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Production, Sensory Characteristics and Microbiological Properties of Ripened Plantain Fruit Wine During Storage

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ABSTRACT
Wine production from ripened plantain fruits presents a novel approach to value addition, reducing post-harvest losses while offering an alternative to conventional fruit wines. This study investigated the physicochemical, sensory and microbiological properties of plantain wine during storage. Both pasteurized and non-pasteurized samples were assessed for physicochemical properties, total bacterial and fungal counts, and sensory attributes using standard methods. *Saccharomyces* spp. and *Candida* spp. were the predominant yeasts identified, contributing to fermentation and flavor development. However, non-pasteurized plantain wine (NPPW) exhibited significantly higher microbial counts, ranging from 1.8 x 10^4 to 2.2 x 10^4 and in pasteurized plantain wine the microbial growth ranges from 1.0 x 10^4 to 1.55 x 10^4. Microbial diversity included *Staphylococcus* spp., *Rhodococcus* spp., and *Aspergillus* spp., suggesting increased contamination risks. Total bacterial and fungal counts increased over time, with NPPW exhibiting faster spoilage rates due to the absence of heat treatment. Pasteurization effectively slowed microbial proliferation, preserving sensory attributes such as aroma, taste, and clarity. Sensory characteristics using a nine-point hedonic scale revealed that pasteurized plantain wine (PPW) was generally preferred, with better acceptability for appearance, taste, and overall quality. Physicochemical analysis indicated that pH, sugar content, and specific gravity fluctuated during storage, influencing microbial dynamics and product stability. These findings highlighted the importance of pasteurization, proper storage, and microbial control in extending the shelf life of plantain wine. The study also contributed valuable insights into the commercial potential of plantain wine, which can assist in promoting agricultural practices and economic diversification in wine production.

Keywords: Microbial stability, pasteurization, production, plantain wine, sensory attributes

INTRODUCTION
Wine production is a well-established industry, traditionally utilizing grapes as the primary raw material. However, there has been growing interest in diversifying the sources of raw materials for wine production, particularly in tropical regions where other fruits are abundant. One of such fruit is the plantain (Musa spp.), a staple in many tropical countries, which can be used for wine production due to its high sugar content when ripened. (Akubor and Ogbadu, 2019). Plantains are widely cultivated in tropical

and subtropical regions, serving as a source of carbohydrates, vitamins, and minerals (Ezenwa and Eze, 2020). They come in various cultivars, each with unique physical and chemical characteristics. The ripening process of plantain fruits alters their sugar content, acidity, and flavor profile, making them suitable for fermentation. (Okafor, *et al.*, 2018). Despite their abundance, plantains are underutilized in value-added products like wine. Exploring their potential for wine production not only adds value to the crop but also provides an opportunity to reduce post-harvest losses. Shelf life is a critical factor for any beverage, including plantain-based wines, as it determines the product's stability over time in terms of flavor, aroma, color, and safety (Kester and Olaniran 2020). The preservation of desirable sensory qualities, such as aroma, taste, mouth feel, and after taste, is essential for ensuring the wine's marketability and consumer preference. In this regard, the sensory evaluation of plantain wine becomes an important tool for assessing its quality, as it involves the systematic assessment of the wine's sensory attributes by trained panels or consumer groups (Ezenwa and Eze, 2020). Sensory analysis helps identify the key attributes that influence consumer acceptance, which is essential for determining whether plantain wine can compete in the growing market for novel alcoholic beverages. Sensory evaluation, which assesses the wine's aroma, taste, texture, and overall appeal, plays a significant role in determining the consumer acceptability of such a product. The ripeness of the plantains used in winemaking has a significant impact on the microbial quality of the wine. As plantains ripen, the starch content is converted into sugars, which creates a more favourable environment for yeast and other fermentative microorganisms to thrive. However, overripe or decaying plantains can harbour spoilage organisms such as moulds and undesirable bacteria. Yeasts such as *Saccharomyces cerevisiae*, the primary fermentative microorganism, thrive in the high-sugar environment of ripened plantains, converting sugars into alcohol and carbon dioxide (Fleet *et al.*, 2019). However, if the plantains are overripe, they may also support the growth of spoilage yeasts and molds, which can negatively impact the quality of the wine by producing off-flavors and reducing alcohol yield (Yakubu *et al .,* (2021).

