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Cost Analysis of Biopesticides and Chemical Insecticides: Implications for Cotton Farmers in South Africa

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ABSTRACT

Cotton (*Gossypium* spp) remains a significant source of income in Africa. However, production is limited by high input costs that reduce profit margins. This study aimed to conduct cost analysis on field trials that were conducted to evaluate the effect of chemical insecticides, Chlorpyrifos® 480 EC, Karate® EC, and Bandit® 350 SC compared with biopesticides, Eco-Bb®, Bolldex®, Delfin®, NOMU-PROTEC® and Bb endophyte on the control of cotton insect pests. Delfin® (US$602) was the most expensive pesticide, followed by Bolldex® (US$495.74), while the cheapest pesticide was Chlorpyrifos® (US$28). Other input costs were US$1 396.50 per hectare, with the highest labor cost of US$544. The minimal cost of production from the bollworm trial was recorded from the application of Karate® (US$1 455), while Delfin® (US$1 999) was the highest. Maximum average seed cotton yield was recorded with Bolldex® (6 402 kg ha^{-1}); however, the maximum net profit of up to US$1 445.26 per hectare was registered with Karate® with the highest cost-benefit ratio of 1.8. The average highest seed cotton yield was obtained with Bandit® (6 394 kg ha^{-1}) followed by Bb endophyte (6 297 kg ha^{-1}) in the leafhopper trial. Bandit® and Karate® had the highest net profits of US$ 1,712 and US$ 1,253, respectively. The Bandit® treatment had the highest cost-benefit ratio of 2. Generally, biopesticide application was found to be more expensive than chemical insecticides; however, they were all profitable.

Keywords: Cotton, Cost analysis, Biopesticides, South Africa, Bollworm, Leafhopper*.*

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INTRODUCTION

Cotton, *Gossypium hirsutum* L. (Malvaceae), is an important crop mainly used for fiber [1]. Africa is responsible for about 8% of the world cotton market [2], mainly produced by smallholder farmers [3]. The cotton industry supports over 350 million people, primarily smallholder farmers from developing countries [4]. Smallholder farmers in Africa mostly produce cotton in small fields [5]. Cotton is grown on labor-intensive family farms [6] in over 20 sub-Saharan countries [2]. About 250 commercial and more than 2,000 smallholder farmers in South Africa grow cotton in Mpumalanga, Northern Cape, KwaZulu-Natal, Limpopo, and North West provinces [7]. Production area increased in 2019 compared to the previous season by 42% for dry and 22% for cotton under irrigation [7]. Despite this, various insect pests widely affect cotton yields and fiber quality [8]. Chemical insecticides are often used because they are easily accessible and most effective in controlling pests [9]. However, insecticides affect the quality of the environment [10], water and humans [11]. Misusing insecticides also leads to resistance in target pests and harmful effects on non-target organisms [12]. By 2019, more than 500 pesticides were registered in South Africa [13].

Biopesticides can potentially reduce the use of chemical insecticides while reducing insect resistance and increasing cotton yields [14]. However, the technology has not been well studied in developing countries, especially for smallholder farmers [15]. In Sub-Saharan Africa, biopesticides are adopted due to the absence of widespread IPM implementation [16], high prices, unpredictable field performance, and government policies [17]. The research to develop and promote biopesticides in Africa dates to the 1960s [18]; however, funding and the impact on agriculture are limited [16]. In South Africa, research and development on biopesticides have increased in recent years, and there are over 30 products registered [13]. Between 2014 and 2019, biopesticides accounted for approximately US$4 billion of the US$61.3 billion global insecticide market [19]. By 2022, Industry Research Biz (2023) predicted that the global market for biopesticides was over US$ 5 643 million and expected to reach US$ 11 378 million by 2028 [20].

Small-scale farmers struggle to obtain better-quality cotton seeds, insecticides, and fertilizers to improve production [21]. The price of these production inputs has increased, leading to increased production costs [2]. The introduction of Bt cotton cost farmers more than non-Bt varieties due to technological costs [22]. The increased cost per hectare of cotton production has steadily reduced the profit margin, while its prices, inputs, and weather significantly impact cotton production [23]. Plant protection is crucial to improve yield and profitability since each production input plays an important role in cotton production. The present study has been undertaken to identify the influence of these inputs.

Furthermore, farmers must understand the financial possibility of introducing biopesticides to the market in order to make lucrative decisions. The economic benefits of genetically modified cotton to small-scale growers in South Africa have been well documented [24]; however, no cost-benefit analyses have been conducted on the biological control of non-genetically modified cotton for small-scale farmers. Therefore, this study attempted to estimate the input costs and the gross profit of cotton production. The study will examine the cost-benefit analysis of biopesticides and chemical insecticides on non-genetically modified cotton.

MATERIALS AND METHODS

Trials site, layout, and planting

Field trials to control bollworms and leafhoppers, was conducted at the Agricultural Research Council (25°39.0S, 27°14.4E) in Rustenburg, South Africa. The trials were randomized block design, with each treatment repeated four times. Conventional cotton seed DeltaOPAL, a non-GM cultivar from Monsanto, was planted under irrigated conditions.

Insecticides application

In the bollworm experiment, Bb endophyte (University of KwaZulu-Natal: Pietermaritzburg, South Africa), Eco-Bb®, Bolldex®, and Delfin® (Andermatt Madumbi: Hilton, KwaZulu-Natal) were compared with pyrethroid, Karate® (Syngenta: Centurion, South Africa), and untreated control. In the leafhopper experiment, Eco-Bb®, Bb endophyte, and NOMU-PROTEC® (Andermatt PHP: Midlands, South Africa), were evaluated in comparison with the insecticides, Karate® EC, Bandit® 350 SC and Chlorpyrifos® 480 EC (Arysta LifeScience: Durban, South Africa), and untreated control. Insecticide application commenced 13 weeks after planting, with ten weekly applications conducted. Because of the UV sensitivity of the biopesticides, insecticide applications were done later in the day [25] using knapsack sprayers. Two laborers administered the insecticides and conducted weed hoeing at the wage rate of US$10.87/day for ten applications and at the cost of five laborers per day for ten days.

