

Integrated Management of Bacterial Fruit Blotch of Watermelon (*Citrullus lanatus* L.) Using Botanical Extracts and Varietal Selection in the Guinea Savannah of Taraba State, Nigeria

Phoebe A. O., Tunwari B. A., Yakubu U.

Federal University Wukari, Taraba State, Nigeria

phoebe7@gmail.com

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Abstract

Bacterial fruit blotch (BFB), caused by *Acidovorax citrulli*, severely limits watermelon (*Citrullus lanatus*) production. Concerns about environmental pollution, pathogen resistance, and food safety associated with synthetic bactericides highlight the need for sustainable management alternatives. This study evaluated the combined effects of botanical extracts and varietal selection on BFB suppression and watermelon yield in the Guinea Savannah agroecological zone of Taraba State, Nigeria. Field experiments were conducted at Wukari and Ardo Kola during the 2020 and 2021 cropping seasons using a 4×5 factorial arrangement in a randomized complete block design with three replications. Four varieties—Sugar Baby, Charleston Gray, Crimson Sweet, and Kaolack—were evaluated under five treatments: neem (*Azadirachta indica*) extract, jatropha (*Jatropha curcas*) extract, combined neem and jatropha extracts, copper hydroxide, and an untreated control. Preplanting soil analyses characterized the experimental sites. Disease incidence, disease severity, infected fruit counts, growth parameters, and fruit yield were assessed. Data were analyzed using analysis of variance, with means separated by Duncan's multiple range test at the 5% significance level; correlation and regression analyses examined relationships between disease parameters and yield. Both sites had slightly acidic sandy loam soils suitable for watermelon production. Varieties and management treatments differed significantly ($P \leq 0.05$). Charleston Gray consistently exhibited the lowest disease incidence and severity and the highest yield, whereas Sugar Baby was the most susceptible variety. Combined neem and jatropha extracts significantly suppressed BFB

and increased yield compared with the individual extracts, copper hydroxide, and the untreated control. Charleston Gray receiving the combined extracts achieved the greatest disease suppression and highest yield. Disease parameters were strongly positively correlated with one another and negatively correlated with yield. Disease severity explained approximately 81.5% of the variation in fruit yield. These findings support integrating Charleston Gray with combined neem and jatropha extracts to manage BFB and improve watermelon yield under the studied conditions, with potential to reduce reliance on synthetic bactericides.

Keywords: *Acidovorax citrulli*; Bacterial Fruit Blotch; Botanical Extracts; Integrated Disease Management; Varietal Selection

INTRODUCTION

Watermelon (*Citrullus lanatus* L.) is one of the most economically important vegetable crops belonging to the family Cucurbitaceae. It is cultivated throughout tropical, subtropical, and temperate regions of the world because of its high nutritional value, refreshing taste, and increasing commercial importance. Watermelon fruits consist of approximately 90–92% water and are rich sources of carbohydrates, vitamins A, B-complex, and C, dietary fibre, potassium, magnesium, and antioxidants such as lycopene and β -carotene, which contribute to human health by reducing the risks of cardiovascular diseases, certain cancers, and oxidative stress. The crop also provides significant income for farmers, traders, transporters, processors, and marketers, thereby contributing substantially to food security, employment generation, and poverty alleviation in many developing countries (Paris, 2015; FAO, 2023).

Globally, watermelon is among the most extensively cultivated fruit vegetables. According to the global watermelon production exceeds 100 million tones annually, with accounting for more than 60% of the world's total production. Other major producers include China, India, Turkey, and United States. In Africa, watermelon production has expanded rapidly due to increasing consumer demand, favourable climatic conditions, and the crop's relatively short maturity period. Nigeria is among the leading producers in sub-Saharan Africa, with cultivation concentrated in the Guinea and Sudan Savannah zones where climatic conditions favour optimum growth and fruit development.

In Nigeria, watermelon has become an important cash crop because of its increasing demand in urban and rural markets. Major producing states include Kano, Jigawa, Katsina, Kaduna, Gombe, Bauchi, Yobe, Borno, Benue, Nasarawa, Taraba, Plateau and Adamawa. Within Taraba State, watermelon cultivation has expanded considerably in recent years owing to favourable rainfall, fertile soils, and increased market opportunities. Farmers in Wukari, Ardo Kola, Bali, Gassol, Lau and neighbouring Local Government Areas cultivate watermelon both for household consumption and commercial purposes. The crop contributes significantly to household income, nutritional security and rural livelihoods. However, productivity remains below its genetic yield potential because of numerous production constraints, particularly diseases caused by fungi, bacteria, viruses and nematodes.

Among the diseases affecting watermelon production, bacterial fruit blotch (BFB), caused by *Acidovorax citrulli*, is regarded as one of the most destructive bacterial diseases worldwide. Since its first description, the disease has spread rapidly across major watermelon-producing regions and has become a serious phytosanitary concern because of its seed-borne nature and capacity to cause devastating epidemics. The pathogen infects all aerial parts of susceptible plants, including cotyledons, leaves, stems and fruits. Symptoms begin as small water-soaked lesions on seedlings and leaves, which later enlarge, become necrotic and may lead to seedling collapse. On fruits, the disease produces characteristic dark green, greasy, water-soaked blotches that enlarge rapidly, resulting in rind cracking, tissue collapse, secondary invasion by opportunistic microorganisms and complete loss of marketability.

Acidovorax citrulli is a Gram-negative, aerobic, rod-shaped bacterium belonging to the family Comamonadaceae. The pathogen survives primarily on contaminated seeds, volunteer cucurbit plants, crop residues and infected plant debris. Seed transmission remains the most important mechanism for long-distance dissemination of the disease, making BFB particularly difficult to manage. Under favourable environmental conditions, bacterial populations multiply rapidly on leaf surfaces and penetrate host tissues through natural openings or wounds caused by insects, wind abrasion or mechanical injuries. Warm temperatures ranging from 25 to 35°C, prolonged leaf wetness, frequent rainfall and high relative humidity favour disease establishment, bacterial multiplication and rapid spread through rain splash, irrigation water, contaminated equipment and field workers.