Using decaying plantains increases the risk of introducing harmful microorganisms into the fermentation process, such as *Aspergillus* and *Penicillium* species, which can produce mycotoxins (Bokulich and Bamforth, 2019). These fungi not only reduce the microbial quality of the wine but also pose health risks to consumers. Therefore, careful selection of plantains at the optimal stage of ripeness is crucial to ensure microbial quality.

The shelf life of any alcoholic beverage is crucial for its marketability and consumer acceptance. The stability of wine is determined by various factors, including the chemical composition of the fruit, fermentation process, and storage conditions. Understanding how ripened plantains influence these factors can provide valuable insights into the development of plantain-based wines with extended shelf life and consistent quality. In many tropical countries, including Nigeria, plantains often experience significant post-harvest losses due to inadequate preservation techniques and low demand for fresh consumption during peak harvest seasons. This study seeks to bridge this knowledge gap by investigating the production process, shelf-life stability in relation to its microbial properties and sensory characteristics of wine made from ripened plantain fruit under different storage conditions.

MATERIALS AND METHODS

Materials

Overripe giant horn plantain (*Musa paradisiaca*) was obtained from New market Wukari Taraba State, Nigeria. It was then transported to microbiology laboratory for analyses.

SAMPLE PREPARATION

Pasteurised plantain wine

Ripe firm plantains were peeled and cut into small pieces to increase the surface area for juice extraction. One and half kilogram (1.5kg) of the cut plantains were placed in a pot with 3 liters of water. The mixture was heated gently for 20 minutes at approximately 70-80°C to extract the starches and sugars (Romano, *et al .,* 2020). The heating process ensures the release of sugars that yeast can ferment into alcohol. After cooling to room temperature, the mixture was strained through a sterile cheese cloth to separate the liquid from the solid residues (Romano, *et al .,* 2020). The liquid was then pasteurised at 80°c for 3 minutes, the liquid was allowed to cool to room temperature, and then transferred into a fermentation vessel. The mixture was allowed to ferment at room temperature (28±1 ºC) for 7 days. A hydrometer was used to measure the specific gravity of the liquid, which will help monitor the fermentation progress. After fermentation was completed, the wine was strained to remove any remaining solids. The wine was transferred into clean sterile plastic bottles.

Non pasteurised plantain wine

One and half kilogram (1.5kg) of the ripe plantain were washed, peeled and cut into smaller pieces. 3 litres of water was added to the fermentation vessel and the plantain was added. The vessel was covered tightly and allowed to ferment for 7 days. After fermentation was completed, wine was strained to remove the remaining solids a
and was transferred into clean plastic bottles.

Both pasteurised and non-pasteurised plantain wines were stored at ambient conditions and in   refrigerator and analyses were carried out for a period of 4 weeks. Parameters such as color, clarity, sugar levels, pH, and microbial stability were evaluated weekly.

Sensory Evaluation

The samples were scored on a nine- point Hedonic scale where "9" represented extremely liked and "1" represented extremely dislike as described by Ihekoronye and Ngoddy (1985). It was used to assess the organoleptic properties of the samples. A 30-man semi-trained panellist consisting of students from Department of Microbiology, Federal University Wukari, Taraba State. The panellist evaluated the samples on the following attributes: colour, appearance, taste, aroma, mouth feel and general acceptability. The samples were presented in a clean transparent cup. It was served simultaneously to ease possibility of panellist evaluating the sample. Precautions were taken to prevent bias of panellist.

Microbiological Analysis
Media Preparation
Nutrient agar, MacConkey agar, Potatoe dextrose agar and peptone water were used for isolation and enumeration of microorganisms from the plantain wine samples. Appropriate quantities were weighed according to manufacturer's instruction, dissolved in distilled water and sterilized by autoclaving at 121^{o}C for 15mins.

