



In Vitro Evaluation of Different Fungicides Against Hard Rot Pathogen of *Annona muricata* L.

Kayode Samson ABIDOYE*¹, Olufunke O. OLAYODE², Oluseye Faith OYEDEJI³, Olaniyi Christopher OLUWADARE⁴ and Mercy AKOUN⁵

¹Yaba College of Technology, P.M.B. 2011, Lagos, Nigeria Email: kayode.abidoeye@yabatech.edu.ng

²Ekiti State University, P.M.B. 5363, Ado-Ekiti, Ekiti State, Nigeria, Email: olufunke.olayode@eksu.edu.ng

³Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho Forest Hill, Ibadan, Nigeria Email: faitholuseye@gmail.com

⁴Yaba College of Technology, P.M.B. 2011, Lagos, Nigeria Email: olaniyi.oluwadare@yabatech.edu.ng

⁵Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho Forest Hill, Ibadan, Nigeria Email: mercyakoune@gmail.com

*Correspondence: kayode.abidoeye@yabatech.edu.ng, Tel: +2349060859422

Received: 19/07/2026

Accepted: 18/10/2026

Available online: 20/10/2026



Copyright: ©2026 by the author(s).

This work is licensed under a Creative Commons Attribution 4.0 License.

<https://creativecommons.org/licenses/by/4.0/>

Abstract: Postharvest fungal diseases remain a major constraint to the production, storage, and marketing of *Annona muricata* L. (soursop), causing significant economic losses through reduced fruit quality and shelf life. This study evaluated the in vitro efficacy of three commercial fungicides against *Colletotrichum gloeosporioides* associated with hard rot of soursop fruits. Diseased fruits exhibiting characteristic hard rot symptoms were collected from Ado-Ekiti, Nigeria, and the pathogen was isolated on Sabouraud Dextrose Agar (SDA). Pure cultures were obtained through subculturing and evaluated using the poisoned food technique. Three fungicides—Ridomil Gold® (Metalaxyl-M + Mancozeb), Tandem® (Copper (I) oxide + Metalaxyl), and Z-Force® (Mancozeb 80% WP)—were incorporated into SDA at varying concentrations, after which fungal radial growth was monitored daily under laboratory conditions. Fungicidal efficacy was assessed based on mycelial growth rate and percentage inhibition relative to the untreated control. The untreated control recorded the highest radial growth (14.11 mm day⁻¹), confirming the aggressive growth of the pathogen in the absence of fungicidal treatment. Ridomil Gold® exhibited the greatest inhibitory effect, achieving 86.2% and 90.2% inhibition at 5 and 6 g L⁻¹, respectively, and complete (100%) inhibition at 7 and 9 g L⁻¹. Z-Force® produced moderate inhibition at lower concentrations but completely suppressed fungal growth at 5 g L⁻¹. Tandem® reduced mycelial growth substantially, reaching a maximum inhibition of 83.8%, but failed to achieve complete inhibition within the concentration range evaluated. The findings demonstrate that fungicide efficacy varies with formulation and concentration, with Ridomil Gold® proving the most effective against *C. gloeosporioides* under in vitro conditions. The study provides baseline information for the chemical management of soursop hard rot and highlights the need for greenhouse and field evaluations to validate laboratory findings before large-scale application.

Keywords: *Annona muricata*; *Colletotrichum gloeosporioides*; Fungicide efficacy; Hard rot; Postharvest disease management.

INTRODUCTION

Annona muricata L. (Annonaceae), commonly known as soursop, is an economically important tropical fruit tree cultivated across Africa, the Caribbean, Central and South America, and parts of Southeast Asia. The fruit is highly valued for its nutritional and medicinal properties, being rich in carbohydrates, dietary fibre, vitamins, minerals, and bioactive phytochemicals such as acetogenins, flavonoids, alkaloids, tannins, and phenolic compounds with

antioxidant, antimicrobial, anti-inflammatory, anticancer, and antidiabetic activities (Moghadamtousi *et al.*, 2015; Coria-Téllez *et al.*, 2018; George *et al.*, 2020). Consequently, the cultivation and commercialization of *A. muricata* have expanded in many tropical countries, including Nigeria, where it contributes to food security, income generation, and the pharmaceutical industry (Akinmoladun *et al.*, 2019).

Despite its economic importance, soursop production is constrained by several biotic and abiotic factors, among which fungal diseases are the most significant. These diseases reduce fruit yield, market quality, shelf life, and export value, resulting in substantial postharvest losses. In tropical environments characterized by high humidity and warm temperatures, fungal pathogens readily infect fruits during production, harvesting, transportation, storage, and marketing (Ploetz, 2015; Sharma *et al.*, 2009; Zhang *et al.*, 2021). Hard rot and anthracnose are among the most destructive postharvest diseases of soursop, causing tissue hardening, fruit decay, and considerable economic losses, particularly in developing countries where postharvest handling facilities are often inadequate (FAO, 2022; Romanazzi *et al.*, 2016).