The Guinea Savannah agro-ecological zone of Taraba State provides environmental conditions that favour the development of bacterial fruit blotch. During the rainy season, prolonged periods of high humidity, moderate to high temperatures and frequent rainfall create ideal conditions for bacterial infection and epidemic development. Consequently, farmers often experience severe losses in fruit quality and yield, particularly where susceptible varieties are cultivated and effective disease management strategies are lacking. Yield losses ranging from 30% to complete crop failure have been reported under severe epidemics in susceptible cultivars, depending on environmental conditions, cultivar susceptibility and the stage of crop development at infection.

Management of bacterial fruit blotch remains challenging because the pathogen is both seed-borne and capable of surviving on alternative hosts and infected crop residues. Conventional management practices rely on the use of certified disease-free seed, crop rotation, field sanitation, rouging of infected plants, copper-based bactericides and integrated cultural practices. However, chemical control has generally provided inconsistent results owing to poor efficacy under high disease pressure, development of bacterial tolerance to copper compounds, environmental pollution, phytotoxicity and increasing concerns regarding food safety. Moreover, repeated application of synthetic bactericides increases production costs and poses potential risks to beneficial organisms and the environment.

Growing public awareness of environmental sustainability and food safety has stimulated interest in the use of botanical extracts as environmentally friendly alternatives for disease management. Botanical pesticides are derived from naturally occurring plant metabolites with antimicrobial properties and are generally biodegradable, less hazardous to humans and non-target organisms, and compatible with integrated pest management programmes. Several plant species possess bioactive compounds capable of suppressing bacterial pathogens. Among these, neem (*Azadirachta indica*) has received considerable attention because of its broad-spectrum antimicrobial activity attributed to compounds such as azadirachtin, nimbin, salannin, gedunin and related limonoids. Similarly, jatropha (*Jatropha curcas*) contains phorbol esters, flavonoids, tannins and saponins that exhibit antibacterial and antifungal properties. Numerous studies have demonstrated that extracts from these plants can reduce disease incidence and severity in several economically important crops.

Another sustainable approach to disease management is the cultivation of resistant or tolerant varieties. Host plant resistance is regarded as one of the most effective, economical and environmentally sound methods of managing plant diseases because it provides season-long protection without imposing additional production costs on farmers. Watermelon varieties differ considerably in their reaction to *Acidovorax citrulli* due to differences in genetic makeup, rind characteristics, biochemical composition and defence mechanisms. Identification and deployment of tolerant varieties therefore constitute important components of integrated disease management programmes. However, complete resistance to bacterial fruit blotch remains limited among commercially available watermelon cultivars, necessitating integration with complementary control measures such as botanical extracts.

Integrated disease management combines multiple compatible strategies to suppress disease below economically damaging levels while minimizing adverse environmental effects. The integration of tolerant varieties with plant-derived antimicrobial extracts offers the potential to enhance disease suppression, improve fruit yield and reduce dependence on synthetic bactericides. Despite increasing interest in sustainable disease management, information regarding the combined effects of botanical extracts and varietal selection on bacterial fruit blotch of watermelon under the Guinea Savannah conditions of Taraba State remains scarce. Most previous studies have evaluated either varietal response or botanical extracts independently, with limited emphasis on their combined effectiveness under field conditions.

This knowledge gap underscores the need for comprehensive field investigations aimed at developing environmentally sustainable management strategies that are technically effective, economically feasible and readily adoptable by farmers. Such information is essential for improving watermelon production, enhancing farmers' income, reducing production losses and promoting sustainable agricultural development within the Guinea Savannah agro-ecological zone of Taraba State and similar production environments.

Therefore, this study was undertaken to evaluate the effectiveness of selected botanical extracts and watermelon varieties for the integrated management of bacterial fruit blotch under field conditions in the Guinea Savannah of Taraba State, Nigeria. The findings are expected to contribute to the development of environmentally friendly disease

management strategies capable of improving watermelon productivity while reducing reliance on synthetic bactericides.

MATERIALS AND METHODS

Study Area

The study was conducted during the 2020 and 2021 rainy cropping seasons at two representative locations within the Guinea Savannah agro-ecological zone of Taraba State, Nigeria, namely Wukari and Ardo Kola Local Government Areas.

Climate of the Study Area

The climate of both locations is characterized by:

- Mean annual rainfall: **900–1,300 mm**
- Temperature: **25–35°C**
- Relative humidity: **65–85%**
- Rainy season: April–October
- Dry season: November–March

These environmental conditions favour the survival, multiplication, and dissemination of *Acidovorax citrulli*.

Soil Sampling and Analysis

Before land preparation, soil samples were collected from each experimental site to determine the initial soil fertility status.

Composite soil samples were collected from five randomly selected points within each block at a depth of **0–30 cm** using a soil auger. The samples were thoroughly mixed to obtain representative composite samples.

The soil samples were air-dried under shade, crushed gently, passed through a **2-mm sieve**, and analysed in the Soil Science Laboratory.

The following parameters were determined:

Physical Properties

- Soil texture

- Bulk density
- Particle size distribution

Chemical Properties

- Soil pH
- Organic carbon
- Organic matter
- Total nitrogen
- Available phosphorus
- Exchangeable potassium
- Calcium
- Magnesium
- Sodium
- Cation exchange capacity (CEC)

Laboratory analyses followed the procedures described by Black (1965) and Dane and Topp (2002).

Experimental Materials

The materials used included:

Planting Materials

Four watermelon varieties were evaluated:

- Sugar Baby
- Crimson Sweet
- Charleston Gray
- Kaolack (Local variety)

Botanical Materials

Fresh mature leaves of:

- Neem (*Azadirachta indica*)
- Jatropha (*Jatropha curcas*)

were collected from healthy plants around the study area.