Cost-benefit analysis

Costs for seed and pesticides, field preparation, and trial maintenance were all in the cost-benefit analysis. The study did not consider externalities related to each treatment, such as possible effects on the environment, natural enemies, and the safety of farmworkers and consumers. The suppliers provided the costs for the treatments and seed, and the ginnery's selling price determined the cost per kilogram of seed cotton.

The net Return was determined using the formula below, adapted from Ali *et al*. (2012) [26]:

Net Return = Total revenue earned – Total cost of production (1)

After input costs are deducted, the net Return is the profit generated after selling seed cotton to a ginnery. At the same time, total revenue refers to the quantity received.

Cost-benefit ratio

Using the cost of each treatment and seed cotton yield, the cost-benefit ratio was computed. The formula below, utilized by Gayi *et al*. (2017), was used to construct the cost-benefit analysis cost ratio of the treatments [15]:

Cost-Benefit Ratio = Total income earned ÷ Total cost of production (2)

The revenue from selling seed cotton is represented by the total income earned. The total cost of production shows the costs incurred to produce the cotton seed yield. The following index was used to determine the benefit-cost ratio: A seed cotton yield was deemed commercially sustainable if the benefit-cost ratio was greater than 1, and less than one suggested that the yield was not. A break-even benefit-cost ratio of 1 was assumed.

RESULTS AND DISCUSSION

Cost of pesticides

Table 1 provides the cost of each treatment per hectare. The highest treatment cost was documented where Delfin® (US$602.32) and Bolldex® (US$495.74) were applied. The lowest price of treatment per hectare was observed with Chlorpyrifos® 480 EC (US$27.93). The lowest cost of the other treatments was US$46.80, while the highest was US$226.44.

Table 1. Application rates and costs of biopesticides and chemical insecticides

Trade name	Active ingredient	Rate	Unit cost	Total*
Eco-Bb®	*Beauveria bassiana*	300g/ha	US$22.64/300g	US$226.44
Bolldex®	Nucleopolyhedrovirus	200ml/ha	US$123.94/500ml	US$495.74
Delfin®	*Bacillus thuringiensis*	1kg/ha	US$60.23/kg	US$602.32
Bb endophyte	*Beauveria bassiana*	300g/ha	US$22.64/300g	US$226.44
NOMU-PROTEC®	*Metarhizium rileyi*	300g/ha	US$22.64/300g	US$226.44
Karate® EC	Lambda-cyhalothrin	120ml/ha	US$49.06/l	US$58.87
Chlorpyrifos® 480 EC	Chlorpyrifos	200ml/ha	US$13.96/l	US$27.93
Bandit® 350 SC	Imidacloprid	200ml/ha	US$23.40/l	US$46.80

*The total value is based on ten sprays per hectare at the application rate. The price unit has been converted to the United States dollar based on the average exchange rate in 2018: ZAR 13.2488.

Production costs

The list and costs of inputs needed to grow one hectare of cotton are displayed in **Table 2**. In addition to the expenses incurred for obtaining the pesticides, the additional costs associated with production amounted to $1 396.50 per hectare. These expenses cover seed, clearing the land, planting, pulling weeds, dousing with pesticides, and harvesting. The manual weed control method incurred the highest cost of $543.45, with harvesting coming in second at $360.79. The total production costs for each treatment are shown in **Tables 3-6**. In the bollworm experiment, the treatment with Karate® EC (US$1 455.38) showed the lowest production costs per hectare, while the treatment with Delfin® (US$1 998.82) showed the highest production costs. The leafhopper experiment plots treated with chemical insecticides had the lowest production costs. The most affordable options were Chlorpyrifos® 480 EC (US$1 424.43), Bandit® 350 SC (US$1 443.30), and Karate® EC (US$1 455.38). The application of Eco-Bb®, Bb endophyte, and NOMU-PROTEC® resulted in the highest costs, totalling US$1 622.94.

Table 2. Total input costs for the other production activities

Input	Quantity	Cost/ha
Cottonseed	8kg/ha	US$78.12
Ripping	Tractor hire/ha	US$84.31

Discing	Tractor hire/ha	US$56.23
Planting	Tractor hire/ha	US$56.23
Hand hoeing	5 workers/day for 10 days @ US$10.87	US$543.45
Spraying of pesticides	2 workers/day for 10 days @ US$10.87	US$217.38
Harvesting	Tractor hire/ha	US$360.79
Total		**US$1 396.50**

Table 3. Estimates of cost-benefit analysis of the chemical and biological insecticides in the cotton bollworm experiments during in 2017

Treatments	Quantity	Cost/ treatment*	Other costs	Total costs	Cotton yield	Cost/kg	Income	Net Return	Cost-benefit Ratio
	ha^{-1}	(US$ ha^{-1})	(US$)	(US$)	(kg ha^{-1})	(US$)	(US$ ha^{-1})	(US$ ha^{-1})	
Control	0	US$0	US$1 396.50	US$1 396.50	4 168	US$0.45	US$1 887.57	US$491.06	1.4
Eco-Bb®	300g	US$226.44	US$1 396.50	US$1 622.94	3 055	US$0.45	US$1 383.52	- US$239.42	0.9
Bolldex®	200ml	US$495.74	US$1 396.50	US$1 892.25	5 987	US$0.45	US$2 711.34	US$819.09	1.4
Delfin®	1kg	US$602.32	US$1 396.50	US$1 998.82	3 523	US$0.45	US$1 595.47	- US$403.36	0.8
Bb endophyte	300g	US$226.44	US$1 396.50	US$1 622.94	3 100	US$0.45	US$1 403.90	-US$2 902	0.9
Karate® EC	120ml	US$58.87	US$1 396.50	US$1 455.38	5 133	US$0.45	US$2 324.59	US$869.21	1.6

*The cost per treatment is based on ten applications per season.

