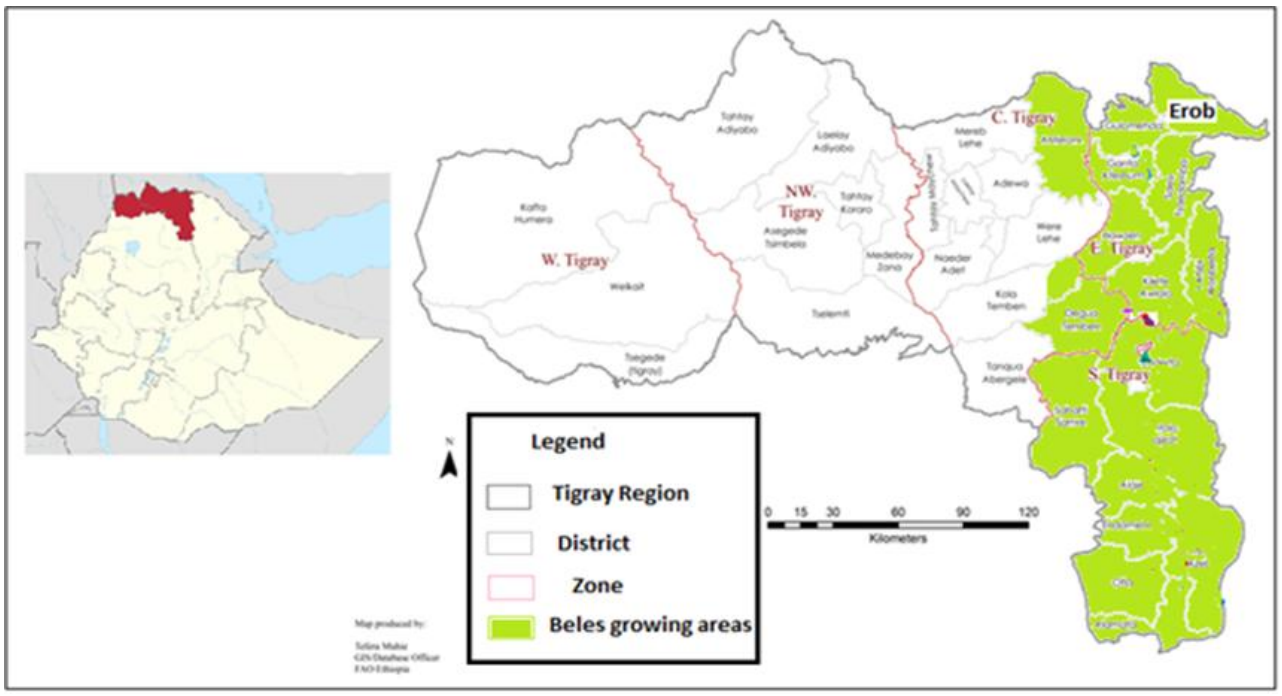

Figure 1. Cactus pear growing areas in Tigray, Ethiopia.

Figure 2. Cactus pear dominated vegetation in the Eastern (Left) Southern (Right) zones of Tigray, 2006.

According to the Bureau of Agriculture and Rural Development estimates, before the introduction of the cochineal insect, cactus pear fruit production involved 183,234 households (Table 1). This figure does not include the many individuals involved in the marketing and distribution of the produce, which is seasonal in nature. Roadside vending of cactus pear fruits is common, especially among schoolchildren and girls, providing an important source of income for those involved. This income is often used to cover school expenses, with the peak of cactus pear production coinciding with school breaks, creating a prime opportunity for children to participate.

Additionally, the benefits of cactus pear extend beyond those involved in production. Many community members rely on wild, communal cactus pear for fruit and livestock feed. While these benefits are

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seasonal, it is estimated that approximately 2 million people, both directly and indirectly, benefit from cactus pear cultivation.

Table 1. Beles growing areas and number of beneficiary households before cochineal infestation

No	Zone	Wereda	Tabia[1]	Beles's area (ha)	Beneficiary Households
1	Southern	3	32	18039	38225
2	Southeastern	5	57	53775	49655
3	Eastern	11	132	95119	95324
	Total	**19**	**221**	**166,933**	**183,234**

[1] Tabia is the lowest administrative structure below district in the Tigray region. BoANR assessment report 2024.

According to a 1994 report by SAERT (1994b), the total area under cactus pear cultivation in Tigray was estimated at 355,242 hectares. A later assessment by Helvetas in 2012, based on surveys conducted in eight major cactus pear-growing districts, reported 70,039 hectares of cactus pear orchards. However, estimates of total cactus pear coverage in Tigray vary significantly across sources. Brutsch (1997) estimated the area at 360,000 hectares, while SAERT (1994b) suggested 355,242 hectares. Unpublished annual reports from the Bureau of Agriculture and Rural Development (BoARD) have also presented varying figures. To date, there is no widely agreed-upon estimate of the total area covered by cactus pear in the region.

A 2024 report by the Bureau of Agriculture and Rural Development (BoARD) estimated the total area of cactus pear coverage in Tigray at 166,934 hectares, comprising 118,020 hectares (70%) of family-owned cultivated land and 48,914 hectares (29.3%) of communal, wild-growing vegetation. A more recent revised assessment by the same office (unpublished data) placed the total coverage at 129,064 hectares (Table 2). These discrepancies likely stem from inconsistent data collection methods, leading to variation in reported figures. Additionally, the expansion of agriculture into cactus pear-dominated foothills—prior to the introduction of the cochineal insect—and large-scale land clearing for investment purposes in areas such as the Mekhonee and Chercher plains, once densely covered with cactus pear, have likely contributed to the decline in overall coverage. This factor, often overlooked in earlier assessments, should be recognized as a significant driver behind the reduction in cactus pear cultivation across the region.

Despite the discrepancies and limitations in the available data, one clear trend emerges, the cochineal infestation has led to a dramatic reduction in cactus pear coverage in recent years. The presence of this invasive pest remains the primary driver of the rapid decline, highlighting the cactus pear's vulnerability to such threats. Prior to the cochineal outbreak, 19 woredas and 221 tabias were recognized for their significant Beles production potential (Table 2).

Table 2. Cactus pear growing area by district and Zone in Tigray, 2024 estimate

Zone	District	Area (ha)	Zone	District	Area (ha)
Central	Tahtai Machew	26	**Southeastern**	Enderta	2,900
	Adiet	6		Degu'a Tembien	1,360
	Ahferom	534		Hintalo	25,400
	Hahaile	534		Wejerat	25,400
	Kola Tembien	72		Samre	310
	subtotal	1,172		Sehartee	310
Eastern	Atsbee	2,700		subtotal	55,680
	Tsrae Wemberta	2,000	**Southern**	Emba Alaje	500
	Kilte Aulaelo	2,000		Bora	500
	Gerealta	NA		Selawa	500
	Hawzien	4,500		Neqsege	NA
	Tsaeda Emba	4,400		Enda Mekhonee	NA
	Sa'esi'e	4,400		Ofla	NA
	Ganta Afeshum	900		Zata	NA
	Bizet	900		Raya Azebo	5,356
	Gulo Makda	5,300		Raya Chercher	5,356
	Erob	29,300		Raya Alamata	3,600
	Subtotal	56,400		subtotal	15,812
	Overall total area = **129,064**				

Source: Bureau of Agriculture and Rural Development, 2024 (Unpublished data).

The role of cactus pear as a key source of food, feed, and income in Tigray

The Eastern, Northeastern, and Southern zones of Tigray are the primary regions for cactus pear (Beles) production, where the crop holds significant agricultural and economic importance. Prior to the cochineal outbreak, 19 woredas and 221 tabias were identified as having strong potential for cactus pear cultivation (BoARD Assessment Report, 2024, unpublished). In these areas, cactus pear played a vital role in addressing seasonal food shortages, sustaining communities for five or more months of the year. It also served as an essential feed source for livestock throughout much of the year. A study by Meaza *et al.* (2010) underscores the crop's multifaceted value, highlighting its importance not only as a food and fodder resource but also as a critical source of income for local households.