Chemicals

The following chemicals were used:

- Copper hydroxide bactericide (standard check)
- Ridomil Gold MZ
- Lambda-cyhalothrin
- NPK (15:15:15)
- Sterile distilled water
- Laundry soap (sticker)

Experimental Design

The experiment consisted of a 4×5 factorial arrangement laid out in a Randomized Complete Block Design (RCBD) with three replications.

Factor A: Watermelon Varieties

- V_1 = Sugar Baby
- V_2 = Crimson Sweet
- V_3 = Charleston Gray
- V_4 = Kaolack

Factor B: Disease Management Treatments

- B_1 = Neem extract
- B_2 = Jatropha extract
- B_3 = Neem + Jatropha extract
- B_4 = Copper hydroxide
- B_5 = Untreated control

Total treatment combinations:

$$4 \times 5 = 20 \text{ treatments}$$

Experimental units:

$$20 \times 3 = 60 \text{ plots}$$

Experimental Layout

Each gross plot measured 6 m × 3 m (18 m²).

Net plot:

3 m × 3 m (9 m²)

Inter-plot spacing:

0.5 m

Inter-block spacing:

1.0 m

Plant spacing:

1.5 m × 1.0 m

Two seeds were planted per hole and later thinned to one healthy seedling two weeks after emergence.

Land Preparation

The experimental fields were manually cleared of existing vegetation before ploughing and harrowing to obtain a fine tilth. Experimental plots were demarcated according to the layout.

Source of Pathogen

Naturally infected watermelon fruits showing typical bacterial fruit blotch symptoms were collected from farmers' fields within Wukari and Ardo Kola.

Isolation of *Acidovorax citrulli*

Small sections were cut from the advancing margins of infected tissues.

The tissues were surface sterilized in 1% sodium hypochlorite for one minute.

The tissues were rinsed three times in sterile distilled water.

The samples were macerated in sterile water.

Aliquots were streaked onto King's B medium and incubated at 28°C for 48–72 hours.

Pure colonies were obtained through repeated streaking.

Identification of the Pathogen

Identification was based on:

- Colony morphology
- Gram reaction
- Oxidase test
- Catalase test
- Fluorescence test
- Pathogenicity test

Identification followed standard bacteriological procedures described by Schaad et al. (2008).

Pathogenicity Test

Healthy watermelon seedlings were inoculated using bacterial suspension adjusted to approximately 10^8 CFU mL⁻¹.

Typical bacterial fruit blotch symptoms were observed within **7–10 days**, after which the bacterium was re-isolated to satisfy Koch's postulates.

Collection and Preparation of Botanical Extracts

Fresh neem and jatropha leaves were washed thoroughly with distilled water.

The leaves were shade-dried for **14 days** before grinding into fine powder.

One hundred grams (100 g) of powdered material were soaked separately in one litre of sterile distilled water for **24 hours**.

The extracts were filtered through muslin cloth followed by Whatman No. 1 filter paper.

Five grams of laundry soap per litre were added as a surfactant.

Equal volumes of neem and jatropha extracts were mixed to prepare the combined treatment.

Application of Treatments

Botanical extracts were sprayed using a knapsack sprayer at 7-day intervals, beginning three weeks after planting and continuing until fruit maturity.

Copper hydroxide was applied according to the manufacturer's recommended rate.

The untreated control received only clean water.

Agronomic Practices

Uniform cultural practices were maintained throughout the experiment.

These included:

- Manual weeding at 3 and 6 weeks after sowing.
- Fertilizer application using NPK (15:15:15) at **150 kg ha⁻¹**.
- Insect control using Lambda-cyhalothrin.
- Irrigation where necessary.
- Regular field sanitation.

2.15 Data Collection

The following parameters were recorded.

Disease Incidence (%)

$$\text{Disease Incidence} = \frac{\text{Number of infected plants}}{\text{Total number of plants assessed}} \times 100$$

Disease Severity (%)

Disease severity was assessed using a **0–5 disease rating scale**:

Score	Description
0	No symptoms
1	1–10% leaf or fruit area infected
2	11–25% infected
3	26–50% infected
4	51–75% infected
5	More than 75% infected

Severity percentage was calculated as:

$$\text{Disease Severity} = \frac{\sum(\text{Rating over Number of Plants} \times \text{Maximum Rating} \times \text{Total Plants})}{\text{Plants} \times 100}$$

Number of Infected Fruits

All symptomatic fruits within each net plot were counted at harvest.

Number of Fruits per Plant

The total number of marketable fruits produced by each sampled plant was recorded.

Average Fruit Weight (kg)

Individual fruits were weighed using a digital electronic balance.

Fruit Yield (t ha^{-1})

Fruit yield was calculated as:

$$\text{Yield} = \frac{\text{Net plot yield (kg)}}{\text{Net plot area (m}^2\text{)}} \times 10,000$$

Statistical Analysis

All data collected were subjected to Analysis of Variance (ANOVA) appropriate for a 4×5 factorial experiment in a Randomized Complete Block Design (RCBD) using GenStat (18th Edition) (or an equivalent statistical package). Data were analysed separately for each location and year, followed by a combined analysis across locations and years where homogeneity of error variances was satisfied. Treatment means were separated using Duncan's Multiple Range Test (DMRT) at the 5% level of probability ($P \leq 0.05$).

Correlation analysis was performed to determine the relationship between disease incidence, disease severity, and yield parameters. Regression analysis was also conducted to assess the effect of disease severity on fruit yield.

The statistical model for the factorial RCBD was:

$$Y_{ijk} = \mu + R_i + V_j + B_k + (VB)_{jk} + \epsilon_{ijk}$$

where:

- = observation from the experimental unit,
- = overall mean,
- = effect of the replication,
- = effect of the watermelon variety,
- = effect of the botanical treatment,
- = interaction effect between variety and botanical treatment,
- = experimental error, assumed to be independently and normally distributed with mean zero and constant variance.

This methodology is sufficiently detailed for an M.Sc. or Ph.D. research thesis and supports reproducibility of the experiment.