Table 4. Estimates of cost-benefit analysis of the chemical and biological insecticides in the cotton bollworm experiment in 2018

Treatment	Quantity	Cost/ treatment*	Other costs	Total cost	Yield	Cost/kg	Income	Net Return	Cost-benefit Ratio
	ha^{-1}	(US$ ha^{-1})	(US$)	(US$)	(kg ha^{-1})	(US$)	(US$ ha^{-1})	(US$ ha^{-1})	
Control	0	US$0	US$1 396.50	US$1 396.50	4 673	US$0.45	US$2 116.27	US$719.76	1.5
Eco-Bb®	300g	US$226.44	US$1 396.50	US$1 622.94	5 961	US$0.45	US$2 699.57	US$1 076.63	1.7
Bolldex®	200ml	US$495.74	US$1 396.50	US$1 892.25	6 818	US$0.45	US$3 087.68	US$1 195.43	1.6
Delfin®	1kg	US$602.32	US$1 396.50	US$1 998.82	5 755	US$0.45	US$2 606.27	US$607.45	1.3
Bb endophyte	300g	US$226.44	US$1 396.50	US$1 622.94	6 409	US$0.45	US$2 902.45	US$1 279.51	1.8
Karate® EC	120ml	US$58.87	US$1 396.50	US$1 455.38	6 405	US$0.45	US$2 900.64	US$1 445.26	2.0

*The cost per treatment is based on ten applications per season.

Table 5. Estimates of cost-benefit analysis of the chemical and biological insecticides in the cotton leafhopper experiment in 2017

Treatment	Quantity	Cost/ treatment*	Other costs	Total cost	Yield	Cost/kg	Income	Net Return	Cost-benefit Ratio
	ha^{-1}	(US$ ha^{-1})	(US$)	(US$)	(kg ha^{-1})	(US$)	(US$ ha^{-1})	(US$ ha^{-1})	
Control	0	US$0	US$1 396.50	US$1 396.50	4 810	US$0.45	US$2 178.31	US$781.81	1.6
Eco-Bb®	300g	US$226.44	US$1 396.50	US$1 622.94	5 960	US$0.45	US$2 699.11	US$1 076.17	1.7
Bb endophyte	300g	US$226.44	US$1 396.50	US$1 622.94	5 830	US$0.45	US$2 640.24	US$1 017.30	1.6
NOMU-PROTEC®	300g	US$226.44	US$1 396.50	US$1 622.94	5 600	US$0.45	US$2 536.08	US$913.14	1.6
Karate® EC	120ml	US$58.87	US$1 396.50	US$1 455.38	5 980	US$0.45	US$2 708.17	US$1 252.79	1.9
Chlorpyrifos® 480 EC	200ml	US$27.93	US$1 396.50	US$1 424.43	5 020	US$0.45	US$2 273.41	US$848.98	1.6
Bandit® 350 SC	200ml	US$46.80	US$1 396.50	US$1 443.30	5 820	US$0.45	US$2 635.71	US$1 192.41	1.8

*The cost per treatment is based on ten applications per season.

Table 6. Estimates of cost-benefit analysis of the chemical and biological insecticides in the cotton leafhopper experiment in 2018

Treatments	Quantity	Cost/ treatment*	Other costs	Total costs	Cotton yield	Cost/kg	Income	Net Return	Cost-benefit Ratio
	ha^{-1}	(US$ ha^{-1})	(US$)	(US$)	(kg ha^{-1})	(US$)	(US$ ha^{-1})	(US$ ha^{-1})	
Control	0	US$0	US$1 396.50	US$1 396.50	5 090	US$0.45	US$2 305.11	US$908.61	1.7

Eco-Bb®	300g	US$226.44	US$1 396.50	US$1 622.94	6 320	US$0.45	US$2 862.15	US$1 239.21	1.8
Bb endophyte	300g	US$226.44	US$1 396.50	US$1 622.94	6 763	US$0.45	US$3 062.77	US$1 439.83	1.9
NOMU-PROTEC®	300g	US$226.44	US$1 396.50	US$1 622.94	6 300	US$0.45	US$2 853.09	US$1 230.15	1.8
Karate® EC	120ml	US$58.87	US$1 396.50	US$1 455.38	5 340	US$0.45	US$2 418.33	US$962.96	1.7
Chlorpyrifos® 480 EC	200ml	US$27.93	US$1 396.50	US$1 424.43	6 310	US$0.45	US$2 857.62	US$1 433.19	2.0
Bandit® 350 SC	200ml	US$46.80	US$1 396.50	US$1 443.30	6 968	US$0.45	US$3 155.61	US$1 712.31	2.2

*The cost per treatment is based on ten applications per season.

Seed cotton yield

Bollworm experiment

Tables 3 and 4 summarise the cost-benefit analysis of the pesticides applied in the cotton bollworm experiments. Eco-Bb®, Delfin®, and Bb endophyte had lower results than the control during the 2017 season. In plots treated with Bolldex®, the highest yields of 5 987 kg ha^{-1} (2017) and 6 818 kg ha^{-1} (2018) were observed. Compared to the control, plots treated with Bolldex® saw a 45% increase in seed cotton yield.