Isolation and Enumeration of Micro-organisms
The method as described by Obasi *et al.,* (2025) were used with little modification. The stock culture was prepared by dissolving 1ml of plantain wine samples into 9ml of sterile peptone water. Each wine sample was serially diluted using the serial dilution method of Ten-fold (10^{-10}) in sterile peptone water. 1ml of appropriate dilution was poured on various media using pour plate method, dilution 10^{-2} and 10^{-4} were incubated at 37^{o}C between 24-48 hours for bacterial cell count and enumeration. Fungi plates were counted after 3 to 5 days of incubation. All enumerations were expressed as colony forming unit per millilitre (cfu/ml) of plated samples.

Data Analysis
The experimental design used was factorial design and the data obtained were subjected to analysis of variance (ANOVA) using the statistical package for social sciences version 17.0 (SPSS). Duncan's multiple range test was used to compare the difference mean.

RESULTS AND DISCUSSION
Physicochemical Properties
Table 1. shows the Physicochemical properties of pasteurized and non-pasteurized plantain wine samples during storage. The pH of the samples of pasteurised plantain wine, (PPW) and non-pasteurised plantain wine (NPPW) ranged from 2.97-4.02 and 3.09 – 4.52 respectively. The specific gravity ranged from 1.03 – 0.99 in sample PPW and 1.05 – 1.00 in NPPW. pH significantly influences wines taste, stability and aging potential. Lower pH (higher acidity) generally leads to a crisp refreshing taste, while higher pH (lower acidity) results in a softer rounder flavour. Specific gravity in wine indicates the amount of alcohol present, influencing the wines sweetness, alcohol contents and overall flavour profile. As yeast consumes sugar and produce alcohol, the specific gravity decreases. Sugar level plays a crucial role in wine, as source for yeast during fermentation which converts it into alcohol. Sugar levels decrease during fermentation as yeast consume the sugar in the must and converts them into alcohol.

The result obtained from the study as presented on Table 1 shows that the physicochemical properties of plantain wine varied significantly over the storage period. The pH levels increased from 2.97 in Week 1 to 4.02 in Week 4 for Sample PPW, and from 3.09 to 4.52 for Sample NPPW. This increase suggests a reduction in acidity, which could be attributed to microbial metabolic activities consuming organic acids or the breakdown of acidic compounds (Oba *et al .,* 2022). The result of this study is in agreement with the study of other workers as reported by (*Zhao et al .,* 2020) who observed a similar trend in other fruit-based wines, where extended storage resulted in gradual pH elevation due to microbial adaptation. The specific gravity (S.G.) showed fluctuations, starting at 0.99–1.00 in Week 1 and increased to 1.03–1.05 by Week 4**.** These changes align with fermentation activities, where yeast metabolism converts sugars into ethanol, altering the density of the wine. A study by Akinmoladun *et al.* (2019) on banana wine fermentation observed a similar trend, where specific gravity reduced initially but increased slightly in aged samples due to secondary fermentation. The sugar levels showed a decline over time, with sample PPW decreasing from 10.11% to 6.81% and sample NPPW from 5.21% to 4.30% by Week 4. The reduction in sugar concentration is a direct consequence of yeast activity, converting sugars into alcohol and other metabolites (Ramos *et al.,* 2019). A similar reduction was reported in pineapple wine, where prolonged fermentation reduced sugar levels significantly (Martínez *et al.,* 2021).

Comparing the two samples, Sample PPW had a higher sugar concentration throughout the storage period, suggesting either incomplete fermentation or differences in initial sugar content. This finding is consistent with Olawaniyi *et al .,* (2018), who noted that variations in sugar content between fruit wines are influenced by differences in the carbohydrate composition of the raw material. A significant observation was the increase in pH levels, which impacts wine stability and microbial activity. Higher pH levels above 4.0 create conditions favorable for spoilage organisms (González *et al.,* 2018). The increase in pH in both samples suggests that storage conditions may influence microbial proliferation.

