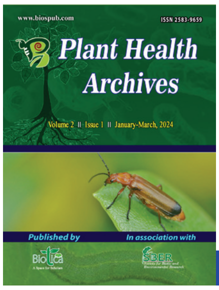

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Evaluation of Post-Harvest Microbial Deterioration of Ripe Banana Fruits in Different Markets

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Abstract

This study intends to evaluate the influence of microflora in various types of banana fruits on moisture content and health risks related to bacterial growth at different fruit ages. Over four weeks, 120 banana fruit samples were gathered from three marketplaces in Kano State, Nigeria and dissected for pH, moisture content and microbiota. These three samples were then dissected to perform tests on pH, moisture content and microbiota. Some were subject to a moisture content that ranged from 77.22% to 80.29% and the samples' pH values ranged from 4.60 to 5.10. The fungal counts displayed a range spanning from 1.40×10^6 to 3.30×10^6 cfu ml^{-1}, while the bacterial counts exhibited a broader spectrum, fluctuating between 3.80×10^6 and 7.30×10^6 cfu ml^{-1}. The bacteria identified in the samples were *Proteus vulgaris*, *Bacillus* sp., *Xanthomonas campestris*, *Corynebacterium xerosis*, *Pseudomonas* sp., *Erwinia carotovora*, *Dickeya parasidiaca* and *Ralstonia solanacearum*. The fungal isolates included *Aspergillus niger*, *Fusarium* sp., *Alternaria* sp., *Mucor* sp., *Cordana johnsonii*, *Chrysonilia* sp., *Cladosporium* sp., *Doratomyces microspores*, *Rhizopus stolonifer* and *Colletotrichum musae*. Fungi and bacteria detected in these samples prove their significant contribution causing the deterioration after harvest. This results in post-harvest diseases which consequently lead to the decline in the fruit's quantity and quality. Apart from the diminished commercial value of this kind of fruit, it can also pose chemical dregs, a health hazard to human beings. The knowledge gained from this research may facilitate the development of strategies for controlling banana fruit spoilage, resulting in improved product quality before consumption.

Keywords: Bacteria, Banana, Deterioration, Fungi, Post-harvest, Spoilage

Introduction

Bananas have become a household favorite because their high nutritional value and affordability are unequaled (Yazew, 2022). However, the fruits are notably susceptible to microbial deterioration, substantially diminishing their shelf life and economic viability (Nayab and Akhtar, 2023). This microbial degradation can manifest at various stages, from harvesting through handling, transportation and storage, ultimately resulting in significant losses and potential health risks for consumers. Notably, bacterial contamination can be particularly concerning, leading to the presence of perilous toxins and spores, thereby precipitating food-borne illness outbreaks (Ardiyansyah *et al.*, 2022). Even though bananas were recognized as a very important commodity concerning wealth creation and the dietary needs of the human population, they still encountered obstacles in the agricultural business. Among these issues are the postharvest losses for microbial degradation, transport-related conveniences such as overloading and stricter regulatory discrimination regarding residue levels at main targeted markets (Saha *et al.*, 2021). Furthermore, the recent global upheaval caused by the COVID-19

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pandemic has exerted a substantial impact on the banana trade, resulting in diminished export quantities (Martínez-Solórzano and Rey-Brina, 2021; Olivares *et al.*, 2022). In response to these challenges that are affecting ripe banana fruits, the research that is being carried out focuses on the microbiological decay that is affecting the ripe banana fruits within the 3 prominent banana fruit markets situated in Kano State, Nigeria. This research is conducting an in-depth analysis of bacteria that cause bananas to spoil and are a huge threat to public health since they can be the reason for the health problems of consumers. Getting a well-rounded overview of the role-players in banana berry deterioration and the correlated health issue is a must, since only then can we build a plan that is of high effectiveness and aimed at preventing post-harvest losses together with ensuring the safety of banana consumption.

Hypothesis

We anticipate variations in microbial contamination levels among ripe banana fruits across different markets, influenced by market conditions, handling practices and environmental factors. More so, we expect certain bacterial species to be consistently present across all markets, contributing significantly to banana spoilage and posing health risks to consumers.

Materials and Methods

Collection of Samples

A total of 120 bananas from the markets being sold within three different markets were sampled from the vendors in Kano State, Nigeria. The markets were nominated because of their prominent status and widespread patronage in the trade of bananas in the local markets which is namely, Tarauni, Yanlemo and Yankura. As to the bananas that had been purchased, some of them had visible symptoms of spoilage while others seemed well-kept. The study was set up to guarantee accurate outcomes by obtaining ten samples from each market and putting them right into clean polyethylene bags and then the bags were transported to the Microbiology Laboratory at Skyline University Nigeria for analysis. A thorough assessment of the microbial deterioration of ripe banana fruits sold in well-known markets in Kano State was made possible by this extensive sampling strategy.