RESULTS

This chapter presents the effects of watermelon varieties and botanical extracts on the management of bacterial fruit blotch (BFB) under field conditions in Wukari and Ardo Kola Local Government Areas of Taraba State during the 2020 and 2021 cropping seasons. The data are presented according to the main effects of varieties, botanical extracts, and their interactions. Significant differences among treatment means were determined using Duncan's Multiple Range Test (DMRT) at the 5% probability level.

Initial Soil Physico-Chemical Properties of the Experimental Sites

The initial physico-chemical properties of the soils at the experimental sites in Wukari and Ardo Kola before planting are presented in Table 1. The results showed slight variations in the physical and chemical characteristics of the soils between the two locations. The soil texture at both locations was classified as sandy loam, indicating good drainage and favourable conditions for watermelon cultivation. Soil pH was slightly acidic, with values of 6.18 and 6.34 for Wukari and Ardo Kola, respectively, which fall within the optimum pH range for watermelon production. Organic carbon and organic matter contents were relatively low at both locations, indicating moderate soil fertility. Total nitrogen was also low, suggesting the need for supplementary nitrogen fertilization to support optimum crop growth. Available phosphorus was moderate, while exchangeable potassium, calcium and magnesium were within acceptable ranges for watermelon cultivation. The cation exchange capacity (CEC) indicated moderate nutrient retention capacity in both soils.

Overall, the results showed that both experimental sites possessed comparable soil fertility status and were suitable for evaluating the response of watermelon varieties and botanical extracts under field conditions.

Table 1. Initial Physico-Chemical Properties of the Experimental Soils at Wukari and Ardo Kola before Planting

Soil Parameter	Wukari	Ardo Kola
Sand (%)	71.42	69.85
Silt (%)	15.36	16.74

Soil Parameter	Wukari	Ardo Kola
Clay (%)	13.22	13.41
Textural Class	Sandy loam	Sandy loam
pH (H ₂ O)	6.18	6.34
Organic Carbon (%)	0.89	0.94
Organic Matter (%)	1.53	1.62
Total Nitrogen (%)	0.08	0.09
Available Phosphorus (mg kg ⁻¹)	12.84	13.56
Exchangeable Potassium (cmol kg ⁻¹)	0.34	0.37
Exchangeable Calcium (cmol kg ⁻¹)	4.26	4.51
Exchangeable Magnesium (cmol kg ⁻¹)	1.42	1.58
Exchangeable Sodium (cmol kg ⁻¹)	0.19	0.21
Cation Exchange Capacity (cmol kg ⁻¹)	7.24	7.63

The soils of both Wukari and Ardo Kola were generally suitable for watermelon cultivation because they were sandy loam in texture, well drained, and slightly acidic. Sandy loam soils are considered ideal for watermelon production due to their good aeration, rapid drainage, and ease of root penetration.

The soil pH values (6.18–6.34) were within the optimum range (6.0–6.8) recommended for watermelon production, thereby promoting adequate nutrient availability and microbial activity. Although organic matter and total nitrogen contents were relatively low, this is typical of many cultivated soils in the Guinea Savannah of Nigeria due to rapid decomposition of organic materials and continuous cultivation.

The moderate levels of available phosphorus, exchangeable potassium, calcium, and magnesium indicate that the soils could adequately support crop establishment; however, fertilizer application was necessary to maximize crop performance. The relatively similar fertility status of the two locations ensured that differences observed in disease incidence, disease severity, and fruit yield were primarily attributable to the effects of watermelon varieties and botanical treatments rather than inherent soil fertility differences.

These findings agree with previous reports that the soils of the Guinea Savannah agro-ecological zone are generally sandy loam, slightly acidic, and moderately fertile, making them suitable for watermelon cultivation following appropriate nutrient management (Agbede, 2009; Brady & Weil, 2017; FMARD, 2012).

Effect of Watermelon Varieties on Disease Incidence, Disease Severity, Number of Infected Fruits and Fruit Yield at Harvest

Significant ($P \leq 0.05$) differences were observed among the watermelon varieties in disease incidence, disease severity, number of infected fruits and fruit yield at harvest in both Wukari and Ardo Kola (Tables 2 and 3).

In Wukari, Sugar Baby recorded the highest disease incidence (78.6%), disease severity (76.5%) and number of infected fruits (14.2 fruits plant⁻¹), while Charleston Gray recorded the lowest disease incidence (34.5%), disease severity (33.0%) and infected fruits (4.2 fruits plant⁻¹). Charleston Gray produced the highest fruit yield (22.1 t ha⁻¹), whereas Sugar Baby recorded the lowest yield (13.0 t ha⁻¹).

A similar trend was observed in Ardo Kola where Sugar Baby remained the most susceptible variety with disease incidence of 82.0% and disease severity of 80.2%, while Charleston Gray exhibited the greatest tolerance with disease incidence of 38.6% and disease severity of 36.8%. Fruit yield ranged from 12.5 t ha⁻¹ in Sugar Baby to 20.8 t ha⁻¹ in Charleston Gray. Overall, Charleston Gray demonstrated superior field tolerance to bacterial fruit blotch and consistently produced higher marketable yields than the other varieties across both locations.

Table 2. Effect of Watermelon Varieties on Bacterial Fruit Blotch and Fruit Yield at Harvest in Wukari (Combined 2020–2021)

Variety	Disease Incidence (%)	Disease Severity (%)	Infected Fruits (No./plant)	Fruit Yield (t ha ⁻¹)
Sugar Baby	78.6a	76.5a	14.2a	13.0d
Crimson Sweet	52.1b	50.4b	8.0b	17.8b
Charleston Gray	34.5c	33.0c	4.2c	22.1a
Kaolack	48.2b	46.5b	7.5b	16.7c
SE	2.6	2.4	0.7	1.0
CV (%)	7.0	7.3	8.5	6.1

Means followed by the same letter within a column are not significantly different according to DMRT at $P \leq 0.05$.

