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Effect of Silver Nanoparticles on In Vitro Shoot Regeneration of Banana

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ABSTRACT

Banana is propagated almost entirely by vegetative means, and shoot-tip culture on cytokinin-supplemented medium is the standard route to clean, uniform planting material. Two recurring problems of that route, microbial contamination and the loss of vigour that follows stress in the culture vessel, have made silver nanoparticles an attractive additive, since silver is antimicrobial and silver ions interfere with ethylene action. This narrative review asks what the published literature allows us to say about the effect of silver nanoparticles on in vitro shoot regeneration of banana. It draws on work on banana tissue culture, on the antimicrobial and plant biology of silver nanoparticles, and on oxidative stress and hormesis, and it reports no new data. Reports from other species describe both benefit and harm, with the outcome depending on dose, particle size, coating and the way the particles are delivered, and a pattern in which low exposure helps and higher exposure harms is plausible but not established for banana. Few of the studies we could draw on test banana directly, most describe particles poorly, and silver ions released from the particles are seldom separated from the particles themselves. The review concludes that a modest, narrow-window benefit is a reasonable hypothesis, sets out the controls a convincing banana experiment would need, and flags the questions of genetic stability and environmental release that any routine use would have to answer.

Keywords: Banana; Musa; Silver nanoparticles; Shoot regeneration; Micropropagation; Hormesis; Narrative review

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Article Class: Narrative Review

1. Introduction

Bananas are grown from suckers and cuttings, not from seed, because the cultivated types are largely sterile and seedless (1, 2). That makes clean planting

material a matter of some importance. Pathogens such as the *Fusarium* wilt fungus travel in infected rhizomes and soil, and the disease is a serious threat to production (3, 4). Plantlets raised in the laboratory from shoot tips offer a way to



start fields with healthy, uniform stock, and the method has been used on a commercial scale since the 1980s (5).

The laboratory route has its own difficulties. Cultures rich in sugar attract bacteria and fungi, and a vessel that looks clean at transfer can show growth a week later. Stressed shoots brown, stall or turn glassy, and repeated multiplication can bring variation of its own (6, 7). Silver nanoparticles have been proposed as an additive because silver is a long-known antimicrobial and because silver ions interfere with the action of ethylene (8, 9).

Whether silver nanoparticles actually improve shoot regeneration in banana is less obvious than the enthusiasm suggests. A particle that kills bacteria may also stress plant cells, and a dose that helps one species may harm another (10, 11). This review sets out what is known about banana shoot culture, what silver nanoparticles do in plant tissue and in microbes, how the two might meet in the culture vessel, and how much weight the published evidence can carry. It reports no new data and no local experiment; every statement rests on published work. The aim is a fair account of what is known and what is merely repeated.

2. Literature Review

2.1 Banana and Its Shoot Culture

Cultivated bananas descend mainly from wild *Musa acuminata*, sometimes with contributions from *Musa balbisiana*, and most edible forms are triploid (1, 2), which makes breeding slow and difficult (12). Shoot-tip culture was adapted to banana in the early 1980s, and the protocols that followed, built on a long history of plant tissue culture (13), allowed one plant to give rise to very large numbers of rooted plantlets in a year (5).

The standard protocol uses a mineral-salt medium of the Murashige and Skoog type

(14) with a cytokinin, usually benzyladenine, to push axillary buds into growth, followed by a transfer to lower cytokinin and an auxin for rooting (15). Higher cytokinin gives more shoots, but intensive multiplication may increase the risk of off-types (16, 17). Small differences in hormone balance look minor in a single vessel, but they add up across many subcultures.

Contamination deserves separate mention. Explants come from field-grown plants carrying surface microbes and, often, microbes inside the tissue that sterilisation does not reach; these may stay silent for several subcultures and then appear when the culture is stressed (7). Table 1 gathers the main difficulties and the place silver might occupy among them.

Table 1. Problems met in banana shoot-tip culture and where silver might act.

Problem	Usual response	Possible role of silver
Microbial contamination	Surface sterilisation, antibiotics, culture indexing (7)	Antimicrobial additive (8, 18)
Ethylene build-up	Vented closures, careful vessel handling	Silver ions block ethylene action (9, 19)
Phenolic browning and stress	Transfers, antioxidants	Unclear; may add oxidative stress (20)
Hyperhydricity and disorders	Adjust medium and humidity (6)	Not established
Somaclonal variation	Limit cycles, use true-to-type checks (16, 17)	Unknown; rarely examined

Note: Qualitative summary of the cited literature; the right-hand column states a hypothesis, not a demonstrated effect in banana.

2.2 Silver Nanoparticles as Antimicrobials

Silver nanoparticles have been studied intensively as antimicrobial agents. Reviews describe activity against many



bacteria and fungi through several proposed mechanisms, including damage to the cell envelope and release of silver ions (8, 21). Work on *Escherichia coli* showed that the particles accumulate in the membrane (22, 23).