The variations in physicochemical properties indicate the importance of proper storage conditions**,** as temperature, oxygen exposure, and microbial interactions significantly affect wine stability (Nwachukwu *et al .,* 2020). Refrigeration or controlled fermentation processes could mitigate these changes and improve wine longevity. The results obtained from this study is in - line with the findings of Adepoju *et al.,*(2021), who emphasized the importance of pasteurization and controlled fermentation in stabilizing fruit wines. The study also highlights the necessity of monitoring acidity levels to maintain the sensory and microbial quality of the wine

TABLE 1.: Physicochemical Properties OF Plantain Wine During Storage

Sample code	Parameter	Storage period/Weeks			
		1	2	3	4
PPW	**pH**	$2.97^{d}\pm0.01$	$3.37^{c}\pm0.01$	$3.72^{b}\pm0.01$	$4.02^{a}\pm0.01$
	Specific gravity	$1.03^{a}\pm0.01$	$1.02^{b}\pm0.01$	$1.01^{c}\pm0.01$	$0.99^{d}\pm0.01$
	Sugar level	$10.11^{a}\pm0.01$	$8.21^{b}\pm0.01$	$7.91^{c}\pm0.01$	$6.81^{d}\pm0.01$
NPPW	**pH**	$3.09^{c}\pm0.01$	$3.44^{ab}\pm0.02$	$3.86^{ab}\pm0.14$	$4.52^{a}\pm0.02$
	Specific gravity	$1.05^{ab}\pm0.14$	$6.20^{a}\pm2.40$	$1.02^{ab}\pm0.01$	$1.00^{ab}\pm0.02$
	Sugar level	$5.21^{a}\pm0.01$	$4.81^{ab}\pm0.01$	$4.51^{ab}\pm0.02$	$4.30^{c}\pm0.14$

The data values are mean ± standard deviation of the physicochemical properties. Means within a column not followed by the same superscript are significantly different (P ≤ 0.05).

Key: PPW= Pasteurised Plantain Wine, NPPW= Non-Pasteurised Plantain Wine.

Sensory Evaluation

Table 2 below indicates that sample NPPW scored higher in colour, taste, aroma and overall acceptability than sample PPW. The sensory evaluation results compared pasteurized plantain wine (PPW) and non-pasteurized plantain wine (NPPW) based on color, appearance, taste, aroma, general acceptability, and mouth feel. Overall, NPPW scored higher in most attributes, particularly in color (7.00, 6.40), taste (6.77, 6.60), aroma (6.47, 5.90), general acceptability (7.07, 6.90), and mouth feel (7.03 vs. 6.33). This suggests that non-pasteurized wine retained more natural flavor, aroma, and texture, likely due to the presence of active fermentation compounds. However, appearance scores were similar (6.9, 6.93), indicating minimal visual differences between the two samples. The slight advantage of NPPW in sensory attributes may be attributed to the retention of volatile aromatic compounds and a more complex flavor profile. However, pasteurized wine remains the most preferable due to its longer shelf life and microbial stability.

TABLE 2. Sensory Evaluation

Sample Code	Colour	Appearance	Taste	Aroma	General acceptability	Mouth feel
PPW	6.40^{b}±1.50	6.90^{a}±1.45	6.60^{a}±1.57	5.90^{a}±1.88	6.90^{a}±1.47	6.33^{a}±1.65
NPPW	7.00^{a}±1.39	6.93^{ab}±1.44	6.77^{ab}±1.85	6.47^{b}±1.57	7.07^{ab}±1.60	7.03^{ab}±1.83

The data values are mean ± standard deviation of the sensory evaluation. Means within a column not followed by the same superscript are significantly different (P ≤ 0.05).

Microbiological Analysis

Table 3 showed that bacterial count in pasteurized plantain wine (PPW) and non-pasteurized plantain wine (NPPW) increased over time, indicating microbial growth. NPPW exhibited significantly higher bacterial counts compared to PPW, suggesting that pasteurization effectively slows bacterial proliferation. By week 3, bacterial growth in NPPW was at its peak, confirming that microbial contamination progresses in non-pasteurized samples. Coliform count was high in both pasteurized and non-pasteurized samples as storage period progresses. Over time, the bacterial population in PPW and NPPW increased, with NPPW showing higher counts, reinforcing the role of pasteurization in microbial control while yeast growth was observed in both PPW and NPPW, with a steady increase over time. The fungal count in NPPW remained higher than PPW, suggesting that pasteurization helps limit fungal contamination but does not eliminate it. The sharp increase in fungal load from week 1 to week 3 in NPPW highlights the need for proper storage conditions to prevent spoilage.