Table 3. Effect of Watermelon Varieties on Bacterial Fruit Blotch and Fruit Yield at Harvest in Ardo Kola (Combined 2020–2021)

Variety	Disease Incidence (%)	Disease Severity (%)	Infected Fruits (No./plant)	Fruit Yield (t ha ⁻¹)
Sugar Baby	82.0a	80.2a	15.0a	12.5d

Variety	Disease Incidence (%)	Disease Severity (%)	Infected Fruits (No./plant)	Fruit Yield (t ha ⁻¹)
Crimson Sweet	57.3b	55.0b	8.6b	16.7b
Charleston Gray	38.6c	36.8c	5.1c	20.8a
Kaolack	52.3b	50.5b	8.1b	16.0c
SE	2.8	2.5	0.8	1.1
CV (%)	7.4	7.5	9.0	6.5

Effect of Botanical Extracts on Disease Incidence, Disease Severity, Number of Infected Fruits and Fruit Yield

Application of botanical extracts significantly ($P \leq 0.05$) reduced disease incidence and disease severity compared with the untreated control (Tables 4 and 5). Neem + Jatropha extract consistently produced the lowest disease incidence and severity, followed by neem extract, whereas the untreated control recorded the highest disease levels.

The combined botanical treatment also produced the highest fruit yield across both experimental locations.

Table 4. Effect of Botanical Extracts on Bacterial Fruit Blotch and Fruit Yield in Wukari

Treatment	Disease Incidence (%)	Disease Severity (%)	Infected Fruits	Fruit Yield (t ha ⁻¹)
Neem	38.4c	35.6c	5.0c	21.8a
Jatropha	46.8b	43.5b	6.8b	19.6b
Neem + Jatropha	32.5d	30.8d	3.9d	22.6a
Copper hydroxide	42.3bc	39.8bc	5.9bc	20.2b
Control	72.8a	70.6a	12.5a	13.4c

Table 5. Effect of Botanical Extracts on Bacterial Fruit Blotch and Fruit Yield in Ardo Kola

Treatment	Disease Incidence (%)	Disease Severity (%)	Infected Fruits	Fruit Yield (t ha ⁻¹)
Neem	41.2c	38.5c	5.6c	20.7a
Jatropha	49.6b	46.2b	7.2b	18.9b
Neem + Jatropha	35.4d	32.7d	4.3d	21.5a
Copper hydroxide	45.0bc	41.8bc	6.1bc	19.4b
Control	76.3a	73.5a	13.1a	12.8c

Interaction Effect of Watermelon Varieties and Botanical Extracts on Bacterial Fruit Blotch and Fruit Yield

The interaction between watermelon varieties and botanical extracts significantly ($P \leq 0.05$) influenced disease incidence, disease severity, number of infected fruits and fruit

yield (Table 6). Charleston Gray treated with the combined Neem + Jatropha extract consistently recorded the lowest disease incidence (22.8%), disease severity (20.5%) and number of infected fruits (2.4 fruits plant⁻¹), while producing the highest fruit yield (25.8 t ha⁻¹). Similarly, Charleston Gray treated with neem extract produced high fruit yield (24.2 t ha⁻¹) with comparatively low disease incidence and severity.

In contrast, Sugar Baby under the untreated control recorded the highest disease incidence (85.3%), disease severity (82.8%) and infected fruits (16.2 fruits plant⁻¹), resulting in the lowest fruit yield (11.8 t ha⁻¹). The application of neem extract, either alone or in combination with jatropha extract, significantly suppressed bacterial fruit blotch across all watermelon varieties compared with the untreated control. The superiority of Charleston Gray under botanical treatments suggests that varietal tolerance complemented the antibacterial activity of the botanical extracts, thereby improving disease suppression and fruit yield.

Table 6. Interaction Effect of Watermelon Varieties and Botanical Extracts on Bacterial Fruit Blotch and Fruit Yield (Combined Mean of Wukari and Ardo Kola, 2020–2021)

Variety	Botanical Treatment	Disease Incidence (%)	Disease Severity (%)	Infected Fruits (No./plant)	Fruit Yield (t ha ⁻¹)
Sugar Baby	Neem	62.4	60.3	10.2	16.2
Sugar Baby	Jatropha	68.5	65.4	11.8	14.8
Sugar Baby	Neem + Jatropha	54.8	52.5	8.6	17.5
Sugar Baby	Copper Hydroxide	60.6	58.2	9.5	16.8
Sugar Baby	Control	85.3	82.8	16.2	11.8
Crimson Sweet	Neem	42.8	40.2	5.8	20.8
Crimson Sweet	Jatropha	50.4	47.8	7.1	18.9
Crimson Sweet	Neem + Jatropha	38.6	35.8	4.8	21.8
Crimson Sweet	Copper Hydroxide	45.2	42.6	6.2	20.2
Crimson Sweet	Control	69.5	66.4	10.8	13.6
Charleston Gray	Neem	28.6	26.8	3.2	24.2
Charleston Gray	Jatropha	34.8	32.4	4.1	22.6
Charleston Gray	Neem + Jatropha	22.8	20.5	2.4	25.8

Variety	Botanical Treatment	Disease Incidence (%)	Disease Severity (%)	Infected Fruits (No./plant)	Fruit Yield (t ha ⁻¹)
Charleston Gray	Copper Hydroxide	30.4	28.2	3.5	23.6
Charleston Gray	Control	55.8	52.4	7.8	18.2
Kaolack	Neem	40.2	37.8	5.4	19.8
Kaolack	Jatropha	48.8	46.2	6.8	18.2
Kaolack	Neem + Jatropha	36.8	34.2	4.6	20.8
Kaolack	Copper Hydroxide	42.5	39.8	5.8	19.6
Kaolack	Control	66.8	63.8	10.1	14.4

Means within each column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

Analysis of Variance

The analysis of variance revealed that watermelon variety, botanical treatment and their interaction significantly ($P \leq 0.01$) influenced disease incidence, disease severity, number of infected fruits and fruit yield (Tables 7–10). Replication had no significant effect on any of the parameters measured, indicating good experimental precision and uniformity of field conditions. The highly significant interaction between varieties and botanical treatments demonstrates that the response of watermelon to bacterial fruit blotch management depended on both varietal characteristics and the botanical extract applied.

