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Silver nanoparticles synthesized from *Bacillus subtilis* for detection of deterioration in the post-harvest spoilage of fruit☆

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ABSTRACT

Global food shortage is mainly due to the post-harvest spoilage of food, rather than its under-production, especially in the sub-Saharan African countries. Rapid detection tools for the spoilage of fruit such as banana (*Musa acuminata)* would be a great resource in alleviating losses during post-harvest storage. In this study, silver-based colloidal nanoparticle (AgNPs) solution was synthesized using culture supernatant or wet biomass (cell pellets) of *Bacillus subtilis*. The synthesized silver nanoparticles solution was confirmed using UV–Vis Spectrophotometer and further characterized using Scanning Electron Microscope (SEM), X-ray Diffractometer (XRD) and Fourier Transmission Infrared (FT-IR), and then evaluated as a colorimetric sensor for the volatile compound released during the deterioration of *Musa acuminata*. The original reddish brown colour of the silver nanoparticle solution changed to light brown by the end of the fourth day and finally turned transparent on the tenth day. Simultaneous analysis carried out by UV–Vis spectroscopy corroborates our investigation of AgNPs as a colorimetric sensor displaying selectivity and specificity for 1,2-Benzenedicarboxylic acid, bis (2-methyl propyl) ester which was released during the deterioration of *Musa acuminata*. The use of colorimetric sensor as conducted in this study will help in easy detection for control of crop deterioration.

1. Introduction

According to the UN report, the current world population is expected to reach 10.5 billion by 2050, further adding to global food security concerns. Fruits are the fleshy seed-associated structures of a plant which could be sour or sweet, and usually edible in the raw state, such as bananas, oranges, apples, grapes, lemons, and strawberries (Schlegel and Rolf, 2003). They have been strongly associated with reduced risk for some forms of cancer, heart disease, stroke, and other chronic diseases when incorporated into the daily diet (Wargovich, 2000; Tomas-Barberan and Espin, 2001). *Musa acuminata* commonly known as banana, is an edible berry which is usually produced by diverse kinds of large herbaceous flowering plants in the genus *Musa* (Armstrong and Wayne, 2011). The global production of banana was about 148 million tons in 2016 alone; China and India were at the top of the production list with a combined total of 28% of global production, while the Philippines, Ecuador, Indonesia, and Brazil were other main producers (Food and Agriculture Organization (FAO, UN), 2017). Banana make up a key indispensable food crop for millions of people in developing nations like Nigeria (Food and Agriculture Organization (FAO, UN)). Generally, the production of fresh fruits come with its own complexity; fruits are easily spoilt and usually have active metabolism during the storage stage (Singh and Sharma, 2007). It has been reported that 30% of fruit harvested are rendered unfit for consumption and 20% these of fruits are lost as a result deterioration (Kutzemeier, 2006; Barth et al., 2009; Thiyam and Sharma, 2013), especially during post-harvest stages (Singh and Sharma, 2007).

Diverse kinds of bactericides and fungicides have been utilized to alleviate the post-harvest spoilage of banana, yet, there is a need to improve the existing methodologies (Schmidt et al., 2000; Barkai-Golan, 2001). Many biological and physiological changes that accompany the initial deterioration needs to be detected; therefore, a sensitive and specific sensor is considerably needed that can address these issues. In this regard, researchers have developed techniques for qualitative detection of volatiles compounds released during spoilage of spices (Li et al., 2011) and has been compared to an alternative approach like the

☆ Comment: Author should carried out TEM and DLS analysis of the samples. Rebuttals: Morphology of the silver was revealed with micrograph provided using SEM. This study was not based on optimization of the synthesis procedure vis-à-vis morphology rather application of AgNP as colorimetric sensor.

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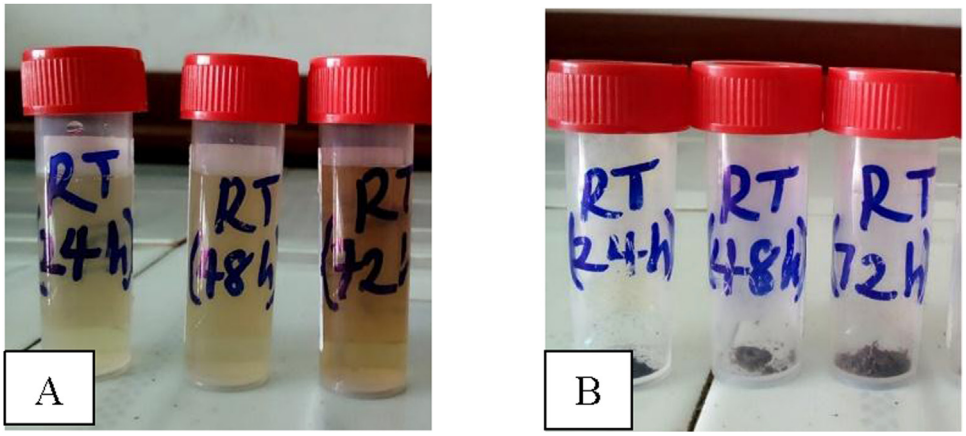

Fig. 1. Vials showing the synthesized silver nanoparticles solution (A) and the dried silver nanoparticles (B).