Although the fruit is seasonal, cactus pear remains a key emergency food, particularly during periods of drought when other food supplies are scarce. For instance, in Wejerat, communities rely heavily on cactus pear, with its fruit typically available from June to October. In the past, before the cochineal invasion wild cactus pear thriving on communal escarpments and hillsides yielded abundant fruit, sustaining both people and livestock, especially during the rainy season when other food and feed sources were depleted. This pattern is common across major cactus pear-producing areas, where the fruit serves as an essential food source, particularly when conventional food supplies run low.

In the Eastern zone of Tigray, except in Erob, cactus pear is predominantly cultivated in homestead and private orchards. In contrast, in the Southern zone and Erob, most of the fruit is harvested from communal wild orchards. In some cactus pear-growing areas, the fruit is the primary food source for poor households during the rainy season. As the season transitions, certain early-maturing crops help

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alleviate dependence on cactus pear by offering dietary variety. Among these, early-maturing barley is particularly significant, as it marks the first harvest of the season, preceding other crops. The timing of the barley harvest aligns with the depletion of cactus pear fruit, making it an indispensable food source that mitigates reliance on cactus pear in the later part of the rainy season.

The critical role of both cactus pear and early-maturing barley in sustaining food security is reflected in a local song (translated to its closest meaning):

"Beles filled my belly in times of need,
Barley arrives early, a true friend indeed"

Beyond its role in human nutrition, cactus pear is also a crucial livestock feed resource in Tigray. A study conducted in Kihen, Eastern Tigray, revealed that most farmers ranked cactus pear as their primary feed source, valuing it more for fodder than for food or income. This preference exhibits the essential role of livestock, particularly cattle, in local agriculture. Livestock is not only vital for plowing fields but also serves as a form of economic security against droughts and famine (FAO, n.d.). In a region where feed shortages are a recurring challenge —especially during the dry season— cactus pear's drought-resistant nature makes it an indispensable source of green forage. It provides a consistent and reliable feed supply, even during extended dry periods (Gebremeskel *et al.,* 2013). While cactus pear serves as a forage source nearly year-round in the Eastern zone, it provides feed for approximately nine months in the Southern zone, likely due to the availability of alternative feed sources in the Southern districts. Interestingly, livestock fed on cactus pear pads require less water, drinking only once every two to four days (Gebremeskel *et al.,* 2013). This reduces pressure on water resources while improving livestock health and productivity, particularly during dry seasons when water scarcity is a major concern. Furthermore, farmers in Erob and Gulomakeda have observed that feeding cactus pads to livestock enhances milk productivity, reinforcing its value as a feed resource (Gebremeskel *et al.,* 2013).

Seasonal yet economically vital, cactus pear plays a significant role in household livelihoods through the sale of its fruit and pads, which are used for livestock feed or planting. In Tabia Kihen, its primary use is as livestock feed, followed by food and, lastly, income generation. While income ranks third in this specific area, cactus pear remains economically important across many cactus pear-growing districts. Meaza *et al.* (2010) reported that the crop contributes between 40 and 85% of annual household income among growers, underscoring its vital role in the local economy. This contribution is particularly significant for medium-income households, where cactus pear supports both food security and financial stability (Tables 1 and 3). With its multifunctional value —as food, feed, and a source of income— cactus pear is an indispensable asset in Tigray's agricultural and economic landscape.

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Table 3. Percent contribution of cactus pear to household income (Kihen, 2009)

Income group	Contribution (%)			
	N	Mean	Min	Max
Nongrowers	18	0	-	0
Medium income Household	85	39.86	0	85.15
Higher income household	17	50.99	15.1	68.48

Source: Meaza *et al.* (2010).

The use of cactus pear as a source of income is typically given third priority by grower households—after livestock feed and food. This prioritization is influenced by the size of farmers' orchards and the availability of alternative livestock feed sources in the area. Farmers with larger orchards can produce enough to meet both household food and livestock feed needs, allowing them to sell the surplus in the market. In contrast, those with smaller orchards often struggle to meet these basic needs, leading them to prioritize feed and food over income generation. Furthermore, in areas where alternative feed sources are more readily available, the reliance on cactus pear as fodder decreases, further influencing its role in both the local economy and farming systems.

Cactus pear productivity and market value in Tigray: Current estimates and economics impact

Recent estimates of cactus pear fruit productivity in Tigray remain limited; however, earlier studies offer valuable insights into its production potential. According to a 1994 study by SAERT (SAERT, 1994b), the annual yield capacity of cactus pear fruit in Tigray was estimated to range between 457,806 and 610,408 tons, with an achievable yield of 293,544 to 391,393 tons—approximately 64% of the total potential.

Helvetas (2012) estimated annual cactus pear production in eight major districts at 4.8 million quintals, with 40% consumed by producer household and 60% sold. At a market price of 5 Birr kg^{-1} (US$ 0.0072 kg^{-1}), the total market value at that time reached 2.4 billion Birr. In 2024, Tigray's cactus pear production was estimated at 965,012.79 tons, with Eastern Tigray contributing approximately 834,828 tons (Table 4). Assuming 40% of the harvest was consumed by producer households (Helvetas, 2012), around 500,896 tons (60%) were marketed in Eastern Tigray alone. With an average fruit weight of 143.5 g (Hailu, 2020) and a price range of 5–10 Birr per fruit (US$0.0072-0.072 per fruit), a conservative estimate of 5 Birr per fruit (35 Birr kg^{-1}) placed the market value at approximately 17.53 billion Birr (~133.45 million USD). This substantial economic figure highlights the critical role of cactus pear production in Tigray's agricultural economy, emphasizing its significance as both a food and feed source and an income generator for local communities.

In a 2006 study, Mondragon and Tegegne examined urban consumption patterns in cities such as Adigrat, Mekelle, and Mehoni, finding that during the summer season, daily cactus pear consumption reached about 105.26 tons. However, this estimate may now be outdated due to population growth, the spread of cochineal infestation, and evolving consumption patterns. Given the rapid urbanization and population increase across the region, it is likely that summer consumption of cactus pear has risen considerably.

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Table 4. Estimated cactus pear fruit yield of major cactus producer districts in Tigray in 2024

Zone	District	Total fruit yield (t)
Central	Ahferom	5,644.66
	Hahaile	5,644.76
	Kola Tembien	864
	Subtotal	12,153.42
Eastern	Atsbee	51,250
	Tsrae Wemberta	21,336
	Kilte Aulaelo	21,336
	Hawzien	28,947.1
	Tsaeda Emba	27,222
	Sa'esi'e	27,222
	Ganta Afeshum	29,647.5
	Bizet	29,647.5
	Gulo Makda	218,203.5
	Erob	355,709.7
	Subtotal	834,828.12
South Eastern	Enderta	2,340
	Degu'a Tembien	19,026.1
	Hintalo	55,016
	Wejerat	55,016
	subtotal	131,398.1
Southern	Raya Azebo	5,470
	Raya Chercher	5,470
	subtotal	10,940
	Grand total	**965,012.788**

Source: BoARD, 2024 (Unpublished data); (Districts that had cactus pear area less than 100 ha are not included).

The introduction and spread of cochineal Tigray: Implications and consequences

The idea of introducing cochineal to Tigray originated from an international workshop in 1997, where cactus pear was identified as a significant invasive species (Zimmermann, 1997; Brutsch, and Zimmermann, 1995). The region's favorable climate and the widespread presence of healthy cactus plants on smallholder farms were considered ideal conditions for cochineal introduction (Haile *et al.,* 2002). In addition to curbing the spread of cactus pear, the initiative aimed to create economic opportunities for local communities by enabling them to collect and sell cochineal for commercial use.

However, the proposal sparked debate; while some researchers and policymakers viewed cactus pear as a growing problem, others cautioned against drastic measures. Brutsch (1997) emphasized the need to weigh its socioeconomic benefits and suggested alternatives, such as using less aggressive bio-control agents like *Cactoblastis cactorum* or employing labor-intensive physical clearing alongside intensified cactus pear utilization. Despite these concerns, the plan to control cactus pear using cochineal proceeded.