Several fungal genera, including *Colletotrichum*, *Lasiodiplodia*, *Fusarium*, *Rhizopus*, *Alternaria*, *Aspergillus*, and *Botryodiplodia*, have been associated with fruit rot diseases of tropical fruits (Dean *et al.*, 2012; Hyde *et al.*, 2014). Among these, *Colletotrichum* species are regarded as some of the most destructive because of their broad host range, aggressive pathogenicity, and ability to establish latent infections that become evident during fruit ripening (Dean *et al.*, 2012; Damm *et al.*, 2012). Disease development is facilitated by fungal production of extracellular enzymes that degrade host cell walls, while environmental factors such as high humidity, rainfall, mechanical injuries, and poor sanitation further enhance infection and disease progression (Kubicek *et al.*, 2014; Ploetz, 2015).

Management of postharvest fungal diseases requires an integrated approach involving orchard sanitation, resistant cultivars, biological control, proper harvesting and storage, and the judicious use of fungicides (Romanazzi *et al.*, 2016; Palou *et al.*, 2016). Nevertheless, synthetic fungicides remain indispensable because they provide rapid and reliable protection against economically important fungal pathogens. Contact fungicides such as copper compounds and mancozeb disrupt multiple metabolic processes in fungal cells, whereas systemic fungicides such as metalaxyl inhibit nucleic acid synthesis and suppress fungal development within host tissues (Brent & Hollomon, 2007; Gisi & Sierotzki, 2015).

Commercial fungicides including Tandem® (Copper(I) oxide + Metalaxyl), Ridomil Gold® MZ 68WG (Metalaxyl-M + Mancozeb), and Z-Force® (Mancozeb 80% WP) are widely used for controlling fungal diseases in horticultural crops. Their different modes of action contribute to effective disease suppression while helping to reduce the risk of fungicide resistance (Brent & Hollomon, 2007; FRAC, 2024). However, information on their comparative efficacy against the hard rot pathogen of *A. muricata* under Nigerian conditions remains limited, highlighting the need for laboratory-based evaluations to guide effective disease management and fungicide selection (Russell, 2004; FRAC, 2024).

The poisoned food technique is a reliable method for assessing fungicide sensitivity by measuring fungal growth on fungicide-amended media (Grover & Moore, 1962).

Such in vitro evaluations provide valuable preliminary information for selecting effective fungicides before greenhouse and field testing. Therefore, this study was undertaken to isolate and identify the fungal pathogen associated with hard rot of *Annona muricata* fruits and to evaluate the in vitro efficacy of selected commercial fungicides—Tandem®, Ridomil Gold®, and Z-Force®—at different concentrations using radial mycelial growth inhibition as an indicator of fungicidal activity.

MATERIALS AND METHODS

Study Area

The laboratory experiments were conducted in the Plant Pathology Laboratory, Faculty of Agricultural Sciences, Ekiti State University (EKSU), Ado-Ekiti, Ekiti State, Nigeria. Ekiti State is situated in southwestern Nigeria between latitudes 7°15'–8°05' N and longitudes 4°45'–5°45' E. The state experiences a tropical humid climate characterized by distinct wet (April–October) and dry (November–March) seasons, with mean annual rainfall ranging from approximately 1,200 to 1,500 mm and average temperatures between 24 and 30°C. These climatic conditions favor the development and proliferation of several fungal pathogens affecting tropical fruits.

Collection of Fruit Samples and Fungicides

Naturally infected fruits of *Annona muricata* L. (soursop) showing characteristic symptoms of anthracnose were purchased from the Satellite Market located near the EKSU Mini Gate, Ado-Ekiti, Nigeria (approximately 7.716° N, 5.252° E). Fruits exhibiting typical dark, sunken lesions were carefully selected and transported to the laboratory in sterile polyethylene bags for immediate isolation of the causal organism. Three commercial fungicides commonly recommended for fungal disease management were evaluated.

Tandem® WP (Copper(I) oxide 60% + Metalaxyl 12%)

Ridomil Gold® MZ 68WG (Metalaxyl-M + Mancozeb)

Z-Force® WP (Mancozeb 80%)

All fungicides were obtained from a registered agrochemical dealer in Ado-Ekiti and stored according to the manufacturers' recommendations until use.

Surface Sterilization of Fruit Samples

Fruit samples were washed thoroughly under running tap water to remove adhering debris before surface sterilization. Symptomatic tissues were disinfected by immersion in 1% sodium hypochlorite solution for 2 minutes, followed by rinsing three times with sterile distilled water. The sterilized tissues were subsequently immersed briefly (30–60 seconds) in 70% ethanol and finally rinsed with sterile distilled water. Sterile filter paper was used to blot the tissues dry before pathogen isolation. All glassware and laboratory instruments were sterilized before use by washing thoroughly, rinsing with distilled water, and autoclaving at 121°C and 15 psi for 15 minutes.