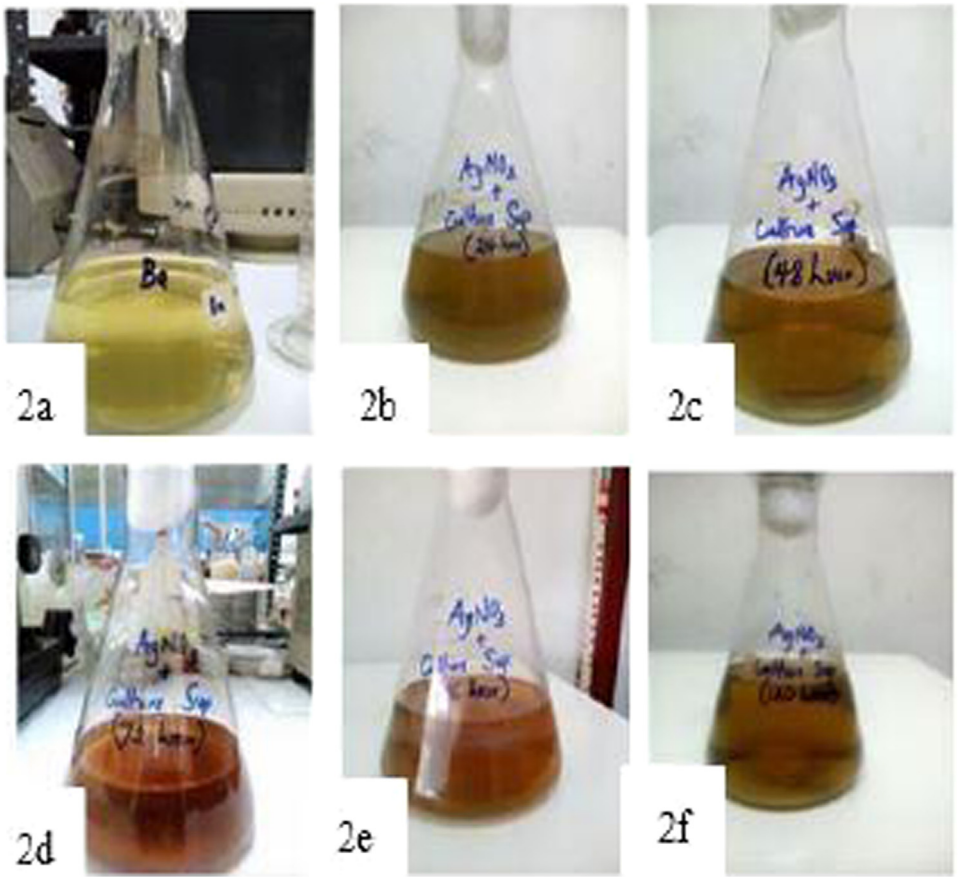

Fig. 2. Culture supernatant of *Bacillus subtilis* NCIB 3610 only (2a), and the culture supernatant of *Bacillus subtilis* NCIB 3610 with silver nitrate (1 mM $AgNO_3$) after 24 (2b), 48 (2c), 72 (2d), 96 (2e) and 120 (2f) hours of incubation at room temperature.

E-nose technology (Russo et al., 2013; Konduru et al., 2015). Yet, E-nose technology involves highly complex calculations and preparation of customized gas chambers which could lead to erroneous output due to operational problems. Nanotechnology presents alternative pathway to monitor deterioration that occurs during post-harvest spoilage, for instance visual detection of post-harvest spoilage in spices was achieved using chemically synthesized silver-based nanomaterial as a selective colorimetric sensor (Divya et al., 2016). While this report opens new opportunity for nanomaterials in crops post-harvest management, sustainability must be prioritized. For such application to be sustainable, then, green science must be embarrassed.

Green synthesis is simple, rapid, safe and environmentally friendly, cost-effective because the biological agents are readily available, requires no complex calculations and energy, and could be easily applied anywhere in the world (Kalishwaralal et al., 2008). This synthesis has emerged as a promising field of research as nano-biotechnology. Microorganisms such as bacteria, algae, and fungi possess the natural ability to reduce/oxidizing metal ions into metallic/oxide nanoparticle (Rai et al., 2008; Vijayaraghavan and Nalini, 2010). The collaborations between metals and microbes (or plants) have been utilized for diverse kinds of biological applications in the fields of bioremediation, biosensors, drug delivery, energy, bio-corrosion, etc (Joerger et al., 2000; Parikh et al., 2008; Nath and Banerjee, 2013). The use of bacteria for nanoparticles synthesis can also exhibit excellent poly-dispersity and