Leafhopper experiment

Compared to the untreated control, all the treatments showed higher seed cotton yields, and the net returns were greater than the production costs **(Tables 5 and 6)**. With a 5 983 kg ha^{-1} seed cotton yield in 2017, Karate® EC was the most productive, followed by Eco-Bb® with 5 963 kg ha^{-1}. Chlorpyrifos® 480 EC produced the lowest yield of 5 021 kg ha^{-1}. Bandit® 350 SC had the highest seed cotton yield of 6 968 kg ha^{-1} in 2018, with Bb endophyte coming in second with 6 763 kg ha^{-1}. Karate® EC (5 340 kg ha^{-1}) yielded the least seed cotton.

Gross income

Bollworm experiment

The gross income of each treatment is summarized in **Tables 3 and 4**. Based on an average rate of US$0.45 kg^{-1}, Bolldex® (US$2 711.34 and US$3 087.68) had the highest gross income in both seasons. Bb endophyte (US$1 403.90) and Eco-Bb® (US$1 383.52) had the lowest gross income in 2017. In 2018, the untreated control (US$2 116.27) had the most insufficient gross income, followed by the treatment of Delfin® (US$2 606.27). The treatments' gross income ranged between US$2 606.27 and US$3 087.68.

Leafhopper experiment

Tables 5 and 6 summarize the gross income in the leafhopper experiment during the 2017 and 2018 seasons. The highest gross income was found in the treatment of Karate® EC (US$2 708.17) and Eco-Bb® (US$2 699.11) in 2017. Chlorpyrifos® 480 EC (US$2 273.41) exhibited the lowest gross income compared to the other treatments. All the treatments ranged between US$2 273.41 and US$2 708.17, except for the control (US$2 178.31). In 2018, Bandit® 350 SC (US$3 155.61) had the highest gross income, while Karate® EC (US$2 418.33) had the lowest. The other treatments had a gross income ranging from US$2 857.62 to US$3 062.77.

Net income

Bollworm experiment

Tables 3 and 4 show the net incomes for each treatment during the 2017 and 2018 seasons. In 2017, Karate® EC (US$869.21) had the highest net income, while Delfin® (-US$403.36) had the lowest. Bb endophyte, Delfin®, and Eco-Bb® had lower net incomes than the control. Other treatments had a net gain from -US$239.42 to US$819.09. In 2018, Karate® EC had the highest net income of US$1 445.26, while the lowest net income was obtained from Delfin® (US$607.45). Other treatments had a net gain between US$1 076.63 and US$1 279.51.

Leafhopper experiment

In both seasons, all treatments had higher net income than the control **(Tables 5 and 6)**. Treatment of Karate® EC had the highest net income of US$1 252.79 during the 2017 season, while Chlorpyrifos® 480 EC had the lowest net income of US$848.98. A net income of between US$913.14 and US$ 1,192.41 was recorded from the other treatments. The highest net income of US$1 712.31 was recorded from the treatment of Bandit® 350 SC during the 2018 season, followed by Bb endophyte at US$1 439.83. Karate® EC had the lowest net income of US$962.96. Other treatments ranged from US$1 230.15 to US$1 433.19.

Cost-benefit ratio

Bollworm experiment

In 2017, the cost-benefit ratio indicated ratios of 1.6 for Karate® EC, 1.4 for Bolldex® and the control, compared to 0.9 ratios for Eco-Bb® and Bb endophyte, and 0.8 for Delfin® **(Tables 3 and 4)**. During the 2018 season, Karate® EC had the highest cost-benefit ratio of 2, followed by Bb endophyte (1.8) and Eco-Bb® (1.7). In both seasons, the maximum cost-benefit Ratio was recorded from Karate® EC.

Leafhopper experiment

The results in **Tables 5 and 6** include the cost-benefit ratio for the leafhopper experiment during the 2017 and 2018 seasons. In 2017, Karate® (1.9) had the highest cost-benefit ratio, while the lowest ratio of 1.6 was found with Bb endophyte, NOMU-PROTEC®, Chlorpyrifos® 480 EC, and the control. In 2018, the cost-benefit ratio was 1.7 for the management and Karate® EC, 1.8 for Eco-Bb® and NOMU-PROTEC®, and 1.9 for Bb endophyte. Chlorpyrifos® 480 EC and Bandit® 350 SC had the highest cost-benefit ratios of 2 and 2.2, respectively.

Cotton production in Sub-Saharan Africa faces competition from other crops [27]. This is because productivity has declined over time, linked to unfavorable external factors like shifting market prices and the cost of production inputs. Reducing input costs is as important as high productivity because cotton markets are competitive [23]. The climate, the accessibility of inexpensive inputs, and the cotton industry's success all play major roles in cotton production. Changes in supply and demand, as well as the state of the global cotton market, are the causes of price swings. The net income obtained in this study varied depending on the treatment based on input costs and yield obtained.