The total bacterial count revealed an increasing trend, with NPPW showing higher values than PPW throughout the storage period. Nutrient agar supports a broader range of bacteria, including both Gram-positive and Gram-negative species, explaining the observed microbial diversity (Chukwuma *et al.,* 2019). The continuous increase in bacterial load, especially in NPPW, highlights the risks of microbial spoilage and potential health concerns due to the presence of pathogenic species. Pasteurization, combined with aseptic packaging and controlled fermentation, has been recommended as an effective strategy to minimize spoilage risks in fruit wines (Li *et al .,* 2020). The results obtained from this study confirmed that non-pasteurized plantain wine has a shorter shelf life and requires refrigeration or preservatives to maintain quality.

The total Coliform count showed a significant increase in microbial load over the storage period, with NPPW exhibiting higher counts than PPW. The result obtained from his study is in agreement with the findings by Yakubu *et al.* (2021) that pasteurization effectively reduces initial microbial load but does not prevent post-processing contamination. The higher bacterial count in NPPW by week 3 suggests that non-pasteurized wine is more susceptible to spoilage due to microbial proliferation. The high count of coliform specifically indicates the presence of Gram-negative bacteria, which can negatively impact wine quality by producing off-flavors and biofilms (González *et al .,* 2018). These findings underscore the importance of pasteurization and proper storage to extend the shelf life of plantain wine. The total fungal count also exhibited an increasing trend over time, with NPPW showing a significantly higher fungal load than PPW. Fungi such as *Aspergillus spp.*, *Penicillium spp.*, and *Saccharomyces spp.* were observed, with *Aspergillus spp.* being a potential producer of mycotoxins, which can compromise wine safety (Olawuyi *et al.,* 2021). The rapid increase in fungal count in NPPW suggests that spoilage yeasts and molds thrive in non-pasteurized conditions. The result of this study is similar to the studies on fruit wine production by (Zhu *et al.,* 2019), who also had indicated that fungal contamination accelerates oxidative spoilage in his study leading to undesirable changes in aroma, texture, and acidity. Effective storage conditions, including temperature control and antimicrobial treatments, are necessary to prevent fungal spoilage in plantain wine. Pasteurization clearly played a role in extending microbial stability in PPW compared to NPPW in relation to shelf life. Pasteurized samples showed lower microbial loads throughout the storage period, indicating slower spoilage rates. The result obtained from this study compared favourably with reports by (Amienyo *et al.,* 2020 and Martínez *et al .,* 2021) whose studies suggested also that heat treatment at optimal temperatures can inactivate spoilage microorganisms while preserving the sensory qualities of fruit wines. However, pasteurization alone may not be sufficient to maintain long-term stability, necessitating additional preservation techniques such as chemical preservatives, refrigeration, or vacuum sealing to prolong shelf life (Adesokan *et al .,* 2018).

Table 3: Total Aerobic Plate Count OF Bacterial Cells, Coliform and Yeast Count (CFU/ML) in Plantain Wine During Storage

Storage period	PPW	NPPW
Zero week	1.3×10^3	1.2×10^3
Week 1	1.0×10^4	1.8×10^5
Week 2	1.2×10^5	1.95×10^5
Week 3	1.55×10^{-4}	2.2×10^4
Coliform Count		
Zero week	1.45×10^4	1.5×10^4
Week 1	1.66×10^4	1.75×10^4
Week 2	1.87×10^4	2.15×10^4
Week 3	2.32×10^4	2.00×10^4
Yeast Count		
Zero week	1.2×10^3	1.5×10^3
Week 1	1.00×10^4	1.22×10^4
Week 2	1.89×10^4	1.98×10^4
Week 3	2.22×10^4	2.45×10^4

Key : PPW: pasteurized plantain wine , NPPW: non pasteurized plantain wine

Morphological Characterization and Identification of Bacterial and Yeast Isolates

Figure 1.0 showed the bacterial and yeast species identified from pasteurized plantain wine (PPW) and non-pasteurized plantain wine (NPPW) which exhibited diverse morphological characteristics. *Staphylococcus spp*. was found in both PPW and NPPW, indicating its ability to survive in different storage conditions. The result obtained in this study is in agreement with the findings of Chukwuma *et al*. (2019), who reported similar microbial resilience in fruit wine production. *Penicillium, Bacillus* and *Aspergillus spp*. were present in PPW, suggesting potential contamination by spore-forming bacteria or fungi. *Rhodococcus spp*., *Micrococcus spp.,* and *Streptomyces spp*. were identified in NPPW, highlighting a more diverse microbial population in non-pasteurized samples. The presence of filamentous and rhizoid structures in NPPW suggests the growth of soil-associated or environmental bacteria, likely due to lack of heat treatment. Bacterial isolates in pasteurized (PPW) and non-pasteurized (NPPW) plantain wine varied significantly.