Preparation of Culture Medium

Sabouraud Dextrose Agar (SDA) was used for isolation and culture of the fungal pathogen. The medium was prepared according to the manufacturer's instructions by dissolving 6.5 g SDA powder in 150 mL distilled water. The medium was sterilized by autoclaving at 121°C for 15 minutes. After cooling to approximately 50°C, chloramphenicol (50 mg L⁻¹) was aseptically added to suppress bacterial contamination. The amended medium was poured into sterile 90-mm Petri dishes under aseptic conditions inside a laminar airflow cabinet (or adjacent to a Bunsen burner flame) and allowed to solidify before inoculation.

Isolation of the Pathogen

Small tissue segments (approximately 5 × 5 mm) were excised from the advancing margins between healthy and diseased portions of infected fruits using sterile scalpels. The tissue pieces were surface sterilized as described previously and aseptically transferred onto SDA plates amended with chloramphenicol. The inoculated plates were incubated at 25 ± 2°C for 5–7 days. Emerging fungal colonies were observed daily for growth characteristics.

Purification of Fungal Isolates

Distinct fungal colonies developing from infected tissues were purified using the hyphal-tip technique. Small portions of actively growing mycelia were aseptically transferred onto fresh SDA plates supplemented with chloramphenicol. Each isolate was subcultured twice to obtain pure cultures. Pure cultures were incubated at 25 ± 2°C for 5–7 days and maintained on SDA slants for subsequent experiments.

Preparation of Fungicide-Amended Media

The poisoned food technique was adopted to evaluate the sensitivity of the fungal isolate to different fungicides. Sterile molten SDA cooled to approximately 45–50°C was amended separately with predetermined concentrations of each fungicide and mixed thoroughly before dispensing into sterile Petri dishes. The fungicide concentrations evaluated were:

Tandem®

- 0 g L⁻¹ (Control)
- 5.00 g L⁻¹
- 6.00 g L⁻¹
- 7.33 g L⁻¹
- 8.67 g L⁻¹

Ridomil Gold®

- 0 g L⁻¹ (Control)
- 5.00 g L⁻¹
- 6.00 g L⁻¹
- 7.33 g L⁻¹
- 8.67 g L⁻¹

Z-Force®

- 0 g L⁻¹ (Control)
- 1.27 g L⁻¹
- 2.53 g L⁻¹
- 3.73 g L⁻¹

- 5.00 g L⁻¹

Each treatment was prepared in triplicate.

Note: Fungicides were incorporated into sterilized molten agar after autoclaving and cooling to approximately 45–50°C to avoid thermal degradation of active ingredients.

Preparation of Conidial Suspension

Conidial suspension was prepared from 14-day-old pure cultures grown on SDA. Sterile distilled water containing 0.05% Tween-20 was added to each culture plate, and the colony surface was gently scraped with a sterile glass rod to release conidia. The suspension was filtered through sterile muslin cloth to remove mycelial fragments. Spore concentration was adjusted using a haemocytometer to approximately 1 × 10⁶ conidia mL⁻¹.

Inoculation and Fungicide Sensitivity Test

A 5-mm diameter mycelial disc obtained from the actively growing margin of a seven-day-old fungal colony was placed centrally on each fungicide-amended SDA plate. Each treatment was replicated three times in a Completely Randomized Design (CRD). The inoculated plates were incubated at 25 ± 2°C, and radial mycelial growth was measured daily for nine days along two perpendicular axes drawn beneath each Petri dish. Colony diameter was calculated as the average of the two measurements after subtracting the diameter of the inoculum disc. The percentage inhibition of mycelial growth relative to the untreated control was calculated using the equation:

$$\text{Percentage inhibition} = \frac{C-T}{C} \times 100$$

where:

C = colony diameter in the control

T = colony diameter in fungicide-treated plates

Experimental Design and Statistical Analysis

The experiment was arranged in a Completely Randomized Design (CRD) with three fungicides evaluated at different concentrations. Each treatment consisted of three independent replicates. Data on colony diameter and percentage mycelial growth inhibition were subjected to Analysis of Variance (ANOVA) using an appropriate statistical software package (e.g., SPSS, R, or SAS). Treatment means were separated using Duncan's Multiple Range Test (DMRT) at the 5% probability level ($P \leq 0.05$).

RESULTS

A. Macromorphological Characteristics of the Fungal Isolate Associated with Hard Rot of *Annona muricata*

The fungal pathogen isolated from diseased *Annona muricata* fruits exhibited rapid growth on Sabouraud Dextrose Agar (SDA), with visible colony development within 48 hours of incubation (Plate 1a). The colonies initially appeared white to greyish-white with abundant aerial mycelia and a cottony texture. As incubation progressed to four days, the colonies became denser with dark grey to olive pigmentation at the centre, while the

reverse side of the culture developed a darker coloration (Plate 1b). These macromorphological characteristics were consistent with those commonly reported for *Colletotrichum gloeosporioides*.