Physicochemical Properties

Determination of pH

A glass electrode pH meter was used which was previously calibrated with a neutral buffer, irrational order of the words was corrected. When the mixture was mashed, the banana juice was then transferred to clean beakers with an immersed pH instrument for pH meter readings (Cho and Koseki, 2021).

Moisture Content

One gram of banana sample was weighed using a weighing crucible of precise weight and sterilization status. Subsequently, the sampler was dried at 105 °C, in the overnight incubator. Once the distillation process was over, the weights of each crucible were measured. The difference was noted down as the weight of the dry sample. An average value of percentage moisture content was determined by using the drying methods of the American Public Health Association (APHA) standard procedure, as shown by Khanjani and Sharifinia (2022), where the starting weight of the sample was used along with the amount of the weight loss during the process.

Total Bacterial and Fungal Colonies

The standard pour plate technique was used to determine the overall bacterial and fungal number, from the banana samples. Nutrient agar and potato dextrose agar were used as bacterial and fungal isolation media of choice. One of the stages of this process is the crushing of 1 g of the sample in a sterile mortar with a pestle and then the addition of 9 ml of sterile distilled water. This process is called dilution series and the dilution factors extended up to 10^{-6} based on the previous works. Later, 1 ml of the appropriate dilution prepared was used to inoculate the nutrient medium. Post inoculation, the agar plates were incubated at a controlled temperature of 37±2 °C, that of the potato dextrose agar plates being maintained at ambient room temperature. To be precise, the bacterial and fungal growth on the nutrient and the potato dextrose agar plates was observed after the fixed periods of 24 and 72 hours, respectively. According to Etim *et al.* (2022), the identification and quantification of bacterial and fungal cultures rely on distinct morphological and cultural characteristics unique to each type.

Results and Discussion

The analysis of the pH values in bananas exposed in the markets confirms that the fruits are acidic with the pH range extending from 4.60 to 5.10.

The Mean of Moisture Content

The results showed that moisture content found in bananas sampled from the three markets varied averaging between 77.22% and 80.29%. The metering for humidity used a painstakingly detailed process whereby each banana sample in a pre-weighed clean container was initially weighed and left for drying in a 105 °C space for 24 hours. The observable difference in weight was also recorded and put together with the initial sample weight. APHA standard was used to measure the percentage of moisture. The approach of the aforementioned work was applied (Ekafitri *et al.*, 2020).

Microbial Isolates

The average bacterial and fungal counts observed in the banana samples sourced from the three distinct markets fell within the range of 3.80×10^6 to 7.30×10^6 cfu ml^{-1}. Notably, the Yanlemo market exhibited the lowest average bacterial counts, while conversely, the Yankura market demonstrated the highest mean bacterial counts among the three markets. Similarly, the lowest mean fungal counts were obtained from the Tarauni market, while the highest mean fungal counts were obtained from the Yanlemo market.

In the study, eight bacterial species were isolated from banana samples obtained from three markets in Kano, Nigeria. The identified bacteria included *Proteus vulgaris*, *Bacillus* sp., *Xanthomonas campestris*, *Corynebacterium xerosis*, *Pseudomonas* sp., *Erwinia carotovora*, *Dickeya parasidiaca* and *Ralstonia solanacearum*. More so, ten fungal species were also isolated from the same banana samples, including *Aspergillus niger*, *Fusarium* sp., *Alternaria* sp., *Mucor* sp., *Cordana johnsonii*, *Chrysonilia* sp., *Cladosporium* sp., *Doratomyces microspores*, *Rhizopus stolonifer* and *Colletotrichum musae*.

The pH levels of the deteriorated banana fruits from the three markets were between 4.60 and 5.10, indicating an acidic environment. This differs from the results reported by Ganduri (2020), which reported a lower pH range of 4.2-4.3. The study suggests that the slight rise in pH could be due to the neutralizing impact of the microbial metabolic substances generated by the initial contaminants found in the banana fruit, as stated by Kuang *et al.* (2021). The moisture content of overripe bananas was found to be significant, ranging from 77.22% to 80.29%, according to the research. This high moisture content creates an environment conducive to the growth and spread of microorganisms within the fruit. Microorganisms require a thin layer of water to thrive. It is worth noting that these results slightly differ from those reported in a previous study (Mostafa, 2021). The distribution of pH levels in deteriorated banana fruits from three different markets is depicted in figure 1, while figure 2 displays the moisture content of the fruits. The findings of this investigation offer valuable insights into the microbial quality of bananas sold in markets located in Kano, Nigeria.