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At the time, some —particularly in the Southern Zone of Tigray— viewed cactus pear as a nuisance due to its rapid spread into farmlands (Brutsch, 1997). Habtu (2005) also highlighted its suppressive effects on other vegetation, including grasses and field crops. Despite these concerns, many farmers recognized cactus pear as a crucial source of feed, food, and income, especially during periods of drought. Given its economic and ecological importance, there was little justification for introducing biological control through cochineal or other natural enemies. Physical clearing may have been a more acceptable and context-sensitive management approach. This disconnects between scientific recommendations and local perspectives foreshadowed the resistance that would later emerge in response to the cochineal introduction.

The implementation of cochineal intervention

Following the workshop's recommendations, the FAO-TCP project, led by Mekelle University, imported cochineal from South Africa in 2003 and released it in 2004 (Tesfay, 2015). By 2007, Foodsafe, a Chilean company, was licensed to produce cochineal in Tigray, training farmers through an out-grower scheme and pledging social benefits, including biogas digesters and school electrification. Tigray's cochineal had a high carminic acid content (21–23%), making it commercially valuable (Tesfay and Bustamante, 2010). The first export occurred in April 2009 (Bustamante, 2010), generating USD $553,900 in a 10-month period by 2011 (Tesfay, 2011). Reports indicate Foodsafe exported approximately 2,000 tons of dried cochineal from Ethiopia over three years (Tesfay, 2015). However, little data exists on the company's overall performance, total exports, or actual revenue.

Community resistance and socioeconomic impacts

Despite its early commercial promise, the introduction of cochineal met strong resistance from local communities, who feared its impact on cactus pear—a resource central to their livelihoods. In Tsehafty village, where cochineal was first released, elderly residents voiced concerns, emphasizing that cactus pear, particularly its fruit, was accessible to all and essential for feeding livestock during times of scarcity. They argued that while cochineal cultivation might benefit the youth, it posed challenges for older community members who relied heavily on the crop. This sentiment reflects a deeper tension between the pursuit of economic gains through cochineal production and the community's dependence on cactus pear for food and fodder.

The situation also raised broader issues around equity and the unintended consequences of biological control interventions. Further compounding community frustration was the failure to fulfill key promises made by food safety, including the construction of biogas digesters and the provision of electricity to local schools—commitments that, when left unmet, deepened local distrust and resentment.

As opposition grew, the government revoked food safe's license, closing its farm in December 2010 (Tigray Bureau of Agriculture and Rural Development, 2010, Unpublished report). However, the illicit collection and trade of cochineal continued, mainly through Djibouti, while the infestation spread, worsening the crisis. The uncontrolled expansion of cochineal increasingly threatened rural communities' livelihoods.

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Table 5. Income from the collection and selling of carmine cochineal by local middle men for the period 2010-2012

SN	Name of local middlemen	Sex	Quantity of dried cochineal (qt) collected	Income earned	
				Birr	USD§
1	Priest Halefom Goitom	Male	30	450,000	25,299.38
2	Hayelom Yowhans	Male	405	6´075,000	34,1541.6
3	Etsay Gebru	Female	21	315,000	17,709.56
4	Kelali Tekle	Male	19	285,000	16,022.94
5	Baluh Hailkiros	Male	24	360,000	20,239.5
6	Syum Kahhsay	Male	14	210,000	11,806.38
7	H/Kebede Abrha	Male	3	45,000	2,529.938
8	Abrha Tekle	Male	10	150,000	84,33.125
9	Tesfay Tekle	Male	16	240,000	13,493.00
			Total	**8,130,000**	**457,075.4**

§: At that time, the average exchange rate was 17.787 Birr for 1 USD. Source: Nega (2014).

The rapid expansion and impact of cochineal infestation on cactus pear coverage

The cochineal infestation spread rapidly, expanding from 17 villages in 2011 to 139 by 2018, with an average annual invasion of 3,890 hectares of cactus pear (Meaza *et al.,* 2024). The affected area increased from 3,804.8 hectares in 2011 to 75,000 hectares by 2018, significantly impacting both wild and cultivated cactus plantations (Table 6, Figure 3). In the Southern Zone alone, 18,654.5 hectares were destroyed, including 15,489 hectares in Raya-Azebo and 3,165.5 hectares in Enda Mehoni (Tsegay and Hebtegiorgis, 2024). While some areas, such as Mekelle and Kilte Awulaelo, saw reductions in infestation due to control efforts, others may have experienced the complete eradication of cactus plants, leaving no vegetation or the cochineal pests.

The rapid spread of cochineal in Tigray was driven by a combination of factors, favorable climatic conditions, prolonged dry spells, the abundance of cactus vegetation, and the absence of natural predators. These ecological conditions were compounded by inadequate local pest control efforts (Berhe *et al.,* 2020) and a poorly designed out-grower scheme, which facilitated both natural and human-assisted dissemination of the insect. The interruption of cochineal harvesting —an activity that might have helped regulate its population— allowed the infestation to progress unchecked. Additionally, strong east-to-west winds that prevail for most of the year significantly accelerated the spread from initial outbreak sites, leading to a rapid and widespread invasion. As a result, vast areas of cactus-growing regions have been overrun (Fig. 3), with the southern and southeastern zones experiencing some of the most substantial losses in cactus pear coverage. Despite repeated containment efforts, the pest's relentless advance has largely gone unimpeded.