The presence of *Penicillium, Bacillus* and *Aspergillus spp*. in PPW suggests potential contamination from environmental sources. These findings align with Akabanda *et al*. (2020), who reported fungal contamination in homemade fruit wines due to poor handling and storage conditions. In contrast, NPPW exhibited greater microbial diversity**,** with the presence of *Rhodococcus* spp., *Micrococcus* spp., and *Streptomyces spp*.**.** The absence of pasteurization likely contributed to the survival and proliferation of these bacteria. Studies by Wang *et al*. (2017) suggest that non-heat-treated fruit wines are more susceptible to environmental contaminants, which impact product stability. The identification of rhizoid and filamentous bacterial structures in NPPW indicates soil-associated bacteria, which further confirms the risk of contamination in non-pasteurized samples (Yakubu *et al .,* 2021). This observation supports the necessity of pasteurization to limit microbial diversity and enhance product safety.

The morphological characterization and biochemical tests of bacterial isolates revealed that PPW contained predominantly *Staphylococcus spp*., *Penicillium , Bacillus*, and *Aspergillus spp*., while NPPW had a higher diversity of bacteria, including *Rhodococcus spp., Micrococcus spp.,* and *Streptomyces spp*. The presence of *Staphylococcus spp*. in both PPW and NPPW indicates that this bacterium can persist in different wine storage conditions. The result of this study had similar trends as reported by Akabanda *et al .,* (2020) in a study on fruit wines. However, the occurrence of *Streptomyces spp*. in NPPW suggests increased microbial complexity due to the absence of pasteurization. Studies have shown that *Streptomyces* species can produce antimicrobial compounds, which may influence the stability and sensory attributes of fermented beverages (Wang *et al .,* 2017). These variations highlight the need for controlled processing to enhance the microbial safety of plantain wine.

Microbial characterization confirms that pasteurization significantly reduces bacterial diversity and potential spoilage organisms. The result obtained in this study is consistent with findings by Ramos *et al*. (2019), which emphasized heat treatment as a key factor in ensuring microbial stability in fruit wines. The production of wine from ripened plantain fruits involves fermentation, which is significantly influenced by microbial activity, storage conditions, and processing methods such as pasteurization. Fermentation relies on yeasts such as *Saccharomyces spp*. and *Candida spp*., which were identified in both pasteurized (PPW) and non-pasteurized plantain wine (NPPW). The yeast characterization result indicated that *Saccharomyces spp*. and *Candida spp*. are the dominant fermentative yeasts, with a higher presence of *Saccharomyces spp*. in NPPW. The result obtained from this study aligns with previous studies by (Ramos *et al.,* 2019) showing that *Saccharomyces* species are key players in alcoholic fermentation, converting sugars into ethanol and flavor compounds. The persistence of *Candida spp*. in both pasteurized and non-pasteurized samples suggested its role in secondary fermentation, contributing to wine aroma and mouth feel. However, uncontrolled yeast activity in NPPW may lead to excessive acid production and spoilage, reducing consumer acceptability (Oba *et al.,* 2022). Effective microbial management, including pasteurization and controlled inoculation, is essential to maintain desirable sensory attributes