As noted by Mon *et al.* (2021), *Fusarium* sp. is a plant pathogen responsible for the deterioration of bananas. Similarly, *Alternaria* sp. contributes significantly to early blight disease and black mold rot in bananas. These fungi also produce tenuazonic acid, a harmful mycotoxin that poses a global health risk (Noohi and Papizadeh, 2022). Research conducted by Al-Otibi *et al.* (2023) revealed that *Mucor* and *Fusarium* species were the primary culprits behind the highest instances of fungal rot in both farm and market samples of banana fruit. Sour rot on bananas, characterized by a sour odor emanating from the fruit's lesions, was attributed to *Mucor* species, as observed by Meena *et al.* (2020). In table 1, fruit samples obtained from the Yanlemo market showed a 6% occurrence rate of *Rhizopus stolonifer*, another opportunistic plant pathogen (Jaiswal *et al.*, 2022). Tables 2 and 3 display findings from banana fruit samples obtained at the Yankura market, where we identified prevalent pathogens linked to dry rot, including *Aspergillus niger* and *Colletotrichum musae*. *Aspergillus niger*, in particular, was found to contribute to 18% of the total post-harvest fruit loss in Nigeria, as reported in (Busari-Ahmed *et al.*, 2015). The analysis of the banana samples also revealed the presence of other fungi including *Mucor*, *Fusarium* species and *Doratomyces microsporus*, with a combined occurrence rate of 18% (Alwakeel *et al.*, 2021). Furthermore, it was discovered that certain strains of *Pseudomonas* and *Bacillus* can cause soft rot in bananas, as stated by Gamez *et al.* (2020). Nevertheless, Sengupta and Sarkar (2022) reported that some *Bacillus* sp. may cause food-borne diseases, leading to various types of symptoms such as nausea, vomiting and abdominal cramps (Megha *et al.*, 2023).

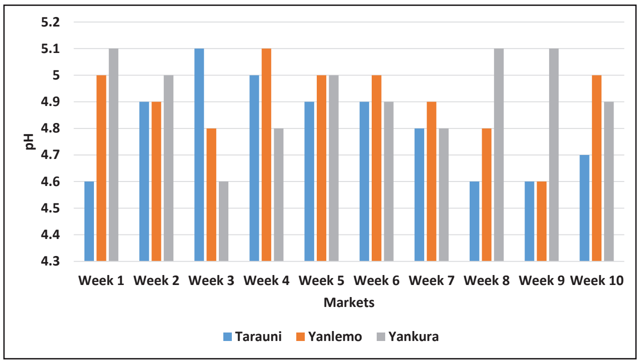

Figure 1: Depicting the average pH levels of bananas sold across various markets in Kano, Nigeria

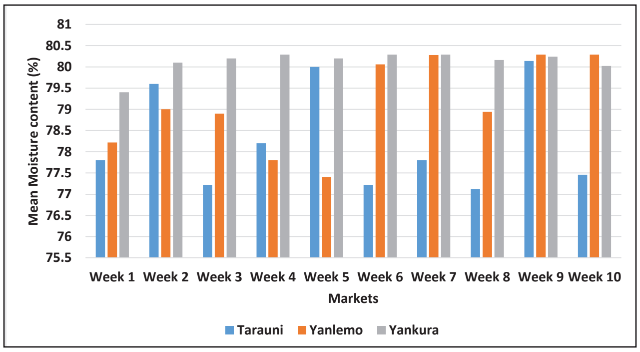

Figure 2: Depicting the average moisture percentage of bananas available in different markets located in Kano, Nigeria

Table 1: Mean of fungal and bacterial counts of the banana samples in the markets

Markets	Mean of total fungal counts (MTFC) (cfu ml^{-1})	Mean of total bacterial counts (MTBC) (cfu ml^{-1})
Tarauni Market	1.40×10^{6}	4.20×10^{6}
Yanlemo Market	3.30×10^{6}	3.80×10^{6}
Yankura Market	2.20×10^{6}	7.30×10^{6}

This study also revealed that bacteria counts surpassed fungal counts, which could be attributed to the bacteria's capacity to produce growth-hindering elements like bacteriocins, which impede the growth of fungi and other bacterial competitors, as reported by Zhang *et al.* (2022). Aside from causing financial losses, certain types of fungi can produce hazardous bioactive substances in the affected region of the fruit, which may pose a health risk to people (Sharma *et al.*, 2023). Moreover, fruits have been associated with outbreaks of food-borne diseases caused by pathogenic bacteria, viruses and parasites (Ranjha *et al.*, 2022). Therefore, to decrease fruit spoilage and the related detrimental health impacts, strict cleanliness, good agricultural practices (GAPs) and good manufacturing practices (GMPs) must be observed throughout the cultivation, harvesting, storage, transportation and marketing stages, as emphasized by Joshi *et al.* (2020).