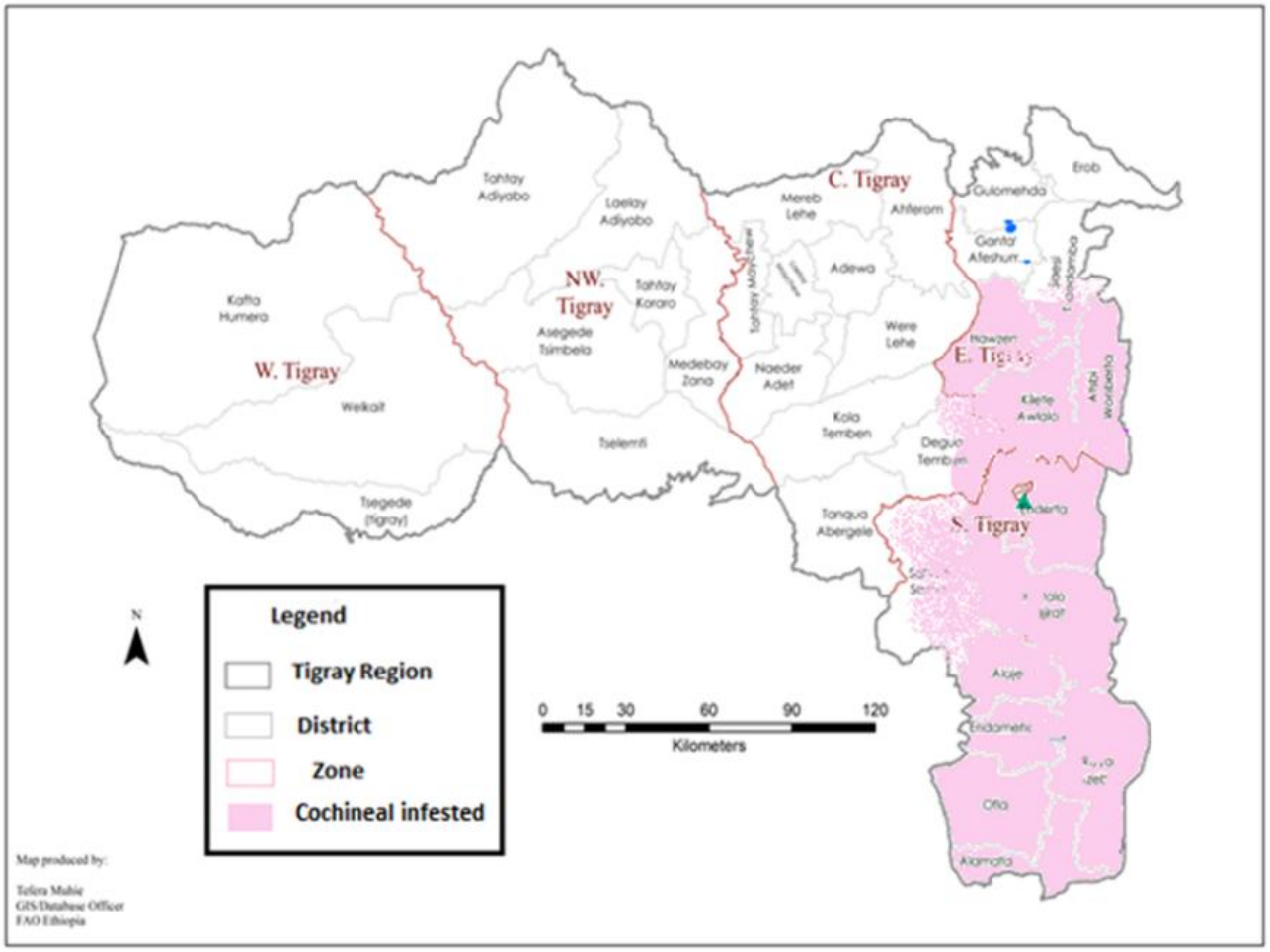

Figure 3. Map showing cochineal infested areas in Tigray.

Table 6. Expansion of cochineal-infested areas in cactus-growing regions of Tigray (2011–2018).

		Infested area (ha)					
No.	**District**	**2011**	**2013**	**2014**	**2016**	**2017**	**2018**
1	Ofla				5	318.5	1,485.5
2	Kilte Aulaelo				150	127	55.5
3	Sehartee Samre				1,247.5	179.3	67.5
4	Raya Alamata			30.8	462	919.5	NA
5	Degua Tembien			65.5	205	329.5	230.3
6	Enderta			1750	1,832.5	1,187	928.5
7	Emba Alaje		14	177.5	967	1,309	884.3
8	Mekele	201	201.5	9	40.5	43.5	11.3
9	Endamekhonee	195	1,200	2,111	3,100	3,114	31,46.5
10	Raya Azebo	1,328.8	2,099	5,591.5	15,752	20,374	15,434.5
11	Hintalo Wejerat	2,080	8,317	15,000	36,337.5	36,921	53,310.9
		3,804.8	**11,831**	**24,825**	**60,099**	**64,824**	**75,790**

Source: BoARD (2024) (Unpublished data).

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The company that launched the cochineal initiative primarily operated through an out-grower scheme, rather than establishing the privately owned farm it had originally promised. Instead of targeting private cactus pear farms, the scheme focused on communal, wild-growing cactus vegetation (Tesfay, 2015). This approach incentivized local community members —particularly landless youth— to introduce the insect into communal areas near their settlements, hoping to profit from the accessible cactus pear resources. As a result, numerous infestation hotspots emerged, largely driven by these youths who viewed cochineal collection and sale as a new livelihood opportunity. This strategy unintentionally accelerated the uncontrolled spread of the pest, further complicating management efforts.

Cochineal infestations and control efforts: Challenges of chemical, mechanical, and large-scale eradication efforts

In response to growing community concerns over the cochineal infestation, repeated applications of insecticides were attempted. However, these efforts proved largely ineffective due to the region's rugged terrain, which limited the reach of manual sprayers and made it difficult to access every nook and cranny. Moreover, re-infestations occurred soon after each treatment, making continued pesticide use unsustainable. The significant volume of water required for spraying, coupled with the logistical challenge of transporting large volumes across hillsides, further complicated the process, rendering it impractical.

As a result, large-scale eradication campaigns were initiated, focusing on cutting, burying, and burning infected cactus pear plants (Fig. 4). These efforts involved extensive community participation, with individuals contributing free labor as part of broader soil and water conservation initiatives. Initial results showed promise, as several hectares were cleared. For instance, in 2012, 1,506.42 hectares were cleared, controlling approximately 9.3% of the total cochineal-infested area that year (Table 7). Similarly, the 2017/2018 campaign involved 232,117 free labor workdays, resulting in 2,997 hectares being cleared (BoAR, 2018, Unpublished report).

However, the sheer scale of the affected areas made it impossible to clear all infested plants in a single season. Even small, overlooked plants acted as reservoirs for the pest, causing continuous re-infestations. Complete eradication proved impossible, as cochineal quickly recolonized newly sprouting plants, leading to recurring infestations. Additionally, attempts to replant healthy cactus pads failed, as untreated volunteer plants and neglected communal vegetation continued to harbor the pest. Cutting and destroying infected plants posed significant challenges, especially in communal wild cactus pear vegetation, which often grows in inaccessible terrain on communal lands. As a result, untreated areas remained breeding grounds for the pest, allowing the infestation to persist.

Despite large-scale control efforts, the long-term effectiveness of this approach was limited due to the immense labor demands required for its implementation. Years of extensive removal and destruction campaigns yielded minimal results, and the infestation continued to spread. This failure fostered a sense of helplessness among farmers, diminishing their willingness to participate in future control efforts. Considering these challenges, efforts shifted toward developing a more sustainable three-tiered management strategy, supported by the FAO.

Table 7. Cochineal infested cactus pear area cleared using mechanical control in Tigray, 2012

No.	District	Area infested (ha)	Area cleared (ha)	% control
1	Endamekhonee	1,600	655	40.9
2	Raya Azebo	3,415	276	8.1
3	Emba- Alaje	161.25	45	27.8
4	Hintalo-Wejerat	10,662	484	4.5
5	Mekelle City	208	39	18.7
6	Enderta	200	0	0
7	Degua-Tembien	10	9	85
	Total	**16,255.25**	**1,508**	

Source: TBoARD (2012).

Figure 4. Physical destruction: cutting and burning of cochineal infested cactus pear.

A structured three management approach

In response to the growing cochineal infestation, a new management strategy was introduced, which categorized infested areas into three zones based on the severity of infestation and suggested the following measures:

Infestation status	Measures to be taken
1. Highly infested areas	• Mechanically destroy infested plants to prevent further spread. • Replant affected areas with healthy cactus pads to restore vegetation.
2. Moderately infested areas	• Apply systemic chemical insecticides to control pest populations. • Physically remove and destroy infested plants. • Stump and clear pathways within orchards to improve accessibility for control activities.
3. New infestations and buffer zones	• Conduct regular monitoring and surveillance to detect early outbreaks.

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- Maintain clear pathways within orchards to facilitate timely interventions.
- Apply chemical insecticides, liquid soap and salt mixtures, or burn infestation hotspots using kerosene.
- Completely destroy infested plants through mechanical and physical methods to prevent further spread.

To reinforce these efforts, a buffer zone was established along the pest's invasion front, where scouts conducted regular surveillance and initiated immediate action upon detecting new infestations. While this structured approach proved more effective than relying solely on chemical sprays or indiscriminate orchard destruction, it still faced limitations. The buffer zones and scout deployments helped slow the rate of new infestations but failed to completely halt the insect's spread. Furthermore, continuous adjustments to the buffer zones were necessary to keep up with shifting infestation patterns. The region's rugged terrain and the insect's highly efficient dispersal mechanism complicated containment efforts, while traditional cactus pear cultivation methods—characterized by dense planting, lack of row spacing, and poor hedge height management—further hindered pest control.

The Tigray War (2021–2023) severely disrupted control efforts. Surveillance and intervention activities were abandoned as scouts disbanded, and buffer zones were left unmanaged. With no coordinated control measures in place, the infestation spread unchecked, advancing rapidly beyond the established buffer zone and into previously unaffected areas.