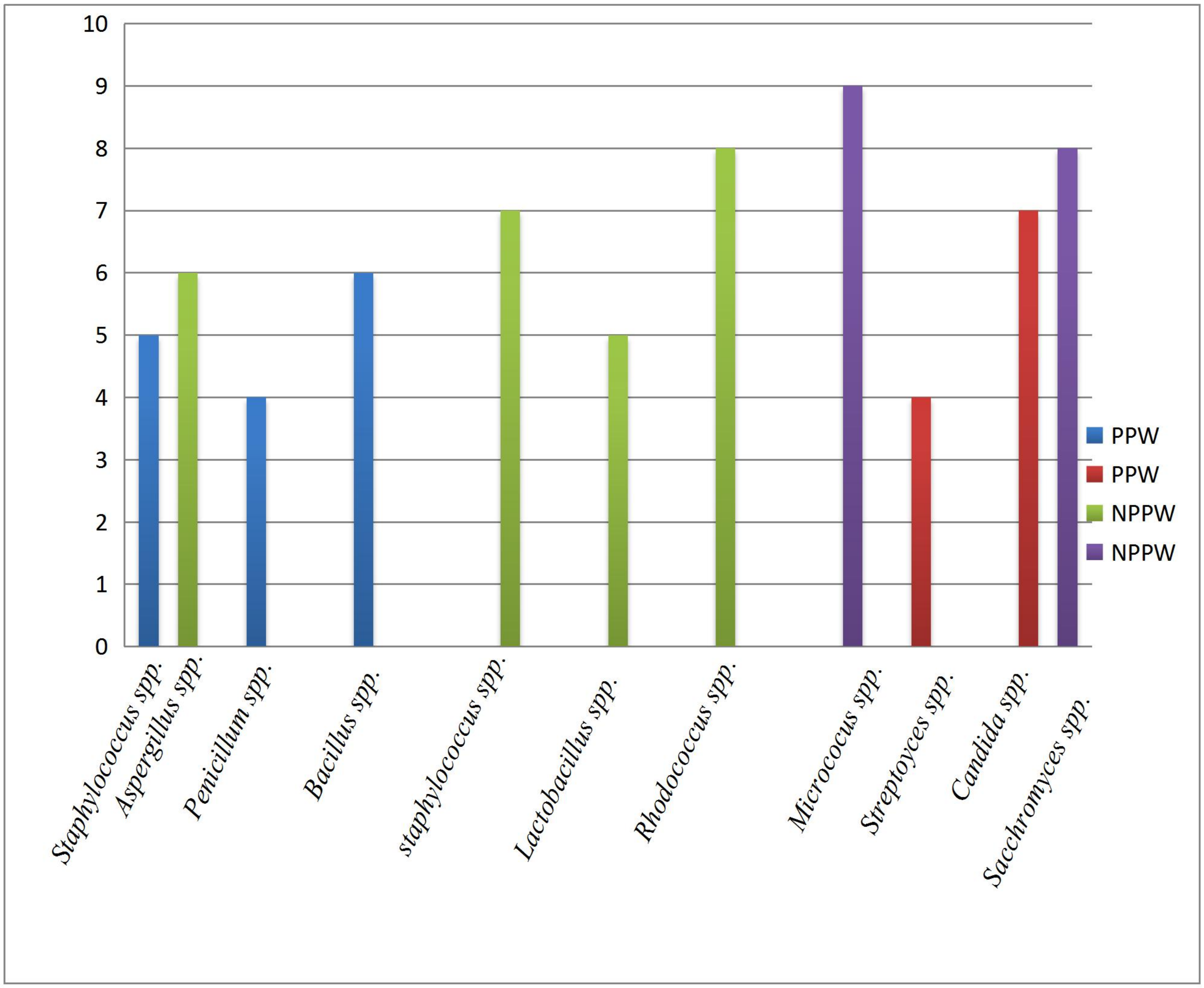

Fig. 1.0: Bacterial and Yeast species obtained from pasteurized and non- pasteurized plantain wine. Key: PPW= Pasteurised Plantain Wine , NPPW= Non-Pasteurised Plantain Wine

CONCLUSION

In conclusion, the physicochemical and sensory attributes of ripened plantain wine were slightly influenced by microbial dynamics and storage conditions. However, pasteurization clearly played a role in extending the shelf life of samples PPW when compared to NPPW. Pasteurized samples showed lower microbial loads throughout the storage period. Pasteurization effectively reduced microbial growth, prolonged stability, and enhanced the product quality, while non-pasteurized samples deteriorated faster due to uncontrolled microbial activity. The findings of this study align with previous research on fruit wine preservation, reinforcing the importance of heat treatment, proper packaging, and microbial monitoring in maintaining wine safety and acceptability.

CONFLICTS OF INTEREST

There is no conflicts of interest declared by the authors.

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