Plate 1a: Macromorphology of Pathogen Isolated from Sour sop Hard Rot on Sabouraud Dextrose Agar



Plate 1b. show the macromorphology of pathogen isolated from sour sop on Sabouraud Dextrose Agar

B. Effect of Selected Fungicides on the Growth of *Colletotrichum gloeosporioides*

1) Effect of Ridomil Gold® on Mycelial Growth

Ridomil Gold® markedly inhibited the radial growth of *C. gloeosporioides* in a concentration-dependent manner (Figure 1). The untreated control recorded the highest growth rate of 14.11 mm day⁻¹, indicating unrestricted fungal growth in the absence of fungicide. Application of Ridomil Gold® at 5 g L⁻¹ reduced the growth rate to 1.95

mm day⁻¹, while further reduction to 1.38 mm day⁻¹ was observed at 6 g L⁻¹. Complete inhibition of mycelial growth (0 mm day⁻¹) was achieved at 7 g L⁻¹ and 9 g L⁻¹, indicating total suppression of fungal development.

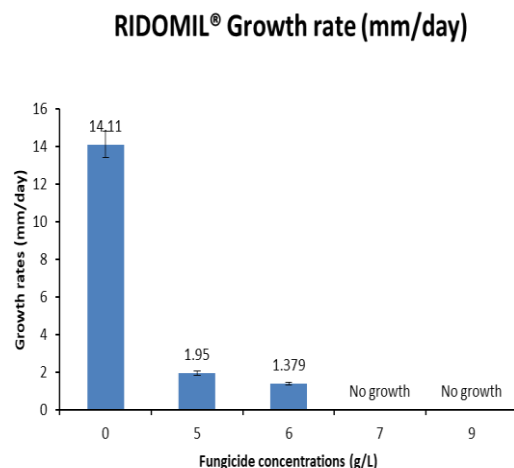


Figure 1: Growth Rate of *Colletotrichum gloeosporioides* associated with Ridomil Fungicide

2) Effect of Z-Force® on Mycelial Growth

The inhibitory effect of Z-Force® increased with fungicide concentration (Figure 2). The untreated control supported unrestricted fungal growth with a growth rate of 14.11 mm day⁻¹. At 1 g L⁻¹, fungal growth was reduced to 6.55 mm day⁻¹, while growth remained evident at 3 g L⁻¹ and 4 g L⁻¹ with recorded growth rates of 7.56 mm day⁻¹ and 3.93 mm day⁻¹, respectively. Complete inhibition of fungal growth occurred only at the highest concentration of 5 g L⁻¹, where no visible mycelial development was observed throughout the incubation period.

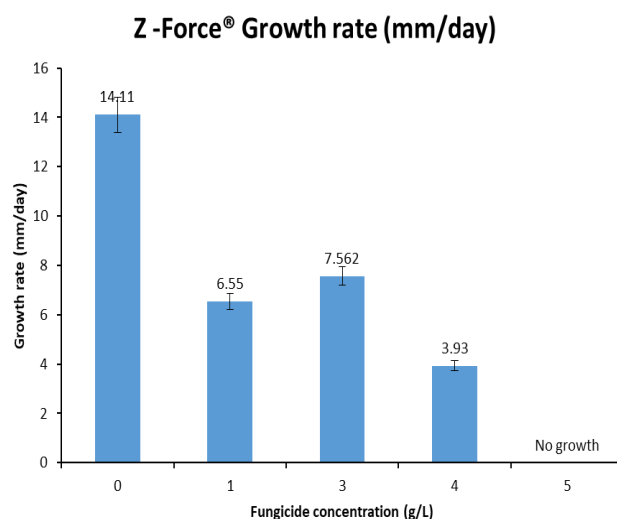


Figure 2: Growth Rate of *Colletotrichum gloeosporioides* associated with Z -Force Fungicide

3. Effect of Tandem® on Mycelial Growth

Tandem® also reduced the growth of *C. gloeosporioides*, although complete inhibition was not achieved at any of the concentrations evaluated (Figure 3). Compared with the untreated control (14.11 mm day⁻¹), the growth rate declined to 6.13 mm day⁻¹ at 5 g L⁻¹ and further decreased to 2.25 mm day⁻¹ at 6 g L⁻¹. Similar growth rates of approximately 2.29 mm day⁻¹ were observed at 7 g L⁻¹ and 9 g L⁻¹, indicating that increasing the concentration beyond 6 g L⁻¹ produced little additional suppression of fungal growth.