Human activity, including the deliberate introduction of cochineal into un-infested areas, also played a role in the pest's rapid expansion. For example, in Sassun Village near Adigrat Town, an individual intentionally introduced infected cactus pear pads into dense cactus thickets, despite being far from known infestation hotspots. Though experts were able to respond quickly by cutting and burning the infected plants, this incident highlighted the persistent threat posed by both natural and human-assisted dispersal.

Social and logistical challenges in containment

Beyond technical obstacles, social and logistical factors significantly hindered efforts to control the cochineal infestation. Within communities, conflicting interests emerged: some individuals profited from collecting and trading cochineal, while others opposed its spread due to its detrimental impact. The labor-intensive nature of pest management, coupled with the high-water demand for spraying, also strained already limited resources.

Many farmers were hesitant to destroy infested plants, perceiving eradication efforts as either futile or believing that responsibility for control rested with the government, given that the pest was introduced under official oversight. Some resisted destroying their orchards, arguing that even infested plants could still serve as livestock fodder. Others requested labor support for cutting and disposing of infected plants through safety net programs or community labor initiatives. In certain cases, the forced destruction of orchards led to frustration and resentment, deepening discontent within affected communities.

Exploring biological control strategies against cochineal in Tigray: Trials, setbacks, and prospects

After the failure of previous control measures, biological control using natural enemies was considered as a potential solution. However, there were concerns about introducing foreign predators, as it might undermine efforts to control invasive cactus species in other regions. This highlighted a policy inconsistency, although *Dactylopius opuntiae* had been successfully introduced in Kenya to manage wild *Opuntia stricta* (Witt *et al.,* 2020), Ethiopia's unique reliance on cactus pear was not adequately considered.

Surveying local natural enemies

Extensive field surveys were conducted to identify potential natural predators within the local ecosystem that could mitigate cochineal infestation. Researchers identified three potential natural enemies, two neuropterans (grey and green lacewings) and an unidentified beetle (Fig. 5). Observations confirmed that both the adult and immature forms of these insect species fed on the cochineal crawlers. However, their inherently low population densities compromised their capacity to exert a meaningful biological control effect.

Efforts to conduct a more thorough taxonomic identification of these predators faced additional challenges, as attempts to collaborate with the Mexican research center in Tecomán, Colima, for species verification were unsuccessful.

Figure 5. An unidentified predator beetle resting close to cochineal colonies (left) and Mating pairs of the same species (right).

Testing exotic biological control agents

Cryptolaemus montrouzieri (Mealybug Destroyer)

The first exotic natural enemy tested against cochineal in Tigray was *Cryptolaemus montrouzieri*, generously donated by Koppert Biological Systems in the Netherlands. This batch included 3,000 larvae, which were delivered via DHL. In laboratory trials, the larvae fed voraciously on cochineal crawlers and successfully matured into adults (Fig. 6). Some adults were also observed feeding on cochineal crawlers within rearing cages. However, a critical issue emerged, the waxy secretions of cochineal became entangled in the predators' legs, impairing their movement and ultimately leading to the death of some of the beetles contained in cages. Despite observing mature adults mating (Fig. 6), no second-generation beetles were recorded, marking the trial as unsuccessful.

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A second batch of *C. montrouzieri*, collected from the wild in Israel, was provided by Prof. Zvi Mendel, who had previously documented its positive impact on *Dactylopius opuntiae* populations in Israel (Mendel *et al.,* 2019). This batch included approximately 1,000 adult beetles, which were transported while sustained on nectar. Upon arrival, the beetles were supplied with live mealy bugs. However, technical constraints and inadequate rearing facilities made it impossible to maintain a viable population. Prolonged reliance on nectar during transport may have diminished the beetles' predation efficiency, as noted in previous studies (Li *et al.,* 2016, 2021). Additionally, the brief time allowed for dietary adjustments may have hindered their ability to effectively target *Dactylopius coccus* (cochineal). Dietary transitions are known to influence the physiological and behavioral readiness of predatory insects (Li *et al.,* 2016, 2021).

Figure 6. Left, larvae; middle, pupae; and right, adult mating pairs of *C. montrouzieri*.

Challenges in acquiring additional exotic species

Efforts to acquire further exotic biological control agents faced significant opposition from stakeholders concerned about the long-term consequences of introducing new natural enemies. There was widespread resistance, particularly regarding the potential implications for future biological control efforts targeting cactus pear as an invasive species elsewhere. This opposition severely limited our ability to secure and test additional exotic predators.

Laetilia coccidivora: A promising candidate

In 2019, 300 pupae of *Laetilia coccidivora* were received from Mexico, marking the most promising progress in the biological control efforts. The moth was successfully reared in the laboratory for up to four generations. However, sustaining the population beyond the fourth generation proved difficult due to resource limitations. Plans to procure a second batch from Mexico were abruptly halted by the outbreak of war in Tigray, preventing further research. Despite these setbacks, *L. coccidivora* showed the most potential for cochineal control. With improved laboratory conditions and better rearing facilities, more successful results could have been achieved.

Identifying resistance to cochineal in cactus pear populations in Ethiopia

The first critical step in combating cochineal infestations was identifying naturally resistant cactus pear varieties within the existing populations in Ethiopia. The Tigray region is known for its remarkable diversity in cactus pear varieties (Welu *et al.,* 2024), which presented a unique opportunity for identifying potential sources of resistance within the local cactus pear population.

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Field observations in cochineal-infested areas revealed significant variation in infestation levels across different cactus pear plants. Interestingly, some plants growing during heavily infested areas remained unaffected, suggesting that certain varieties may possess inherent resistance mechanisms. This observation was the foundation for the next phase of research. Several cactus pear accessions were carefully collected from various regions of Ethiopia and subjected to laboratory conditions (Welu *et al.,* 2024). However, after extensive testing, it was determined that none of the local accessions investigated displayed any measurable resistance to cochineal. Despite screening over 100 accessions, all were found to be highly susceptible to the pest, highlighting the urgent need for alternative sources of resistance.

Testing exotic cactus pear materials for resistance

To find viable resistant varieties, researchers turned to exotic cactus pear materials sourced from international collaborators. The Michael Technology Charitable Organization (USA) and DryGrow Foundation (Italy) provided several species, including *Opuntia ficus-indica*, *Opuntia robusta*, *Opuntia xoconostle*, and *Opuntia stricta* var. Mexicana. These species were chosen based on their known performance in other regions where cochineal infestations had been successfully controlled or mitigated.

To ensure consistent exposure, materials were systematically treated at three-month intervals by attaching cladodes bearing young cochineal colonies. Local susceptible check varieties succumbed rapidly following inoculation with the cochineal insect, necessitating repeated replacement of their pads. Consequently, fresh healthy pads of the susceptible check varieties were replanted every three to six months. In stark contrast, the exotic materials, particularly those from the USA and Italy, showed promising resistance, with certain varieties consistently demonstrating resilience in both laboratory and field conditions. Over a span of seven years, these materials were rigorously tested, further confirming their superior resistance to cochineal compared to local varieties.

Among the tested materials, two varieties —*Opuntia ficus-indica* and *Opuntia robusta*— stood out for their exceptional resistance to cochineal (Fig. 7). These varieties, named ‘Gidey’ and ‘Tsewar,’ respectively, offer a promising solution to the ongoing challenges posed by cochineal infestations in the region. Their resistance not only addresses the immediate issue but also holds potential for enhancing cactus pear cultivation in Ethiopia. These varieties could be particularly valuable in regions where traditional pest control methods, such as chemical sprays or physical removal, have proven either ineffective or unsustainable.

Welu *et al.* (2024) evaluated the susceptibility of various *Opuntia* species to cochineal infestations in the lab, revealing significant variation in resistance among the species tested. Local *Opuntia ficus-indica* materials were found to be highly susceptible, as most cochineal crawlers placed on this species matured and reproduced, leading to substantial infestations. In contrast, *Opuntia stricta* and *Opuntia robusta* exhibited notable resistance, with cochineal crawlers failing to reach maturity or reproduce on these species, effectively minimizing the pest's impact. The mechanism of resistance appears to be antibiosis, as the cochineal crawlers were unable to reach maturity or reproduce on these cactus pear varieties, meaning the plant prevents the development of subsequent generations of the pest.