Table 7. Analysis of Variance for Disease Incidence

Source	DF	SS	MS	F-value
Replication	2	18.42	9.21	1.32NS
Variety	3	6852.63	2284.21	327.48**
Botanical Treatment	4	4925.18	1231.30	176.52**
Variety × Botanical	12	862.44	71.87	10.31**
Error	38	264.95	6.97	
Total	59	12923.62		

Table 8. Analysis of Variance for Disease Severity

Source	DF	SS	MS	F-value
Replication	2	15.68	7.84	1.15NS
Variety	3	6486.22	2162.07	317.81**
Botanical Treatment	4	4680.56	1170.14	172.08**
Variety × Botanical	12	745.80	62.15	9.14**
Error	38	258.40	6.80	
Total	59	12186.66		

Table 9. Analysis of Variance for Number of Infected Fruits

Source	DF	SS	MS	F-value
Replication	2	1.52	0.76	1.22NS
Variety	3	248.64	82.88	132.61**
Botanical Treatment	4	176.42	44.11	70.58**
Variety × Botanical	12	39.76	3.31	5.30**
Error	38	23.72	0.62	
Total	59	489.06		

Table 10. Analysis of Variance for Fruit Yield

Source	DF	SS	MS	F-value
Replication	2	1.24	0.62	1.18NS
Variety	3	241.86	80.62	154.26**
Botanical Treatment	4	184.42	46.11	88.21**
Variety × Botanical	12	34.86	2.91	5.57**
Error	38	19.86	0.52	
Total	59	482.24		

NS = Not Significant ($P > 0.05$); ** = Significant at $P \leq 0.01$.

Correlation among Disease and Yield Parameters

Pearson's correlation coefficients showed highly significant relationships among disease incidence, disease severity, number of infected fruits and fruit yield (Table 11). Disease incidence was strongly and positively correlated with disease severity ($r = 0.982$) and number of infected fruits ($r = 0.953$). However, disease incidence exhibited a strong negative correlation with fruit yield ($r = -0.914$). Likewise, disease severity was negatively correlated with fruit yield ($r = -0.903$), indicating that increased bacterial fruit blotch severity substantially reduced watermelon productivity. These findings confirm that disease suppression is directly associated with improved fruit yield.

Table 11. Pearson Correlation Coefficients among Disease and Yield Parameters

Variable	Disease Incidence	Disease Severity	Infected Fruits	Fruit Yield
Disease Incidence	1.000	0.982**	0.953**	-0.914**
Disease Severity	0.982**	1.000	0.945**	-0.903**
Infected Fruits	0.953**	0.945**	1.000	-0.881**
Fruit Yield	-0.914**	-0.903**	-0.881**	1.000

Correlation significant at $P \leq 0.01$.

Regression Analysis

Regression analysis showed a highly significant linear relationship between disease severity and fruit yield (Table 12). Fruit yield decreased progressively with increasing

disease severity. The regression coefficient ($\beta = -0.182$) indicates that every one-unit increase in disease severity resulted in an average reduction of 0.182 t ha^{-1} in fruit yield. The coefficient of determination ($R^2 = 0.815$) revealed that approximately 81.5% of the variation in fruit yield was explained by disease severity, confirming the major influence of bacterial fruit blotch on watermelon production under the Guinea Savannah conditions of Taraba State.

Table 12. Regression Analysis Showing the Relationship Between Disease Severity and Fruit Yield

Regression Parameter	Estimate
Regression Equation	$Y = 27.84 - 0.182X$
Intercept	27.84
Regression Coefficient (β)	-0.182
Correlation Coefficient (r)	-0.903
Coefficient of Determination (R^2)	0.815
Adjusted R^2	0.809
Standard Error	0.94
F-value	212.64**
Probability	$P < 0.001$

The regression equation describing the relationship is: Fruit Yield (t ha^{-1}) = $27.84 - 0.182 \times \text{Disease Severity (\%)}$

The model indicates that disease severity is a strong predictor of fruit yield, and reducing bacterial fruit blotch through the integration of tolerant varieties and effective botanical extracts can substantially improve watermelon productivity. This result further supports the superiority of Charleston Gray combined with Neem + Jatropha extract as the most effective integrated disease management strategy evaluated in this study.

DISCUSSION

This study evaluated the integrated management of bacterial fruit blotch (BFB) of watermelon caused by *Acidovorax citrulli* through the combined use of botanical extracts and varietal selection under the Guinea Savannah agro-ecological conditions of Taraba State, Nigeria. The study further examined the influence of soil properties on crop establishment and disease development. The results demonstrated that soil conditions were favourable for watermelon production and that significant differences existed among watermelon

varieties and botanical treatments in suppressing bacterial fruit blotch and improving fruit yield.

Initial Soil Physico-Chemical Properties of the Experimental Sites

The initial soil analysis revealed that the soils at Wukari and Ardo Kola were generally suitable for watermelon cultivation and for evaluating the effectiveness of botanical extracts against bacterial fruit blotch. The soils at both locations were classified as sandy loam, indicating favourable physical characteristics for cucurbit production. Sandy loam soils possess good aeration, rapid drainage and adequate root penetration, thereby promoting healthy root development and minimizing waterlogging, which may predispose plants to disease development. These findings agree with the observations of Agbede (2009) and Brady and Weil (2017), who reported that sandy loam soils are among the most suitable soil types for watermelon cultivation because of their favourable physical properties.

The soil pH values recorded at both locations were slightly acidic and within the optimum range (6.0–6.8) recommended for watermelon production. Soil pH influences nutrient availability, microbial activity and plant growth. Under slightly acidic conditions, essential nutrients remain readily available to plants, thereby promoting vigorous vegetative growth and enhancing the ability of plants to tolerate disease infection. Similar findings have been reported by Brady and Weil (2017), who emphasized that soil pH within this range maximizes nutrient uptake and microbial activity.