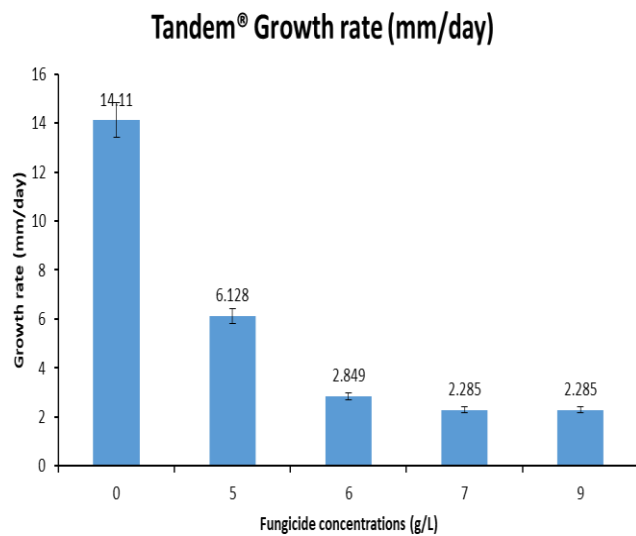


Fig. 3: Percentage Inhibition of *Colletotrichum gloeosporioides*

The percentage inhibition of *C. gloeosporioides* by the three fungicides is presented in Table 1. Ridomil Gold® exhibited the highest inhibitory activity among the fungicides tested. Percentage inhibition increased from 86.2% at 5 g L⁻¹ to 90.2% at 6 g L⁻¹, while complete inhibition (100%) was obtained at both 7 g L⁻¹ and 9 g L⁻¹. Z-Force® produced moderate inhibition at the lower concentrations evaluated. Percentage inhibition ranged from 53.6% at 1 g L⁻¹ to 72.2% at 4 g L⁻¹, while complete inhibition (100%) was achieved at 5 g L⁻¹. Tandem also inhibited fungal growth but was comparatively less effective than Ridomil Gold®. Inhibition increased from 56.6% at 5 g L⁻¹ to 79.8% at 6 g L⁻¹, reaching 83.8% at both 7 g L⁻¹ and 9 g L⁻¹. Unlike Ridomil Gold® and Z-Force®, Tandem® did not completely suppress fungal growth within the concentration range investigated. Overall, the fungicides ranked in order of efficacy as: **Ridomil Gold® > Z-Force® > Tandem** based on their ability to inhibit radial mycelial growth of *C. gloeosporioides*.

Table 1: Percentage Inhibition of *Colletotrichum gloeosponodes* Treated with Different Fungicides

Ridomil Gold® (Metalaxyl-M and 640g/kg mancozeb)		Z-Force ® (Mancozeb80% WP)		Tandem ® (Copper- oxide60%+metala xyl12%WP)	
Concentr ation (g/l)	Perce ntage inhibit ion (%)	Concent ration (g/l)	Perce ntage inhibit ion (%)	Concent ration (g/l)	Perce ntage inhibit ion (%)
5	86.2	1	53.6	5	56.6
6	90.2	3	46.4	6	79.8
7	100.0	4	72.2	7	83.8
9	100.0	5	100.0	9	83.8

DISCUSSION

The present study demonstrated that the growth of *Colletotrichum gloeosporioides*, isolated from diseased *Annona muricata* fruits, was effectively suppressed by the three commercial fungicides evaluated, although the magnitude of inhibition varied among the fungicides and concentrations tested. The poisoned food technique employed in this study clearly showed that increasing fungicide concentration generally reduced mycelial growth, indicating a concentration-dependent antifungal response. This observation is consistent with the fundamental principle that fungicides inhibit fungal metabolism by disrupting essential physiological and biochemical processes required for mycelial growth and sporulation (Brent & Hollomon, 2007; FRAC, 2024).

The rapid radial growth observed in the untreated control confirms the aggressive nature of *C. gloeosporioides* under favourable laboratory conditions. The pathogen colonized Sabouraud Dextrose Agar rapidly, producing extensive mycelial development within a few days of incubation. Such vigorous growth is characteristic of *Colletotrichum* species, which are recognized among the most destructive fungal pathogens affecting tropical and subtropical fruit crops worldwide (Dean et al., 2012). Their ability to establish latent infections and rapidly colonize fruit tissues after harvest contributes significantly to postharvest deterioration and economic losses (Damm et al., 2012; Cannon et al., 2012). The unrestricted growth observed in the control treatment therefore confirms the pathogenic potential of the isolate and demonstrates that the observed reductions in colony growth resulted from fungicide activity rather than environmental limitations. Among the fungicides evaluated, Ridomil Gold® exhibited the highest inhibitory activity against *C. gloeosporioides*. Complete suppression of mycelial growth at 7 and 9 g L⁻¹ indicates that the formulation possesses strong fungitoxic properties against the pathogen under in vitro conditions. The superior performance of Ridomil Gold® may be attributed to the complementary action of its active ingredients, metalaxyl-M and mancozeb. Metalaxyl-M is a systemic phenylamide fungicide that inhibits ribosomal RNA synthesis by interfering with nucleic acid metabolism

in susceptible fungi, while mancozeb acts as a multisite protectant that disrupts sulfhydryl-containing enzymes involved in fungal respiration and metabolism (Gisi & Sierotzki, 2015; FRAC, 2024). The combination of systemic and contact modes of action broadens the spectrum of antifungal activity and reduces the likelihood of pathogen survival compared with single-site fungicides.