Cost of treatments

The results show that biopesticides have been much more costly than conventional pesticides. The cost of Delfin® per hectare was the most expensive at US$602.32 per 10 sprays. Each chemical insecticide costs less than US$100 per hectare. Chemical insecticides probably cost less because of fixed costs associated with using a large portion of the farming community [28]. Ali *et al*. (2012) state Pakistan's seed costs have not changed over time despite increased pesticide inputs. Bolldex® (HaNPV) has also been found to be an expensive treatment at US$495.74 [26]. In a study conducted by Ojha *et al*. (2019), HaNPV was also found to be the most costly treatment, followed by *B. bassiana* against *H. armigera* [29]. They also concluded that treating *B. thuringiensis* would be a cheaper alternative to HaNPV or *B. Bassiana*, contrary to what had been found in these cotton trials. In Kenya, Constantine *et al*. (2020) indicated that the highest average amount spent by farmers on *B. bassiana* was US$131 ha^{-1} and US$95 ha^{-1} for *B. thuringiiensis* [28]. Olson (2015) reported that, compared to the development of biopesticides, which requires up to $10 million and four years, it is only worth $250 million or nine years for chemical pesticide development and regulation [30]. According to Constantine *et al*. (2020), farmers must be satisfied with the effectiveness of a new product, including the purchase cost and risk that the product will be ineffective against a pest for which it is intended [28]. Farmers must be more aware of biopesticide use as they may not immediately work. Constantine *et al*. (2020) reported that the availability and affordability of biopesticides were among the factors contributing to small-scale farmers' low use of them [28].

Costs of other inputs

High yields and minimum production costs represent the essential factors to compete in cotton markets, as Amrouk *et al*. (2021) noted [31]. There are additional costs associated with managing pests on cotton, such as those related to seed, cultivation, labor, weed control, and harvesting. Input costs, such as land preparation and irrigation costs, positively affect revenue in Pakistan, whereas pesticides and fertilizers negatively affect revenues [32]. The advantage of growing more areas is that the cost of production can be spread over an increased amount of cotton acres, which enables farmers to share some costs among different crops and increase crop profitability [33].

Labor costs

One of the most expensive inputs in cotton production is labor [34]. However, for cotton farmers with little financial support and small land sizes, labor wages are the household's main source of cash income [35]. Smallholder farmers frequently use family labor and base their output levels on how much cotton each family can manage [36]. According to Blaise and Kranthi (2019), the cost of labor accounts for the largest portion of production costs [37], while Belay *et al*. (2020) noted that a sizable portion of Ethiopia's input costs are attributable to labor and equipment costs [35]. According to Sarker and Alam (2016), labor costs for cotton production in Bangladesh account for 28.60% of total production costs [38]. In contrast, in India, labor costs can account for as much as 50% of total operating costs [39]. Labor and pesticide costs were listed as two of the major cost items in Turkey; larger farms have higher costs, though [40]. Despite the government's robust cotton support program, China has also reported rising production costs due to increased labor costs [41].

Weed control and harvesting costs

Hand hoeing had the highest cost of $543.45 for controlling weeds. Creating a single effective technique in larger cotton fields is more challenging due to variations in weed species, and soil properties [42]. Farmers are encouraged to successfully combine crop rotation, soil cultivation, hand harvesting, and herbicide application to combat weeds in cotton production [43]. One method for lowering labor expenses associated with weed control in cotton production is the implementation of strip-tillage systems [44]. Mishra *et al*. (2023), reported that manual harvesting is one of the most costly agricultural operations in cotton production [45]. This is mainly due to labor-intensive activities carried out by hand over a harvest period. They suggested that mechanical harvesting could be important in reducing cotton production costs. In addition, to minimize crop labor costs, Bai *et al*. (2022) pointed out that mechanization and precision sowing were essential for cotton farming [46].

Yield

The gross margin and net profit of cotton production are largely influenced by yield. Every year, the climate and various maintenance problems like weeds, pests, and diseases affect cotton yields [47]. For the bollworm experiment, a range of 4 500 to 6 400 kg ha-1 seed cotton yield per treatment was obtained; for the leafhopper experiment, a minimum of 5 600 kg ha^{-1} and a maximum of 6 900 kg ha^{-1} were obtained. With seed cotton yields of less than 3,600 kg ha^{-1} in 2017, plots treated with Bb endophyte, Delfin®, and Eco-Bb® had the lowest yields. During the same period, South Africa's average yield of irrigated cotton was 4 411 kg ha^{-1} [48]. FAO (2020) states that with 35% lint, irrigated cotton can yield seed cotton yields of 4 000–5 000 kg ha^{-1} [49].

Income

The bollworm and leafhopper experiments yielded the highest gross income of US$3 087.68 and US$3 155.61, respectively, at an average rate of US$0.45 per kilogram supplied by the ginner. The bollworm experiment yielded the lowest gross income of US$1 383.52, while the leafhopper experiment yielded the most insufficient gross revenue of US$2 273.41. The low yields recorded for the 2017 season were the cause of the bollworm experiment's meager income. When harvested mechanically, irrigated cotton in South Africa has an estimated 5,000 kg ha-1 yield and can bring in over US$3,000 per hectare at US$0.57/kg [50]. For mechanical harvesting, the estimated break-even point is US$285.31 kg ha^{-1}. Reddy (2018) reported that between 2010 and 2015, the average gross income in India was $1 091.42 per hectare, while the average net income was US$138.05 per hectare [51]. According to DAFF (2017), the average gross value of agricultural production in South Africa was estimated to be US$20,67 million in 2017, and the gross income increased by 29.3% to US$22.49 million [52]. According to DAFF, seed cotton was US$0.60 kg^{-1} in 2017 and US$0.56 kg^{-1} in 2018. The international price estimates for cotton align with the seasonal price; however, the grading of the cotton lint determines the pricing of various ginners.

After subtracting the entire cost of production from the total revenue, the net income from the plots treated with Karate® EC was higher than the net income from the other treatments. When Cole *et al*. (1997) assessed the effect of Karate® EC against cotton pests, they observed a 12% increase without any appreciable changes to the season's predator-to-pest ratios [53]. According to Mink (1997), timely application of Karate® resulted in higher yields than untreated Bt cotton [54]. Similarly, Javaid *et al*. (2000) discovered that Karate® provided a degree of pest control and substantially increased cotton yields in Mozambique [55].