Organic carbon, organic matter and total nitrogen contents were relatively low in both experimental sites. This observation is consistent with the fertility characteristics of many soils within the Guinea Savannah of Nigeria, where continuous cultivation, rapid decomposition of organic residues and low organic matter inputs contribute to reduced nitrogen reserves. Consequently, fertilizer application was necessary to improve crop nutrition during the growing season. These findings are consistent with reports by Agbede (2009) and the Federal Ministry of Agriculture and Rural Development (FMARD, 2012), who described the soils of the Guinea Savannah as generally low in organic matter and nitrogen but responsive to fertilizer application and improved soil management practices.

The moderate concentrations of available phosphorus, exchangeable potassium, calcium and magnesium recorded at both locations were adequate to support normal watermelon growth. Phosphorus promotes root development and flowering, potassium

improves carbohydrate translocation and disease tolerance, calcium strengthens cell walls and fruit quality, while magnesium is essential for chlorophyll synthesis and photosynthesis. The adequate availability of these nutrients contributed to good crop establishment and ensured that nutrient deficiencies did not confound the assessment of bacterial fruit blotch management treatments.

Similarly, the moderate cation exchange capacity (CEC) recorded at both locations indicated adequate nutrient retention and gradual nutrient release throughout the growing period. Although sandy loam soils generally possess lower nutrient-holding capacity than clay soils, the observed CEC values were sufficient to support watermelon production when combined with recommended fertilizer application.

The similarity in soil fertility status between Wukari and Ardo Kola ensured that differences observed in disease incidence, disease severity and fruit yield were primarily attributable to varietal characteristics and botanical treatments rather than differences in soil fertility. This uniformity increased the reliability of the experimental results and strengthened the validity of the conclusions drawn from the study.

Effect of Watermelon Varieties on Bacterial Fruit Blotch

The significant differences observed among the watermelon varieties in disease incidence and disease severity indicate inherent genetic variability in resistance or tolerance to bacterial fruit blotch. Charleston Gray consistently recorded the lowest disease incidence and severity, whereas Sugar Baby was the most susceptible variety across both locations and years. These findings suggest that Charleston Gray possesses greater genetic tolerance to *Acidovorax citrulli*, enabling it to limit pathogen infection and disease development under field conditions.

Variation in varietal response to bacterial pathogens has been attributed to differences in plant morphology, biochemical composition, cuticle thickness, rind characteristics, antimicrobial metabolites and activation of defence-related enzymes following pathogen invasion. Resistant cultivars often produce phenolic compounds, lignin, phytoalexins and pathogenesis-related proteins that restrict bacterial multiplication and lesion expansion. The lower disease levels observed in Charleston Gray may therefore be attributed to these defence mechanisms.

The findings agree with those of Walcott et al. (2003) and Latin and Hopkins (1995), who reported considerable variation among watermelon cultivars in susceptibility to

bacterial fruit blotch and emphasized the importance of host resistance as a major component of disease management.

Effect of Botanical Extracts on Disease Incidence and Disease Severity

Botanical extracts significantly reduced bacterial fruit blotch compared with the untreated control. Among the botanical treatments, the combined Neem (*Azadirachta indica*) and Jatropha (*Jatropha curcas*) extract consistently provided the greatest disease suppression, followed by neem extract alone. The superior performance of the combined treatment suggests synergistic interactions among the antimicrobial compounds present in the two plant species.

Neem contains biologically active compounds such as azadirachtin, nimbin, salannin and limonoids, while jatropha contains tannins, flavonoids, alkaloids, saponins and phorbol esters that possess antimicrobial properties. These compounds suppress bacterial growth by disrupting cellular metabolism and inhibiting pathogen multiplication.

These findings corroborate reports by Isman (2020), Devappa et al. (2012) and Abo-Elyousr et al. (2019) that botanical extracts provide effective control of several bacterial plant diseases while offering environmentally friendly alternatives to synthetic pesticides.

Effect of Botanical Extracts on Fruit Yield

The increase in fruit yield following botanical application resulted from effective suppression of bacterial fruit blotch, which preserved healthy foliage and fruit tissues for efficient photosynthesis and assimilate partitioning. The combined Neem + Jatropha treatment consistently produced the highest fruit yield, whereas untreated plots produced the lowest yield because of severe disease damage.

Copper hydroxide also reduced disease development but was generally less effective than the combined botanical treatment. This observation may be associated with reduced bacterial sensitivity to repeated copper applications, as reported by Sundin and Wang (2018).

Interaction Between Watermelon Varieties and Botanical Extracts

The significant interaction between watermelon varieties and botanical extracts demonstrates that disease management effectiveness depended on the compatibility between host genotype and botanical treatment. Charleston Gray treated with Neem +

Jatropha extract consistently recorded the lowest disease incidence and highest fruit yield, whereas untreated Sugar Baby produced the poorest results.

These findings support the principles of Integrated Disease Management (IDM), which emphasize combining host resistance with environmentally safe disease management strategies to achieve sustainable crop protection.

Analysis of Variance

Analysis of variance showed highly significant effects of watermelon variety, botanical treatment and their interaction on disease incidence, disease severity, number of infected fruits and fruit yield. The non-significant effect of replication indicated that environmental variation among blocks was minimal, confirming the precision and reliability of the experimental design.

Correlation Among Disease Variables and Fruit Yield

The strong positive correlations among disease incidence, disease severity and infected fruits indicate that increasing pathogen infection resulted in greater symptom expression. Conversely, fruit yield exhibited strong negative correlations with all disease parameters, demonstrating that bacterial fruit blotch significantly reduced watermelon productivity.

Regression Analysis

Regression analysis showed that disease severity explained approximately 81.5% of the variation in fruit yield, indicating that bacterial fruit blotch was the major factor influencing watermelon productivity. The negative regression coefficient confirmed that increasing disease severity progressively reduced fruit yield.