The concentration-dependent inhibition observed with Ridomil Gold® agrees with previous reports demonstrating that increasing fungicide concentration generally enhances suppression of fungal growth until complete inhibition is achieved (Grover & Moore, 1962; Brent & Hollomon, 2007). Similar observations have been reported for *Colletotrichum* species associated with mango, avocado, papaya, citrus, and guava fruits, where metalaxyl-containing formulations substantially reduced colony growth and disease severity under laboratory and greenhouse conditions (Arauz, 2000; Ploetz, 2015). Although metalaxyl is primarily recognized for its activity against oomycetes, its combination with mancozeb in Ridomil Gold® enhances the formulation's protective effect against a broader range of fungal pathogens, which may explain the excellent performance observed in this study.

Z-Force®, whose active ingredient is mancozeb, also inhibited the growth of *C. gloeosporioides*, although complete inhibition occurred only at the highest concentration evaluated. Mancozeb is a multisite contact fungicide that reacts with sulfhydryl groups in fungal enzymes, thereby disrupting several metabolic pathways simultaneously (Gullino et al., 2010). Because its activity is restricted primarily to the surface of fungal structures, higher concentrations are often required to achieve fungicidal effects comparable to those of formulations containing systemic components. The gradual reduction in fungal growth with increasing concentrations of Z-Force® observed in this study therefore reflects the dose-dependent activity of mancozeb and agrees with previous studies demonstrating its effectiveness against *Colletotrichum* species causing anthracnose and fruit rot diseases (Sharma et al., 2018; Palou et al., 2016).

Tandem®, containing copper (I) oxide and metalaxyl, also reduced the growth of the fungal isolate but failed to achieve complete inhibition within the concentration range investigated. Although percentage inhibition increased with increasing fungicide concentration, residual fungal growth remained evident even at the highest concentrations tested. Copper-based fungicides primarily act by denaturing proteins and disrupting membrane integrity through the release of copper ions (Lamichhane et al., 2018). However, their effectiveness is influenced by factors such as pH, solubility, formulation, and the inherent sensitivity of the target pathogen. The inability of Tandem® to completely suppress mycelial growth may therefore reflect lower bioavailability of the active ingredients within the agar medium or a reduced sensitivity of the isolate to the copper component. Similar variability in the efficacy of copper-based fungicides against *Colletotrichum* species has been documented in several studies, particularly where isolates

exhibit differing levels of tolerance (Peres et al., 2004; FRAC, 2024).

The differences observed among the three fungicides emphasize the importance of fungicide composition and mode of action in determining antifungal efficacy. Fungicides possessing multiple complementary mechanisms of action generally provide broader and more effective disease control than formulations relying predominantly on a single mode of action (Brent & Hollomon, 2007). The superior performance of Ridomil Gold® compared with Z-Force® and Tandem® in this study supports previous recommendations that fungicides combining systemic and protectant ingredients often provide enhanced suppression of fungal pathogens under laboratory conditions (Gisi & Sierotzki, 2015).

The concentration-dependent response observed across all treatments highlights the importance of selecting appropriate application rates during disease management. Suboptimal fungicide concentrations may suppress fungal growth temporarily without completely eliminating the pathogen, thereby increasing the likelihood of survival and the subsequent development of fungicide-resistant populations (Lucas et al., 2015). Conversely, excessive fungicide applications may increase production costs, leave undesirable residues on harvested fruits, and pose environmental risks. Therefore, determining effective minimum inhibitory concentrations through laboratory evaluations, as undertaken in the present study, represents an important step in developing sustainable disease management programmes.

The present findings also reinforce the usefulness of the poisoned food technique as a rapid laboratory method for screening fungicide efficacy. This technique allows direct measurement of fungal radial growth in fungicide-amended media and has been widely adopted for evaluating the sensitivity of plant pathogenic fungi to fungicides (Grover & Moore, 1962). Although in vitro assays cannot fully replicate the complex interactions occurring under field or storage conditions, they provide valuable preliminary information regarding fungicide performance before greenhouse or field validation. Environmental factors such as temperature, relative humidity, fruit maturity, inoculum density, and host physiological status may influence fungicide efficacy under natural conditions and should therefore be considered when translating laboratory findings into practical disease management recommendations (Ploetz, 2015; Romanazzi et al., 2016).

From a practical standpoint, the results indicate that Ridomil Gold® has considerable potential for managing hard rot-associated *Colletotrichum* infections in soursop fruits. However, reliance on a single fungicide should be avoided because repeated use of the same active ingredient can accelerate the selection of resistant fungal populations (FRAC, 2024). Integrated disease management strategies that combine fungicide rotation, orchard sanitation, timely harvesting, proper postharvest handling, and storage under appropriate environmental conditions remain essential for sustainable disease control (Palou et al., 2016; Romanazzi et al., 2016).