Table 2: The distribution of bacterial isolates among the three markets

Bacterial Isolates	Tarauni Market				Yanlemo Market				Yankura Market			
	WK1	WK2	WK3	WK4	WK1	WK2	WK3	WK4	WK1	WK2	WK3	WK4
P. vulgaris	+	-	-	-	+	+	-	-	+	-	-	-
Bacillus sp.	-	+	-	-	-	-	-	-	-	+	-	-
D. parasidiaca	+	-	-	-	-	+	-	+	+	-	-	-
X. campestris	-	-	-	-	+	-	+	-	-	+	-	-
Pseudomonas sp.	-	-	+	+	-	+	+	-	-	-	-	-
E. carotovora	-	-	-	-	-	-	-	-	-	-	-	-
C. xerosis	-	-	-	-	-	-	-	+	-	-	-	-
R. solanacearum	-	-	-	+	+	-	-	-	+	-	-	-

[Legends: '+': present; '-': absent; WK: week]

Table 3: Occurrence of fungal isolates in the three markets

Fungal Isolates	Markets		
	Tarauni Market	Yanlemo Market	Yankura Market
Alternaria sp.	-	-	+
Aspergillus niger	+	+	+
Chrysonilia sp.	+	-	-
Cladosporium sp.	-	+	-
Colletotrichum musae	+	-	+
Cordana johnsonii	-	+	-
Doratomyces microspores	-	-	+
Fusarium sp.	+	+	+
Mucor sp.	+	+	+
Rhizopus stolonifer	-	+	-

[Legends: '+': present; '-': absent]

According to Kuang *et al.* (2021), controlling the ripening process of banana fruits is advisable to prolong their shelf life during transportation. This strategy effectively manages fungi that can only spoil ripe banana fruits. To ensure that the banana fruits are stored correctly, well-managed storage facilities with the ideal temperatures and relative humidity are essential (Sugianti *et al.*, 2022). To prevent the spread of spoiling, spoiled fruits that have been mechanically damaged or infected with fungus shouldn't be combined with healthy fruits. It is recommended by Taweechat *et al.* (2021) that all farm equipment used in the operation, such as buckets, crates, picking basins and baskets, be disinfected to prevent the spread of spoilage microorganisms from fields and orchards via fruits, vegetables and containers during harvesting.

Conclusion

This study, which involves the assessment of post-harvest microbial damage in ripe banana fruits, addressed some salient issues which are as depicted below. The banana fruits marketed at these markets had microbial quality issues as they recorded significantly high numbers of fungal and bacterial contaminants. *Fusarium* sp. and *Alternaria* sp. were the main fungal pathogens that contributed to bananas' biodeterioration and early blight disease and *Aspergillus niger* was responsible for the black mold rot. These pathogenic fungi could hamper the fruits physically and cause the secretion of mycotoxins that pose a health risk to people. The research has revealed the influence of environmental factors on banana fruit decaying. The lowered pH levels and high moisture in degraded fruits were a perfect medium for microbe replication and development. It highlights the fact that the adoption of improved post-harvest handling and storage operations should be considered as a measure to overcome these factors and lead to prolonged banana shelf life. The research emphasized the importance of the sanitary and phytosanitary (SPS) measures, GAPs and GMPs all along the banana production and trading processes. Tempering the ripeness of banana fruits is no less important than keeping the condition normal for storage since uncontrolled ripeness or unfavorable storage conditions are considered the main cause of spoilage during transit and marketing. The disinfection of agricultural devices and the avoidance of mixing damaged vegetables and microbial-infested crops with healthy ones are essential measures that limit the spread of spoilage bacteria. Hence, taking into account a holistic view and comprising the farmers, distributors and consumers in this regard calls for an integrated approach. Practicing them would prevent losses as well as protect the public's health by eliminating the risk of consuming fruits that are infected with microorganisms and small pests.

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