It is not settled how much of this activity belongs to the particle and how much to dissolved silver. One study that kept the two apart concluded that the antibacterial action seen could be explained by released ions, with little particle-specific activity (24). An experiment lacking an ion control cannot tell which one is working. A benefit that vanishes when the right control is added was never a benefit of the treatment. Table 2 lists the properties that most often change the outcome, with what a report should state about each.

2.3 Silver, Ethylene and Plant Tissue

Silver ions block the action of ethylene, a gas that builds up in sealed vessels and can slow growth and promote senescence (9, 19). If nanoparticles release enough ions at the right place, they might do the same job while also controlling microbes.

Table 2. Properties of silver nanoparticles that change a biological outcome.

Property	Why it matters	Reporting need
Size and shape	Alters surface area and ion release (25)	Measured diameter, method
Coating	Changes stability and uptake (26, 27)	Name the capping agent
Dissolved silver	Ions explain some effects, not all (24, 28)	Ion-only control
Aggregation in medium	Alters effective dose	Characterise in the medium
Synthesis route	Plant extracts add their own compounds (29, 30)	Test the extract alone

Note: Drawn from the cited reviews and experimental papers; direction of effect depends on species and conditions.

That reasoning is attractive but unproven for banana. Silver ions are not benign in plant cells, and the dose that blocks ethylene may sit close to the dose that harms. Silver nanoparticles and silver ions change the expression of many genes in *Arabidopsis*, with overlapping but not identical patterns (31), and particle size and shape affect growth (25).

2.4 Effects on Plants Beyond Banana

Studies of silver nanoparticles in plants reach mixed conclusions. Some report stimulation, for example of seedling growth in rice, accompanied by changes in antioxidant enzymes and gene expression (32), and of growth and metabolism in a medicinal herb (30). Others report inhibition, root damage and reduced biomass, as in ryegrass, where the effect could not be explained by the ions alone (28), and in *Arabidopsis*, where particles were taken up and moved within the plant (33). This is why the same additive can look excellent in one report and unremarkable in the next.

The closest published parallel to the present question comes from vanilla, in which silver nanoparticles used in a temporary immersion system were reported to have antimicrobial effects alongside a hormetic effect on regeneration (34). In a related study of valerian, nano silver was proposed as a way to remove bacterial contaminants from cultures (18). These reports are encouraging, but they concern other species. The point is not that a study is poor, only that its result travels less far than its abstract suggests.

2.5 Stress, Oxidative Damage and Hormesis

Hormesis offers a framework for why a low dose of a harmful agent can look beneficial: a biphasic dose response in which low exposure stimulates and high exposure inhibits, reviewed widely as a



general feature of biology (35, 36). Figure 1 shows where silver might enter the culture cycle, and Figure 2 sketches the pattern that hormesis predicts. Both are conceptual.

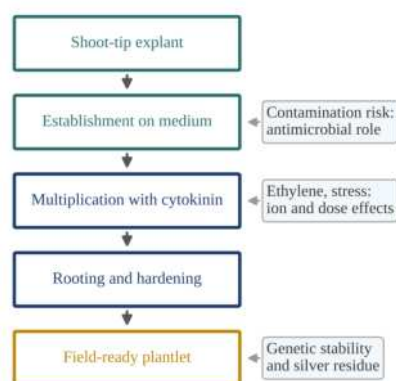


Figure 1. Where silver nanoparticles may enter the shoot-culture cycle (schematic, not data).

3. Materials and Methods

3.1 Scope and Question

The review asks one question in two parts: is there a plausible case that silver nanoparticles improve in vitro shoot regeneration of banana, and what would a convincing test of that case look like? The question was divided into sub-questions about contamination, ethylene, plant stress and genetic stability, and for each we described the trial that would answer it. No new experiment is reported.

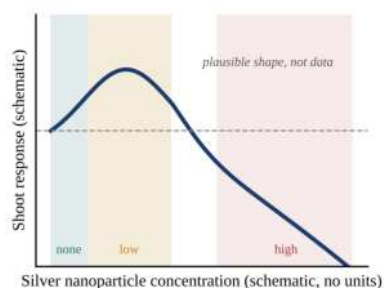


Figure 2. Expected shape of the response to silver dose, a hormetic pattern (schematic of a plausible pattern, not data).

3.2 Literature Assembly

The review draws on peer-reviewed work in four areas: banana biology and

micropropagation; the antimicrobial and toxicological behaviour of silver nanoparticles; silver and ethylene in plant tissue; and oxidative stress and hormesis. Banana studies were sought first; where none existed, work on other plants and on bacteria was used and is labelled as such. We did not run a formal systematic search and we do not claim one; the synthesis is narrative and reflects the authors' judgement, so it guides experimental design better than it sizes any effect. Reviews of this kind are more useful when they say where the evidence stops than when they smooth it over.

3.3 Appraisal Framework

To judge how far a report can be trusted, we worked through four checks. Were the particles characterised in the medium used? Were particles separated from ions, and any extract controlled? Were several doses used, so that a rise and fall could be seen (35)? Was the outcome followed beyond the first culture? Studies meeting most of these checks were given more weight; those meeting few were used only to frame hypotheses. Table 3 summarises the features a banana experiment should have in light of these checks. None of these checks is difficult, but each one is easy to skip.