One limitation of the present study is that fungicide efficacy was evaluated only under laboratory conditions against radial mycelial growth. Other important aspects of pathogen biology, including spore germination, sporulation, infection efficiency, and disease development on intact fruits, were not investigated. In addition, molecular characterization of the fungal isolate was not undertaken. Future studies should therefore incorporate molecular identification techniques, evaluate fungicide performance under greenhouse and field conditions, assess residue persistence on fruits, and investigate the potential integration of chemical control with biological control agents and botanical fungicides to reduce dependence on synthetic pesticides.

This study demonstrates that commercial fungicides differ considerably in their ability to inhibit *C. gloeosporioides* associated with hard rot of *Annona muricata*. Ridomil Gold® provided the highest level of inhibition, followed by Z-Force®, while Tandem® exhibited comparatively lower fungitoxic activity under the conditions of this study. These findings provide useful baseline information for developing integrated management strategies aimed at reducing postharvest losses of soursop fruits in Nigeria and other tropical production regions.

CONCLUSION

This study demonstrated that the growth of *Colletotrichum gloeosporioides* associated with hard rot of *Annona muricata* was effectively inhibited by the commercial fungicides evaluated, with efficacy varying according to fungicide formulation and concentration. Among the fungicides tested, Ridomil Gold® exhibited the greatest antifungal activity, achieving complete inhibition of mycelial growth at 7 and 9 g L⁻¹, while Z-Force® achieved complete inhibition at 5 g L⁻¹. Tandem® also suppressed fungal growth considerably but did not completely inhibit the pathogen within the concentration range evaluated. These findings indicate that Ridomil Gold® is the most effective of the three fungicides tested for the in vitro management of *C. gloeosporioides* associated with soursop hard rot.

The study provides valuable baseline information for the chemical management of soursop hard rot and highlights the importance of selecting appropriate fungicides and application rates for effective disease control. However, since the evaluation was conducted under laboratory conditions, further studies are recommended to validate the efficacy of these fungicides under greenhouse and field conditions, assess their effects on disease severity and fruit quality, and integrate their use with other sustainable disease management practices to reduce postharvest losses and minimize the risk of fungicide resistance.

Conflict of Interest

There are no conflicts of interest declared by the authors.

REFERENCES

- Akinmoladun, A. C., Ibukun, E. O., Dan-Ologe, I. A., & Afor, E. (2019). Phytochemical constituents and antioxidant activity of *Annona muricata*. *Journal of Medicinal Plants Research*, 13(8), 169–178.
- Arauz, L. F. (2000). Mango anthracnose: Economic impact and current options for integrated management. *Plant Disease*, 84(6), 600–611.
- Brent, K. J., & Hollomon, D. W. (2007). *Fungicide resistance: The assessment of risk*. Fungicide Resistance Action Committee.
- Brent, K. J., & Hollomon, D. W. (2007). *Fungicide resistance: The assessment of risk*. Fungicide Resistance Action Committee.
- Cannon, P. F., Damm, U., Johnston, P. R., & Weir, B. S. (2012). *Colletotrichum*: Current status and future directions. *Studies in Mycology*, 73, 181–213.
- Coria-Téllez, A. V., Montalvo-Gonzalez, E., Yahia, E. M., & Obledo-Vázquez, E. N. (2018). *Annona muricata*: A comprehensive review on its traditional medicinal uses, phytochemistry, pharmacological activities, mechanisms of action and toxicity. *Arabian Journal of Chemistry*, 11(5), 662–691.
- Damm, U., Cannon, P. F., Woudenberg, J. H. C., & Crous, P. W. (2012). The *Colletotrichum acutatum* species complex. *Studies in Mycology*, 73, 37–113.
- Damm, U., Cannon, P. F., Woudenberg, J. H. C., & Crous, P. W. (2012). The *Colletotrichum acutatum* species complex. *Studies in Mycology*, 73, 37–113.
- Dean, R., Van Kan, J. A. L., Pretorius, Z. A., Hammond-Kosack, K. E., Di Pietro, A., Spanu, P. D., et al. (2012). The Top 10 fungal pathogens in molecular plant pathology. *Molecular Plant Pathology*, 13(4), 414–430.
- Dean, R., Van Kan, J. A. L., Pretorius, Z. A., Hammond-Kosack, K. E., Di Pietro, A., Spanu, P. D., et al. (2012). The Top 10 fungal pathogens in molecular plant pathology. *Molecular Plant Pathology*, 13(4), 414–430.
- Food and Agriculture Organization. (2022). *The State of Food and Agriculture 2022*. FAO.
- FRAC. (2024). *FRAC Code List 2024: Fungicides sorted by mode of action*. Fungicide Resistance Action Committee.
- Fungicide Resistance Action Committee. (2024). *FRAC Code List 2024: Fungicides sorted by mode of action*. FRAC.
- George, V. C., Kumar, D. R. N., Suresh, P. K., & Kumar, R. A. (2020). Antioxidant, DNA protective efficacy and HPLC analysis of *Annona muricata* leaf extracts. *Journal of Food Science and Technology*, 57, 1460–1469.
- Gisi, U., & Sierotzki, H. (2015). Fungicide modes of action and resistance in downy mildews. *European Journal of Plant Pathology*, 122, 157–167.
- Gisi, U., & Sierotzki, H. (2015). Fungicide modes of action and resistance in downy mildews. *European Journal of Plant Pathology*, 122, 157–167.
- Grover, R. K., & Moore, J. D. (1962). Toxicometric studies of fungicides against the brown rot organism, *Sclerotinia fructicola*. *Phytopathology*, 52, 876–880.