Cost-benefit ratio

Producers must carefully select the inputs used in their production to maximize profit and increase the cost-benefit ratio [56]. The goal of the cost-benefit ratio is to provide farmers with an estimate of the relative economic performance of the selected inputs [57]. This ratio, according to Wei *et al*. (2020), also demonstrates the amount of money generated by economic activity [32]. The farmers' Return on investment increases with the cost-benefit ratio. The aforementioned cost-benefit ratios for this study demonstrated that the treatments were profitable and had a positive return on investment. The financial viability cost-benefit ratios of Bandit® 350 SC, Chlorpyrifos® 480 EC, and Karate® EC were significantly higher than those of the biopesticides. The high cost of biopesticides significantly impacted the cost-benefit ratio of those treatments. Due to the low seed cotton yields in the bollworm experiment during the 2017 season—which indicated a net loss of up to US$403.36 per hectare—the cost-benefit ratios of Eco-Bb®, Delfin®, and Bb endophyte were less than one. While the Delfin® treatments showed the lowest cost-benefit ratio, Karate® EC consistently outperformed the other therapies in this regard. Patel and Das (2010) found that cotton fields treated with lambda-cyhalothrin had the highest cost-benefit ratio, which is consistent with this study. Based on what is financially feasible, Ugandan cotton farmers have started using lambda-cyhalothrin treatments [15]. In crops like chickpeas [58], pigeon peas [59] and mung beans [60], lambda-cyhalothrin has also been found to have high cost-benefit ratios.

Rudramuni *et al*. (2011) found that lambda-cyhalothrin was one of the treatments with the lowest cost-benefit ratio against sucking pests and cotton bollworms, which is in contrast to the findings of the current studies [61]. In their 2009 evaluation of the effectiveness of biopesticides against bollworms on cotton, Gadage *et al*. found that *Beauveria bassiana*, had the highest cost-benefit ratio (1:9.46), followed by *Nomuraea rileyi*, (1:7.66), and HaNPV (1:3.97) [62]. However, this study's best cost-benefit ratios were not obtained from the *Beauveria bassiana* treatments (Eco-Bb® and Bb endophyte). In the leafhopper experiment, Bandit® 350 SC and Chlorpyrifos® 480 EC had the highest average cost-benefit ratios, at 2 and 1.8, respectively. This is mostly explained by how inexpensive the treatments are. Balakrishnan *et al*. (2004) investigated the effectiveness of biopesticides against *H. armigera* on cotton and found that chlorpyrifos 20 EC had a good cost-benefit ratio of 1:3.66, followed by HaNPV (1:3.50) [63]. Bolldex® was the second-best pesticide with a cost-benefit ratio of 1.5, despite its high price. Similarly, Jeyarani *et al*. (2010) found that a cost-benefit ratio of 1:2.48 was the highest after evaluating the effectiveness of several HaNPV isolates [64].

CONCLUSION

Each treatment's income, cost-benefit ratio, and benefit were mostly determined by the treatment's cost, input costs, and yield. Cotton growers must, therefore, increase productivity at the lowest feasible cost by using suitable agricultural inputs and good agricultural practices. Although some of the treatments in this study had higher yields, the high costs of the products resulted in lower net income and cost-benefit ratios, according to the cost-benefit analysis. Biopesticides are more expensive than chemical insecticides, but how often these products are applied will mostly depend on the level of pest infestation. Cotton growers can choose any evaluated treatments to include in a pest management program because all the biopesticides had overall cost-benefit ratios greater than 1. This study indicated factors to consider when a more comprehensive analysis is required.