4. Results

4.1 What the Evidence Covers

The most striking result of the survey is a gap. Silver nanoparticles are well studied as antimicrobials and increasingly studied in plants, but work on banana tissue culture specifically is sparse in the material available to us, and almost none of it addresses genetic stability. Figure 3 gives a qualitative picture of where the cited literature is concentrated. It is a map of coverage, not a count. A laboratory reading a paper on this subject needs the answer to a simple question: would this



work with my cultivar and my medium?

Table 3. Design features a banana silver-nanoparticle experiment should have.

Feature	Reason	Minimum standard
Concentration series	Hormetic pattern needs several doses (35, 36)	Zero plus at least four levels
Ion control	Separates particle from ion effect (31)	Silver nitrate at matched silver
Cultivar stated	Genotypes differ (1, 12)	Name group and cultivar
Unit of replication	Vessels share a shelf and a batch	Replicate at vessel level
Full subculture follow-up	Early gain may fade or carry a cost	Several passages
Plant-level checks	Vigour, rooting, true-to-type (16)	Report all, not only shoots

Note: Recommendations follow from the weaknesses discussed in the text and are not attributed to any single study.

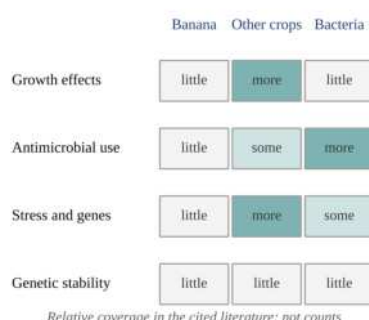


Figure 3. Qualitative matrix of what the cited literature covers (schematic, not data).

4.2 Plausible Routes to Better Regeneration

Three routes from silver to better shoots are plausible. The first is the control of microbes. If contamination is a major cause of lost cultures, an antimicrobial additive could raise the number of usable explants without any direct action on regeneration (8, 18). The second is the blocking of ethylene by released silver ions, which might relieve growth inhibition in sealed vessels (9, 19). The third is hormesis, in which a very low level

of stress stimulates growth (34, 35).

Each route predicts something different. A microbial effect should show up as fewer lost cultures but little change among clean ones; an ethylene effect should be matched by silver nitrate at an equivalent silver content; a hormetic effect should show a rise and fall across doses. An experiment reporting only the mean shoot number at one concentration cannot separate these routes, and so cannot say why a treatment worked. Read this way, absence of an effect in a small experiment is not evidence of absence.

4.3 Plausible Routes to Harm

Silver ions and particles generate oxidative stress in other plants (28, 31), and cells already close to their limit in culture may be pushed over it (37, 38). Genetic stability is the larger unknown. Variation arising in culture has been recognised for decades (17), and high cytokinin does not by itself appear to produce changes detectable with molecular markers in banana (16); whether an added metal stressor would alter that picture has not, to our knowledge, been tested. Silver residues also call for caution, since silver nanoparticles are toxic to some aquatic organisms (39, 40), and uptake into edible plants raises questions about transfer along the food chain (41).

5. Discussion

5.1 Interpretation

The main finding of this review is a conditional one. Silver nanoparticles may help banana shoot culture mostly by controlling microbes and perhaps by modulating ethylene, and a small hormetic benefit is conceivable, but all are hypotheses borrowed from other systems. The same exposure that helps at a low level can harm at a higher one, and the window between the two may be narrow and cultivar-specific (10, 35). That is a modest claim, and it is the one the



evidence will currently bear.

5.2 Limitations

This review has the limits of its type. We did not search systematically and cannot rule out relevant banana work that we missed. Our appraisal is qualitative, much of the evidence is indirect, and biosafety regulation is outside the scope. Naming such limits openly is a habit worth keeping even when the answer seems obvious.

5.3 Future Work

The priorities follow from the gaps: dose-series experiments in banana with ion and extract controls and particle characterisation in the medium (11, 24); follow-up across several subcultures with checks of plantlet quality and genetic fidelity (7, 16); study of the fate of silver in plantlets and discarded media (40, 42); and comparison with existing approaches to contamination. Tissue that has had time to settle behaves differently from tissue that has not, so follow-up matters more than a first impression.

6. Conclusion

Silver nanoparticles are a plausible additive for banana shoot culture, and the idea has real support from antimicrobial studies and from work in other species. The evidence, as we can responsibly summarise it, does not establish that they improve regeneration in banana, or how large any benefit might be. What the literature does show is which controls are needed to interpret an effect and which risks must be checked before routine use.

For the practitioner the message is practical rather than discouraging. Silver can be tested, provided the particles are characterised, the doses are varied, the controls are in place and the plantlets are followed to the end. For the researcher, the task is careful banana experiments. These points apply with equal force to any new

additive, not only to silver.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

H.A. conceived the review and wrote the sections on banana micropropagation. R.H. wrote the sections on silver nanoparticles and their toxicology. S.H. wrote the sections on plant stress physiology and experimental design. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No human participants or animals were involved and no ethical approval was required.

12. Data Availability

No new data were generated. All sources are cited in the reference list.

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