- Grover, R. K., & Moore, J. D. (1962). Toxicometric studies of fungicides against the brown rot organism. *Phytopathology*, 52, 876–880.
- Gullino, M. L., Leroux, P., & Smith, C. M. (2010). Uses and challenges of novel compounds for plant disease control. *Crop Protection*, 29(11), 1188–1195.
- Hyde, K. D., Nilsson, R. H., Alias, S. A., Ariyawansa, H. A., Blair, J. E., Cai, L., et al. (2014). One stop shop: Backbone trees for important phytopathogenic genera. *Fungal Diversity*, 67, 21–125.
- Islam, K.K., Wadud, M.D. and Rahman, G.M.M. 2022. Land and forest cover of Bangladesh. Available at: www.jagroforenviron.com (accessed on 19 May 2021).
- Kubicek, C. P., Starr, T. L., & Glass, N. L. (2014). Plant cell wall-degrading enzymes and fungal pathogenesis. *Annual Review of Phytopathology*, 52, 427–451.
- Lamichhane, J. R., Osdaghi, E., Behlau, F., Köhl, J., Jones, J. B., & Aubertot, J. N. (2018). Thirteen decades of copper-based crop protection products. *Agronomy for Sustainable Development*, 38, 28.
- Lucas, J. A., Hawkins, N. J., & Fraaije, B. A. (2015). The evolution of fungicide resistance. *Advances in Applied Microbiology*, 90, 29–92.
- Moghadamtousi, S. Z., Fadaeinasab, M., Nikzad, S., Mohan, G., Ali, H. M., & Kadir, H. A. (2015). *Annona muricata* (Annonaceae): A review of its traditional uses, phytochemistry and pharmacological activities. *Journal of Ethnopharmacology*, 169, 208–230.
- Palou, L., Ali, A., Fallik, E., & Romanazzi, G. (2016). GRAS, plant- and animal-derived compounds as alternatives to conventional fungicides for the control of postharvest diseases of fresh horticultural produce. *Postharvest Biology and Technology*, 122, 41–52.
- Palou, L., Ali, A., Fallik, E., & Romanazzi, G. (2016). GRAS, plant- and animal-derived compounds as alternatives to conventional fungicides for postharvest disease management. *Postharvest Biology and Technology*, 122, 41–52.
- Peres, N. A. R., Timmer, L. W., Adaskaveg, J. E., & Correll, J. C. (2004). Lifestyles of *Colletotrichum* species and implications for plant biosecurity. *Molecular Plant Pathology*, 6, 435–446.
- Ploetz, R. C. (2015). Management of postharvest diseases of tropical fruits. *Plant Disease*, 99(11), 1503–1513.
- Ploetz, R. C. (2015). Management of postharvest diseases of tropical fruits. *Plant Disease*, 99(11), 1503–1513.
- Romanazzi, G., Smilanick, J. L., Feliziani, E., & Droby, S. (2016). Integrated management of postharvest gray mold on fruit crops. *Postharvest Biology and Technology*, 113, 69–76.
- Romanazzi, G., Smilanick, J. L., Feliziani, E., & Droby, S. (2016). Integrated management of postharvest diseases of fruit crops. *Postharvest Biology and Technology*, 113, 69–76.
- Russell, P. E. (2004). *Sensitivity baselines in fungicide resistance research and management*. Fungicide Resistance Action Committee.
- Sharma, G., Shenoy, B. D., & Hyde, K. D. (2018). Species diversity, biology and management of *Colletotrichum* diseases. *Journal of Fungi*, 4(2), 49.
- Sharma, R. R., Singh, D., & Singh, R. (2009). Biological control of postharvest diseases of fruits and vegetables by microbial antagonists. *Biological Control*, 50(3), 205–221.
- Zhang, H., Mahunu, G. K., Castoria, R., Yang, Q., Apaliya, M. T., & Zhang, X. (2021). Recent developments in the management of postharvest fungal diseases of fruit. *Critical Reviews in Food Science and Nutrition*, 61(12), 2026–2045.