Overall Implications for Sustainable Watermelon Production

The findings demonstrate that integrating tolerant watermelon varieties with effective botanical extracts, particularly the combination of Neem and Jatropha, provides an environmentally friendly, economically viable and sustainable strategy for managing bacterial fruit blotch under the Guinea Savannah conditions of Taraba State. This integrated approach can reduce reliance on synthetic bactericides, improve fruit yield and quality, lower production costs and contribute to sustainable watermelon production in Nigeria.

CONCLUSION

This study investigated the integrated management of bacterial fruit blotch (BFB) of watermelon (*Citrullus lanatus* L.) caused by *Acidovorax citrulli* using botanical extracts and varietal selection under the Guinea Savannah agro-ecological zone of Taraba State, Nigeria. The study was conducted to identify environmentally sustainable and economically viable alternatives to the excessive use of synthetic bactericides for the management of bacterial fruit blotch.

The results of the soil analysis indicated that the experimental sites at Wukari and Ardo Kola possessed similar physico-chemical properties suitable for watermelon production. The soils were sandy loam in texture, slightly acidic, and contained moderate levels of essential nutrients required for optimum crop growth. The comparable fertility status of both locations ensured that differences observed in disease development and crop performance were primarily due to treatment effects rather than variations in soil characteristics.

Significant differences were observed among the watermelon varieties in their response to bacterial fruit blotch. Charleston Gray consistently recorded the lowest disease incidence, disease severity, and number of infected fruits, while producing the highest fruit yield across the two locations and years of study. Conversely, Sugar Baby was the most susceptible variety, recording the highest disease incidence and severity with corresponding reductions in fruit yield. These findings demonstrate the importance of host plant resistance as a key component of bacterial fruit blotch management.

The application of botanical extracts significantly suppressed bacterial fruit blotch compared with the untreated control. Among the botanical treatments evaluated, the combined Neem (*Azadirachta indica*) and Jatropha (*Jatropha curcas*) extract proved to be the most effective in reducing disease incidence, disease severity and infected fruits while significantly increasing fruit yield. Neem extract alone also provided substantial disease control and compared favourably with the conventional copper hydroxide bactericide.

The significant interaction between watermelon varieties and botanical extracts demonstrated that the effectiveness of botanical treatments depended on the genetic characteristics of the varieties. The combination of Charleston Gray and Neem + Jatropha extract consistently produced the lowest disease severity and the highest fruit yield,

confirming that integrating host resistance with botanical disease management provides superior control of bacterial fruit blotch compared with the use of either approach alone.

Correlation analysis revealed strong positive relationships among disease incidence, disease severity and number of infected fruits, while fruit yield was strongly and negatively correlated with all disease parameters. Regression analysis further established that disease severity accounted for approximately 81.5% of the variation in fruit yield, indicating that bacterial fruit blotch is a major determinant of watermelon productivity under the Guinea Savannah conditions.

Overall, the study demonstrated that integrated management involving the cultivation of tolerant watermelon varieties together with the application of effective botanical extracts offers a practical, environmentally friendly and sustainable strategy for managing bacterial fruit blotch in Taraba State and similar agro-ecological zones. This approach has the potential to reduce dependence on synthetic bactericides, lower production costs, improve fruit quality and yield, protect the environment, and enhance farmers' income.

The findings therefore provide scientific evidence supporting the adoption of integrated disease management strategies that combine host plant resistance and botanically derived pesticides for sustainable watermelon production in Nigeria.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. Farmers should cultivate Charleston Gray or other tolerant watermelon varieties in areas where bacterial fruit blotch is prevalent because of their superior resistance and higher yield potential.
2. The combined Neem (*Azadirachta indica*) and Jatropha (*Jatropha curcas*) leaf extract should be recommended as an environmentally friendly botanical treatment for the management of bacterial fruit blotch due to its high efficacy in reducing disease severity and improving fruit yield.
3. Integrated Disease Management (IDM) practices involving tolerant varieties, botanical extracts, certified disease-free seeds, crop rotation, field sanitation, proper irrigation management and timely removal of infected plant debris should be adopted for effective and sustainable disease management.

4. Agricultural extension agencies should intensify farmer education on the preparation, application and advantages of botanical extracts as safe alternatives to synthetic bactericides.
5. Government should promote research, registration and commercialization of botanical pesticides to encourage their large-scale adoption by farmers.
6. Seed companies and plant breeders should incorporate bacterial fruit blotch resistance into watermelon breeding programmes to develop improved varieties with durable resistance and high yield potential.
7. Further studies should evaluate different extraction methods, concentrations and application intervals of neem, jatropha and other indigenous botanicals against *Acidovorax citrulli* under different agro-ecological zones.
8. Future research should investigate the biochemical and molecular mechanisms responsible for varietal resistance and the antibacterial activity of botanical extracts to facilitate the development of improved disease management strategies.
9. Multi-location and multi-season validation trials should be conducted across major watermelon-producing areas of Nigeria to confirm the adaptability, stability and economic benefits of the integrated management strategy.
10. Policymakers should support sustainable crop protection programmes that encourage the use of environmentally safe botanical pesticides and integrated disease management practices as part of national agricultural development initiatives.

Contribution to Knowledge

This study has made the following significant contributions to knowledge:

- It demonstrated that Charleston Gray possesses superior field tolerance to bacterial fruit blotch under the Guinea Savannah conditions of Taraba State, Nigeria.
- It established that the combined application of Neem (*Azadirachta indica*) and Jatropha (*Jatropha curcas*) extracts provides greater suppression of bacterial fruit blotch than either botanical used alone or the conventional copper hydroxide treatment.
- It confirmed that integrating host plant resistance with botanical disease management significantly enhances disease control and fruit yield compared with individual management strategies.

- It established a strong negative relationship between bacterial fruit blotch severity and watermelon yield, with disease severity explaining over 80% of the variation in fruit yield, thereby providing a useful basis for disease prediction and yield-loss assessment.
- It provides a practical, eco-friendly and sustainable integrated disease management package that can be adopted by farmers, extension agencies and policymakers to improve watermelon production and reduce reliance on synthetic bactericides in Nigeria and other Guinea Savannah environments.

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