Additionally, *Opuntia stricta* var. Mexicana has also demonstrated remarkable resistance to cochineal. This variety shows great promise not only as a cochineal-resistant material but also as a potential source of livestock feed, particularly in the Tigray region and other areas where cochineal is considered a pest.

However, a key challenge arises from the fact that the *Dactylopius opuntiae* biotype released in Kenya has been reported to particularly target *Opuntia stricta (*Witt *et al,* 2020). This raises concerns about the future viability of *O. stricta* var. Mexicana as a long-term cochineal-resistant material in Ethiopia. If the *D. opuntiae* biotype released in Kenya can attack this variety, its potential for widespread use in cochineal pest management may be limited.

The introduction of these resistant varieties could revolutionize cactus pear production in Ethiopia. They not only hold promises of increasing yields by minimizing pest damage but could also help reduce the economic losses caused by cochineal infestations. Moreover, “Gidey” and “Tsewar” may become valuable assets in broader agricultural and conservation efforts, helping to safeguard the biodiversity of cactus pear populations while promoting food security for local farmers.

While the discovery of resistant varieties is a significant breakthrough, there remain challenges in scaling this approach. For instance, ensuring that these varieties are effectively propagated and disseminated across the region will require a concerted effort from government bodies, agricultural institutions, and local communities. Additionally, ongoing monitoring of the cochineal population dynamics will be essential to ensure that resistance remains effective over time.

Furthermore, continued research into the underlying resistance mechanisms in “Gidey” and “Tsewar” is necessary. Understanding the genetic and biochemical traits that contribute to resistance could guide the development of even more resilient varieties, potentially offering a long-term solution to cochineal infestations in Ethiopia.

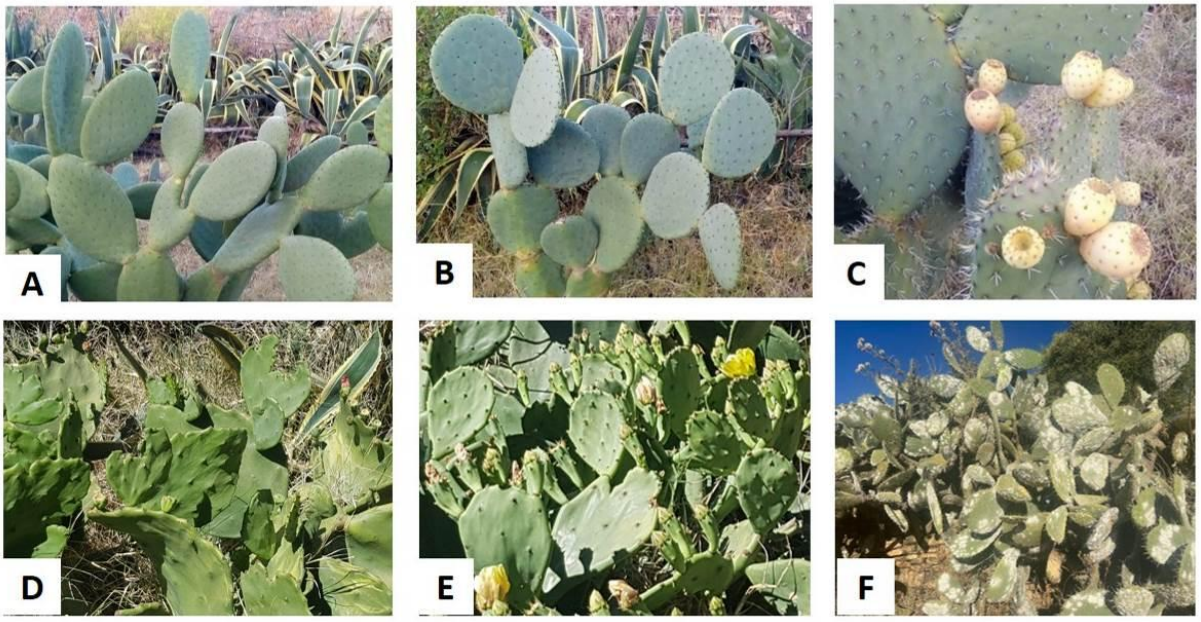

Figure 7. Cactus pear species tested for resistance against cochineal (*D. coccus*): (A) *O. ficus indica*, variety Gidey; (B) *O. robusta*, variety Tsewar; (C) *O. Xoconstle*; (D) *O. stricta* var Mexicana, (E) *O. stricta*, wild, and (F) *O. ficus indica* local susceptible.

Community-led cochineal management

The rapid and unexpected spread of cochineal infestations in Ethiopia has sparked widespread frustration. While some communities have responded with genuine concern, others have sought to exploit the crisis for personal gain. This has led to the emergence of various unproven control methods, ranging from herbal mixtures to kerosene-based treatments, each claiming to combat the pest effectively.

To validate their concoctions and secure patent rights, some individuals have conducted poorly designed experiments, while others have staged field demonstrations to showcase the supposed efficacy of their methods. However, without scientific validation, these approaches risk further complicating efforts to contain the infestation.

However, it is crucial to recognize that cochineal, being a sedentary insect, can be managed using simple, readily available materials—sometimes even just clean water. Pressurized water sprays can effectively dislodge the pests from pads in hard-to-reach areas, while manual techniques such as brushing or crushing the insects by hand also yield positive results. One particularly effective approach involves spraying a liquid soap solution followed by a brine solution (a mixture of rock salt and water). The soap solution dissolves the cochineal's protective waxy coating, allowing the salt solution to induce desiccation, ultimately leading to the insect's demise. Notably, none of the self-proclaimed "innovators" were able to demonstrate that their products performed better than the simple yet effective soap-and-salt spray treatment.

For optimal control of cochineal in orchards, planting cactus pear in rows and managing hedge heights ensure easy access for inspection and pest control. In hard-to-reach areas, spraying a strong jet stream of water is an effective method to dislodge the pest.

A group of proactive farmers (Fig. 8) has demonstrated that cochineal can be effectively managed through a simple yet systematic approach. The best practices identified by these farmers include planting in rows or clearing paths through orchards to improve access, conducting daily inspections to remove cochineal insects using brushes or water sprays, maintaining hedge heights for easier monitoring, stumping old stock to encourage healthy growth, and resorting to insecticides only when necessary. By consistently following these methods, they have successfully maintained relatively clean cactus pear orchards. These practices not only help control cochineal infestations but also encourage a collaborative, community-driven approach to pest management that reduces dependence on harmful chemicals and supports sustainable agricultural practices.

This initiative has catalyzed a growing farmer-led movement against cochineal infestation, with participation steadily expanding to include over 100 farmers. Previously, when infestations were severe, farmers relied on chemical insecticides such as Malathion 57% EC. However, subsequent observations by the farmers revealed that cochineal could be effectively suppressed using water sprays applied via knapsack sprayers—underscoring the method's cost-efficiency and environmental sustainability.

Figure 8. Cactus pear orchards of farmers that effectively managed cochineal using farmers developed practices, on the right stands a pioneering farmer, a leader in the movement.

The dual impact of cactus pear declines on Tigray´s ecosystems

The rapid spread of cochineal infestation in Tigray has led to both devastating consequences and unintended outcomes. While the loss of cactus pear has disrupted food security, livestock feed availability, and ecological stability, it has also allowed certain indigenous plant species to recover and provided opportunities for new land use.

1. Ecological shifts and vegetation dynamics

One of the most notable ecological outcomes of cochineal infestation is the shift in vegetation dynamics. The decline of cactus pear has allowed suppressed native plant species to re-emerge. According to Habtu (2005), farmers in cactus pear-dominated areas recognized the plant's ability to displace local vegetation, with at least ten dominant woody species being suppressed over time.

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Although detailed studies on plant population dynamics in cochineal-affected areas are lacking, early observations indicate that some native species are making a comeback now that the pressure from cactus pear has diminished.