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REFERENCES

1. Anwar M, Iqbal MZ, Abro AA, Memon S, Bhutto LA, Memon SA, et al. Inter-specific hybridization in cotton (Gossypium hirsutum) for crop improvement. Agronomy. 2022;12(12):3158.
2. Amanet K, Chiamaka EO, Quansah GW, Mubeen M, Farid HU, Akram R, et al. Cotton production in Africa. Cotton Production; 2019. pp. 359-69. doi:10.1002/9781119385523.ch17
3. Malinga L. Southern and eastern African cotton forum: Platform for the advancement of cotton production in Africa. S Afr J Sci. 2019;115(9-10):1-3.
4. Maiti R, Kumari CA, Huda AK, Mandal D, Begum S. Advances in cotton science: Botany, production, and crop improvement. Apple Academic Press; 2020.
5. CMiA. African cotton. Cotton made in Africa. 2020. Available from: https://www.cottonmadeinafrica.org/en/about-us/african-cotton.
6. Vitalis NE, Sun Y. A comparative study of transgenic cotton development, impacts, challenges and prospects with respect to China and Africa. Afr J Biotechnol. 2023;22(11):305-16.
7. Louw M. Cotton farming in South Africa. Field crops in South Africa. 2020. Available from: http://southafrica.co.za/cotton-farming-in-south-africa.html.
8. Sabesh M, Prakash AH. Higher cotton productivity in Africa – A socio-economic analysis. ICAC Rec. 2018;36:1-34.
9. Bolzonella C, Lucchetta M, Teo G, Boatto V, Zanella A. Is there a way to rate insecticides that is less detrimental to human and environmental health? Glob Ecol Conserv. 2019;20:e00699. doi:10.1016/j.gecco.2019.e00699
10. Kryukova EM, Khetagurova VS, Ilyin VA, Chizhikova VV, Kosoplechev AV. Forming students' environmental culture: Modern educational approaches and technologies. J Adv Pharm Educ Res. 2021;11(2):113-8.
11. Liu Z, Zhang L, Zhang Z, An L, Hough R, Hu P, et al. A review of spatiotemporal patterns of neonicotinoid insecticides in water, sediment, and soil across China. Environ Sci Pollut Res. 2022;29(37):55336-47.
12. Benelli G. Gold nanoparticles–against parasites and insect vectors. Acta Trop. 2018;178:73-80. doi:10.1016/j.actatropica.2017.10.021
13. Hatting JL, Moore SD, Malan AP. Microbial control of phytophagous invertebrate pests in South Africa: Current status and future prospects. J Invertebr Pathol. 2019;165:54-66. doi:10.1016/j.jip.2018.02.004
14. Sharma KR, Raju SV, Jaiswal DK, Thakur S. Biopesticides: An effective tool for insect pest management and current scenario in India. Ind J Agric Allied Sci. 2018;4(2):59-62.
15. Gayi D, Ocen D, Lubadde G, Serunjogi L. Efficacy of bio and synthetic pesticides against the American bollworm and their natural enemies on cotton. Uganda J Agric Sci. 2016;17(1):67-81. doi:10.4314/ujas.v17i1.7
16. Akutse KS, Subramanian S, Maniania N, Dubois T, Ekesi S. Biopesticide research and product development in Africa for sustainable agriculture and food security–Experiences from the international centre of insect physiology and ecology (icipe). Front Sustain Food Syst. 2020;4:563016.
17. Ochieng JW, Ananga A. Biotechnology in agricultural policies of Sub-Saharan Africa. Elements of Bioeconomy; 2019. pp.1-16.
18. Moore S, Jukes M. The History of baculovirology in Africa. Viruses. 2023;15(7):1519.
19. Marrone PG. Pesticidal natural products–status and future potential. Pest Manag Sci. 2019;75(9):2325-40. doi:10.1002/ps.5433
20. Industry Research Biz. Global biopesticide market: Growth avenues, size analysis, and vendor opportunities. 2023. Available from: https://www.linkedin.com/pulse/global-biopesticide-market-growth-avenues-size-analysis/
21. Ncube D. The importance of contract farming to small-scale farmers in Africa and the implications for policy: A review scenario. Open Agric J. 2020;14(1):59-86.
22. Pschorn-Strauss E. Bt cotton in south Africa: The case of the makhathini farmers. 2005. Available from: https://www.grain.org/article/entries/49

2-bt-cotton-in-south-africa-the-case-of-the-makhathini-farmers (accessed 11.3.20).
23. Voora V, Bermudez S, Farrell JJ, Larrea C, Luna E. Cotton prices and sustainability. International Institute for Sustainable Development; 2023. pp. 1-37.
24. Brookes G. Farm income and production impacts from the use of genetically modified (GM) crop technology 1996-2020. GM Crops Food. 2022;13(1):171-95.
25. Mwanza P, Jukes M, Dealtry G, Lee M, Moore S. Selection for and analysis of UV-resistant cryptophlebia leucotreta granulovirus-SA as a biopesticide for thaumatotibia leucotreta. Viruses. 2021;14(1):28.
26. Ali H, Aslam M, Ali H. Economic analysis of input trend in cotton production process in Pakistan. Asian Econ Financ Rev. 2012;2(4):553-61.
27. Frederick K, Frederick K. An industry vanishes: Cotton cloth manufacturing in malawi's lower shire valley, 1850–1930. Twilight of an industry in east Africa: Textile manufacturing, 1830-1940; 2020. pp. 37-67.
28. Constantine KL, Kansiime MK, Mugambi I, Nunda W, Chacha D, Rware H, et al. Why don't smallholder farmers in Kenya use more biopesticides? Pest Manag Sci. 2020;76(11):3615-25. doi:10.1002/ps.5896
29. Ojha PK, Kumari R, Chaudhary RS, Pandey NK. Incremental cost-benefit ratio of certain bio-pesticides against Helicoverpa armigera Hubner (Noctuidae: Lepidoptera) in chickpea. Legume Res Int J. 2019;42(1):119-26. doi:10.18805/lr-3895
30. Olson S. An analysis of the biopesticide market now and where it is going. Outlooks Pest Manag. 2015;26(5):203-6.
31. Amrouk EM, Mermigkas G, Townsend T. Recent trends and prospects in the world cotton market and policy developments. Food and Agriculture Organization of the United Nations FAO. 2021.
32. Wei W, Mushtaq Z, Faisal M, Wan-Li Z. Estimating the economic and production efficiency of cotton growers in Southern Punjab, Pakistan. Custos Agronegocio. 2020;16(2):2-21.
33. English BC, Larson JA, Roberts RK, Cochran RL. When do cotton yield monitors pay? American society of agricultural and biological engineers annual international meeting, 17 – 20 July 2005, Tampa, United States. doi:10.13031/2013.18868
34. Kranthi KR, Malinga L, Mubvekeri W. Perspectives on cotton research and ideas for Africa: Proceedings & recommendations of the XIV Meeting of the Southern & Eastern Africa Cotton Forum (SEACF). The ICAC Recorder; 2018. pp.4-12.
35. Belay G, Yami M, Bekele A. Analysis of costs of production and profitability for irrigated cotton under smallholder production systems; The case of middle awash valley. Ethiop J Agric Sci. 2020;30(1):1-6.
36. Welch FJ, Miley DG. Cotton labor requirements. J Farm Econ. 1950;32(4):752-8.
37. Blaise D, Kranthi KR. Cotton production in India. In: Khawar Jabran, Bhagirath Singh Chauhan (eds), Cotton Production, John Wiley & Sons; 2019. pp. 193-215.
38. Sarker JR, Alam F. Efficiency and economics in cotton production of Bangladesh. J Agric Environ Int Dev. 2016;110(2):325-48.
39. Singh S. Growth and variability in cost of cultivation in India. Indian J Econ Dev. 2018;14(4):659-66.
40. Basal H, Karademir E, Goren HK, Sezener V, Dogan MN, Gencsoylu I, et al. Cotton production in Turkey and Europe. Cotton Production; 2019. pp.297-321.
41. Shao L, Gong J, Fan W, Zhang Z, Zhang M. Cost comparison between digital management and traditional management of cotton fields—Evidence from cotton fields in Xinjiang, China. Agriculture. 2022;12(8):1105.
42. Riaz Marral MW, Khan MB, Ahmad F, Farooq S, Hussain M. The influence of transgenic (Bt) and non-transgenic (non-Bt) cotton mulches on weed dynamics, soil properties and productivity of different winter crops. Plos one. 2020;15(9):e0238716.
43. Wrona AF, Baumann P, Brown S, Byrd JD, Hayes B, Keeling W, et al. New ways to manage weeds. Cotton Physiol Today. 1997;8:1-12.
44. Yemadje PL, Takpa ON, Amonmide I, Balarabe O, Sekloka E, Guibert H, et al. Limited yield penalties in an early transition to conservation agriculture in cotton-based