A striking example is the resurgence of *Cadia purpurea*—locally known as "Shilen"—a plant traditionally used for fumigating milking and milk storage utensils, as well as for "Tush," a smoke-based traditional Tigrayan sauna. Prior to the widespread expansion of cactus pear, *C. purpurea* was dominant in the mountain regions of Raya-Alamata and Mekhoni-Maichew. However, its presence declined as cactus pear overtook the landscape. Following the cochineal-induced decline of cactus pear, *C. purpurea* has reclaimed its habitat, and has reestablished itself and now dominates the mountainous areas of Tigray's southern zone.

2. Agricultural land use changes

In areas like Tsehafty, where cochineal was first introduced, the infestation has led to the removal of cactus pear, creating new arable land. Farmers have begun utilizing these reclaimed lands for crop cultivation, offering opportunities for agriculture and land restoration. This shift suggests that, despite the destruction caused by cochineal, it has unintentionally allowed for alternative land use in certain regions.

3. Impacts of cactus pear loss on soil stability in Tigray

While the decline of cactus pear has allowed native species to thrive, it has also led to significant ecological challenges. Cactus pear was instrumental in soil conservation, preventing erosion, and providing vital shelter for wildlife. Its loss has exposed the land to soil erosion, particularly in regions like Raya, Wejerat and Endamekhoni, where the absence of cactus pear has intensified erosion, disrupting agriculture and local ecosystems (Fig. 9).

Figure 9. Hillside area around Tsehafty (left) and Gonka (Right), previously covered by cactus pear and currently exposed to soil erosion after the cactus pear was destroyed by cochineal.

The economics of using cochineal or cactus pear and its implication in future cactus pear development in Tigray

The economic and livestock feed contribution of cactus pear

Cactus pear as key livestock feed. The destruction of cactus pear has severely impacted livestock feed availability, causing a cascading effect on agricultural productivity and food security in Tigray. In most cactus pear-growing areas, its value as livestock fodder far exceeded its direct economic contribution. During drought years, cactus pear served as the primary feed source, sustaining cattle,

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sheep, and goats when other forage was scarce. In the Eastern Zone of Tigray, it remained a staple livestock feed for most of the year, whereas in the Southern Zone, where livestock populations are higher, its role as fodder was even more vital. Though the economic value of the feed consumed has not been fully quantified, it is expected to surpass the revenue generated from fruit sales annually.

The most devastating impact of cochineal invasion has been on farmers in the worst-affected areas, who have lost all the benefits once derived from cactus pear. Many households can no longer afford to own plow oxen, as livestock feed shortages have led to declining herd sizes. In subsistence farming systems that depend on oxen-drawn plows, this loss has resulted in significant reductions in agricultural productivity, further exacerbating food insecurity across the region.

Cactus pear as a source of food and household income. In addition to serving as livestock feed, cactus pear is a vital food source for households, particularly during droughts and famine. Reports show that about 40% of the cactus pear fruit produced annually in some areas is consumed by household producers, while the remaining 60% is sold. The economic significance of cactus pear is clear from estimates in the Eastern Zone of Tigray. In 2024, income from cactus pear sales was approximately USD 133.45 million. When including the volume consumed by producer households, the total estimated value rises to USD 232.45 million annually, just for this zone. Cactus pear also provided seasonal employment for women and children involved in fruit marketing, making it a crucial income source for urban and semi-urban poor households.

The cochineal experiment in Tigray: A missed economic opportunity or a necessary lesson?

The introduction of cochineal was originally intended as an economic opportunity, but it instead became an ecological disaster. The plan was to commercialize cochineal for dye production, assuming that cactus pear was an invasive species in the Southern Zone of Tigray. The business was expected to generate additional income for local communities and hard currency for the country while also creating employment opportunities for youth engaged in harvesting and processing cochineal (Tesfay, 2015). Though prematurely terminated, according to Tesfay (2015) the initiative was estimated to generate an annual income of about USD 52 million. While a large portion of this revenue would have gone to private companies, the local community could have benefited as out-growers or collectors, while simultaneously managing cactus pear growth in a sustainable manner. However, the business never took off, leaving behind a devastated cactus pear resource with no viable economic return. Given that the cochineal insect is now firmly established in the region, the question remains, how can the community adapt to this new reality while minimizing further damage?

A multi-dimensional analysis of the failure of the cochineal business in Tigray, Ethiopia

The failure of the cochineal business in Tigray resulted from a complex interplay of economic miscalculations, ecological mismanagement, weak institutional support, and social resistance. The project, initially introduced with the hope of creating an export-oriented natural dye industry, ended up causing widespread devastation to cactus pear (*Opuntia ficus-indica*), a critical resource for local livelihoods. Below is a detailed breakdown of the main reasons behind its failure:

1. Poor planning and lack of feasibility studies

The introduction of cochineal was largely based on economic optimism rather than scientific, social, and ecological assessments. The introduction assumed that cactus pear was an invasive species and

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that the production of cochineal dye would provide economic benefits. However, there was little to no thorough feasibility study on the economic, environmental, and social impacts of introducing the insect. As a result, the devastating consequences for local livelihoods were not anticipated. The lack of foresight led to irreversible damage, undermining the very communities the project aimed at benefiting. While cochineal dye production is a lucrative industry in some parts of the world (e.g., Peru and Mexico), the conditions in Tigray were fundamentally different due to the following reasons:

- Cactus pear was not merely an invasive species but a vital livelihood resource for food, livestock feed, soil conservation, and fencing. Its loss had direct negative consequences.
- No risk assessment was conducted to predict the uncontrolled spread of cochineal beyond designated production areas.

2. Unregulated and rapid spread of cochineal

Cochineal infestations spread much faster than expected, leading to widespread destruction of cactus pear. Since no containment strategies were in place, the insect quickly moved beyond targeted areas, making it impossible to regulate its impact. The cochineal wiped out entire cactus pear populations, leaving communities without a critical resource. Instead of serving as a sustainable industry, cochineal became an ecological disaster, wiping out cactus pear without yielding economic returns.

Unlike controlled commercial farms in Latin America, where cochineal insects are carefully managed, the cochineal introduction in Tigray resulted in unregulated proliferation. The reasons include:

- No containment strategy: The insects spread beyond targeted production zones, devastating cactus pear populations across entire landscapes.
- Absence of natural predators: Unlike their native environment, where natural predators help regulate cochineal populations, in Tigray, no such biological controls existed.
- Climatic conditions favoring infestation: The semi-arid climate of Tigray allowed cochineal insects to thrive unchecked, accelerating their spread.

3. Social resistance and loss of livelihoods

Local communities relied heavily on cactus pear for food, livestock feed, fencing, and soil conservation. The loss of cactus pear due to cochineal infestation led to food insecurity, livestock feed shortages, increased soil erosion, and economic distress. As a result, the business was met with resistance from affected farmers who saw it as a destructive intervention rather than an opportunity.

Cactus pear was deeply embedded in the livelihood system of rural Tigray, serving as a crucial food source for both humans and animals, especially during droughts; a major livestock feed, particularly during dry seasons; a soil conservation tool, preventing erosion and retaining moisture; and a fencing material, reducing dependence on wood and preserving natural vegetation.

The destruction of cactus pear due to cochineal led to food insecurity, livestock feed shortages, increased soil erosion and community backlash. Many households lost a reliable emergency food source during droughts. Farmers who depended on cactus pear to sustain their animals faced severe economic losses, with some losing their plow oxen, which are essential for agricultural productivity. In areas where cactus pear once stabilized the soil, its loss left the land vulnerable to severe erosion,

further decreasing agricultural productivity. Farmers rejected the cochineal business after experiencing its devastating consequences, seeing it as a threat rather than an opportunity. This widespread community resistance contributed to the premature termination of the project. Farmers lacked technical knowledge about cochineal harvesting and cultivation, which further discouraged participation in the project.