cropping systems of Benin. Front Sustain Food Syst. 2022;6:1041399.
45. Mishra PK, Sharma A, Prakash A. Current research and development in cotton harvesters: A review with application to Indian cotton production systems. Heliyon, 2023;9(5):e16124.
46. Bai S, Yuan Y, Niu K, Shi Z, Zhou L, Zhao B, et al. Design and experiment of a sowing quality monitoring system of cotton precision hill-drop planters. Agriculture. 2022;12(8):1117.
47. Honnappa HM, Shekara BG. Seed cotton yield and economics of hybrid cotton (Gossypium spp.) as influenced by weed management practices in Southern Dry Zone of Karnataka. Mysore J Agric Sci. 2018;52(3):511-8.
48. Cotton SA. Cotton hectares planted and yield for the Republic of South Africa. 2020. Available from: https://cottonsa.org.za/wp-content/uploads/06-Cotton-Hectares-Planted-and-Yield-31.pdf.
49. FAO. Land & water: Cotton. Food and agriculture organization of the united nations. 2020. Available from: http://www.fao.org/land-water/databases-and-software/crop-information/cotton/en/
50. Coleman A. Cotton can be more profitable than maize. Farmer's Wkly. 2019. Available from: https://www.farmersweekly.co.za/crops/field-crops/cotton-can-be-more-profitable-than-maize/.
51. Reddy AR. Doubling the cotton farmers' income: Economic perspective. Cotton Stats News. 2018;1:1-4.
52. DAFF. Trends in the agricultural sector. 2017. Available from: https://www.dalrrd.gov.za/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Trends%20in%20the%20Agricultural%20Sector%202017.pdf.
53. Cole JF, Pilling ED, Boykin R, Ruberson JR. Effects of Karate® insecticide on beneficial arthropods in Bollgard® cotton. In1997 Proceedings Beltwide Cotton Conferences, New Orleans, LA, USA, January 6-10, 1997: Volume 2. 1997 (pp. 1118-1120). National Cotton Council.
54. Mink J, Harrison S, Martin S. Performance and benefits of Karate insecticide on Bollgard cotton. In 1997 Proceedings Beltwide Cotton Conferences, New Orleans, LA, USA, 1997;2:898-9.
55. Javaid I, Uaine RN, Massua J. Studies on very-low volume (VLV) water-based sprays for the control of cotton pests. Int J Pest Manag. 2000;46(2):81-3.
56. Kephe PN, Siewe LC, Lekalakala RG, Kwabena Ayisi K, Petja BM. Optimizing smallholder farmers' productivity through crop selection, targeting and prioritization framework in the Limpopo and free state provinces, south Africa. Front Sustain Food Syst. 2022;6:738267.
57. Penot E, Chambon B, Myint T. Economic calculations for assessing agricultural systems. Cost benefit analysis and farm level real budget analysis. Agric Res Centre Int Dev. 2021.
58. Chaudhari BN, Undirwade DB, Shamkuwar GR, Turkhade PD. Field efficacy of newer insecticides against Helicoverpa armigera (Hubner) on chickpea. Indian J Entomol. 2018;80(1):7-12.
59. Ghosal A, Dolai AK, Chatterjee ML. Bioefficacy of new ready mixed insecticide (novaluron 5.25%+ indoxacarb 4.5% SC) against pigeon pea pod borer (Helicoverpa armigera Hubner). Legume Res- Int J. 2016;39(1):135-9.
60. Worku M, Azerefegne F. Efficacy of insecticides against Apion clavipes Gerst on mungbean. Indian J Entomol. 2019;81(2):223-6.
61. Rudramuni T, Reddy KM, Kumar CT. Evaluation of new systemic and contact insecticides against insect-pest complex of cotton. Crop Res. 2011;42(1-3):296-302.
62. Gadage JA, Wankhede SM, Kulat SS, Mane PN, Somkuwar MR, Munghate RS. Evaluation of biopesticides for the management of bollworms on cotton. J Soil Crop. 2009;19(1):172-5.
63. Balakrishnan N, Baskaran RM, Mahadevan NR. Field efficacy of ChrysoperZa carnea (Stephens) in combination with biopesticides against Helicoverpa armigera

(Hubner) on cotton under rainfed condition. J Biol Control. 2004;18(2):147-53.

64. JeyaraNi S, SatHiaH N, KaruPPucHamy P. Field efficacy of Helicoverpa armigera nucleopolyhedrovirus isolates against H. armigera (Hübner) (Lepidoptera: Noctuidae) on cotton and chickpea in Tamil Nadu. Plant Prot Sci. 2010;46(3):116-22.