4. Premature termination and missed opportunities

Due to the uncontrolled spread of cochineal and its severe impact on rural communities, authorities eventually abandoned the business rather than investing in mitigation strategies. This left behind environmental destruction without any economic benefits to compensate for the loss. Instead of developing a controlled cochineal farming system —such as maintaining designated cactus pear plantations for cochineal production— the infestation was allowed to spread unchecked. If cochineal farming had been restricted to specific areas with proper containment measures, it might have been possible to balance economic benefits with environmental sustainability.

The cochineal business was shut down before alternative solutions could be explored. Instead of completely abandoning the project, efforts could have been made to:

- Develop cochineal-resistant cactus pear varieties to sustain both livelihoods and dye production.
- Introduce controlled cochineal farming zones, where cactus pear could be managed alongside dye production.

However, due to the severe impact on local communities and the lack of immediate economic returns, the business was abruptly abandoned, leaving behind environmental damage with no economic compensation.

Evaluating the benefits of cactus pear and cochineal production in Tigray

Cactus pear (*Opuntia ficus-indica*) provides significantly greater benefits to rural communities in Tigray than cochineal production. It plays a crucial role in food security, livestock feed availability, income generation, and ecological stability.

As a food source, cactus pear is indispensable, especially during drought and famine, due to its high carbohydrate, vitamin, and water content. Studies indicate that in some areas of Tigray, 40% of cactus pear production is consumed at home by producer households. In contrast, cochineal offers no nutritional value, as it is solely a commercial product.

For livestock feed, cactus pear is an essential resource, particularly during dry seasons. It provides moisture and nutrients for cattle, sheep, and goats, sustaining them when other fodder sources are scarce. Many farmers in Tigray depend on cactus pear to maintain their plow oxen, which are crucial for agricultural productivity. However, the introduction of cochineal led to widespread cactus pear destruction, resulting in severe feed shortages and reduced agricultural output.

Economically, cactus pear is a significant source of income. In 2024, estimated revenue from cactus pear fruit sales in Tigray reached USD 133.45 million, with its total economic value —including home

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consumption— potentially exceeding USD 232 million annually. It also provides seasonal employment, particularly for women and children who collect and sell the fruit. Although the monetary value of cactus pear as livestock feed has not been fully assessed, it is expected to surpass the revenue generated from fruit sales. In contrast, the cochineal venture failed commercially despite initial projections of USD 52 million annually (Tesfay, 2015).

From an ecological perspective, cactus pears prevent soil erosion, stabilize land, retain moisture, and improve soil fertility. It also provides habitat and food for pollinators, birds, and wildlife. Conversely, the spread of cochineal devastated vast cactus pear plantations, causing severe soil erosion, increased deforestation, and biodiversity loss.

Lessons from the cochineal introduction in Tigray

The introduction of cochineal in Tigray was initially envisioned as a dual-purpose strategy, controlling the spread of cactus pear while simultaneously creating new economic opportunities for local communities. However, what began as an ambitious plan ultimately devolved into a crisis with long-lasting economic, environmental, and social repercussions.

At its core, the failure of the cochineal initiative highlights the dangers of implementing biological control measures without adequately considering local ecological dynamics and socioeconomic dependencies. The widespread reliance on cactus pear for food security, livestock fodder, and income was largely underestimated, leading to strong community resistance. Furthermore, while the cochineal industry had the potential to generate substantial revenue, the benefits were unevenly distributed, and many of the promised community incentives —including biogas digesters and electricity for schools— were never realized. This failure to deliver on commitments further alienated local populations and contributed to the industry's collapse.

The unintended spread of cochineal exacerbated the crisis, wiping out vast tracts of cactus pear and intensifying hardships for smallholder farmers. The rapid expansion of the infestation —driven by favorable environmental conditions, strong winds, and the absence of natural predators— underscored the challenges of controlling a biological agent once introduced into a new ecosystem. The revocation of Foodsafe's license did little to contain the situation, as illegal trade persisted and the infestation spread across multiple regions, leading to large-scale ecological and economic damage.

Several critical lessons from this case:

1. The importance of socioeconomic considerations in bio-control decisions – Any biological control intervention must carefully evaluate the potential social and economic consequences, particularly in regions where the targeted species serves as a livelihood resource.
2. The need for robust pest management strategies – Simply introducing a biological agent without a comprehensive long-term management plan can result in unintended and uncontrollable consequences. Integrated pest management strategies, including containment measures, should have been in place from the outset.
3. Community engagement and transparency – The lack of genuine community involvement in decision-making fueled resistance and distrust. Future interventions should prioritize local voices and ensure that benefits are equitably shared.

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4. Policy consistency and long-term commitment – Government policy reversals contributed to instability, undermining the project's viability. Long-term agricultural and environmental policies should be based on thorough research and consistent implementation.

Ultimately, the cochineal crisis in Tigray serves as a cautionary tale about the risks of top-down interventions that do not fully account for local realities. While biological control can be an effective tool in managing invasive species, its success depends on careful planning, community involvement, and sustainable economic models. Without these safeguards, well-intentioned projects can quickly turn into ecological and economic disasters, leaving communities to bear the consequences.

Conclusions

Cactus pear is essential for rural communities in Tigray, providing food, livestock feed, income, and environmental benefits. The introduction of cochineal caused more harm than good, destroying a vital resource while failing as a commercial venture. Although cochineal created short-term opportunities for a few, its uncontrolled spread devastated cactus pear cultivation, threatening livelihoods and agricultural sustainability. Considering the overall benefits of traditional cactus pear utilization compared to cochineal production, cactus pear offers significantly greater advantages.

The collapse of this crucial food and feed source underscores the urgent need for sustainable solutions to restore cactus pear cultivation and ensure livestock and agricultural resilience in Tigray. Thus, restoring cactus pear and exploring sustainable alternatives should be a priority for recovery and adaptation efforts in Tigray. Engaging communities in decision-making, improving containment efforts, and ensuring continuous monitoring will be key to preventing similar failures in the future.

Recommendations

Moving forward: Adapting to a cochineal infested future

Future efforts must focus on sustainable adaptation strategies that help communities coexist with cochineal while preserving what remains of their cactus pear resources.

Without coordinated management, the continued expansion of the pest remains a major threat to agricultural sustainability and food security. The persistence of cochineal infestations highlights the urgent need for long-term, integrated management strategies that combine biological, chemical, and physical control methods. Addressing social and logistical challenges, strengthening community participation, and ensuring continuous monitoring will be essential in mitigating further damage. Moving forward, a community-centered approach to invasive species management —one that emphasizes sustainable utilization over eradication— offers a more balanced and effective solution.
With the irreversible damage caused by cochineal, there is no turning back to a cochineal-free era. Instead, communities must find ways to coexist with insects while safeguarding the remaining cactus pear resources. Strategies for adapting to this challenge should include:

- Developing and promoting cochineal-resistant cactus pear varieties.
- Implementing sustainable pest control measures to limit further damage.
- Enhancing alternative livestock feed sources to replace lost cactus pear fodder.
- Strengthening soil conservation efforts to mitigate erosion in affected areas.

- Exploring alternative economic opportunities, such as controlled cochineal farming for dye production.
- Train farmers in the management of cactus in family gardens.

Integrating resistant cactus pear varieties with other pest management strategies, such as biological control and habitat management, will be crucial for developing sustainable farming practices that can withstand the challenges posed by invasive pests like cochineal. Additionally, farmer-identified cochineal management practices should be incorporated alongside the deployment of resistant cultivars. A farmer-based movement should be encouraged and supported to reach the cochineal-infested areas of the region. Without effective control measures, the remaining cochineal-free cactus pear orchards in Tigray are unlikely to remain uninfected over the next decade. The rapid expansion of cochineal infestation —from 3.8 hectares in 2011 to 75,000 hectares by 2019— underscores the urgency of implementing comprehensive management strategies to protect these vital agricultural resources.

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Not applicable

CONSENT FOR PUBLICATION

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AVAILABILITY OF SUPPORTING DATA

All data generated or analyzed during this study are included in this published article.

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The author declares that he has no competing interests.

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