# Fermentation-Driven Changes in Microbial Dynamics, Physicochemical Characteristics, and Proximate Composition of Yam (*Dioscorea* spp.) in Southwestern Ethiopia

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## ABSTRACT

Yam (Dioscorea spp.) is a widely consumed root-tuber crop across Africa and holds cultural significance as a prestige food among rural communities in southwestern Ethiopia. Despite its importance, traditional processing methods, particularly boiling, do not effectively extend the shelf life of yam, resulting in considerable post-harvest losses. This study was conducted to evaluate the effects of natural fermentation on the physicochemical properties, microbial dynamics, and proximate composition of yam. Mature tubers of white (T1) and brown (T2) yam varieties were collected, processed, and fermented in micro-silo jars under laboratory conditions for seven days. Physicochemical parameters, microbial dynamics, and proximate composition were subsequently analyzed throughout the fermentation period. The results showed a consistent increase in titratable acidity, ranging from 0.45 to 1.74, as fermentation progressed. In contrast, pH and moisture content significantly decreased ($p < 0.05$), with pH values declining from 6.73 to 3.89 and moisture content from 61.3% to 54%. Microbial analysis revealed a reduction in yeast and mold counts from 5.34 to 4.57 CFU/ml and the complete elimination of Enterobacteriaceae (<1.00 CFU/ml) by the fifth day of fermentation. Total viable counts remained relatively high throughout the fermentation period, while lactic acid bacteria populations increased until day five, followed by a slight decline. Proximate composition analysis indicated that crude protein and total carbohydrate contents increased during fermentation, whereas crude fat, crude fiber, and ash contents decreased. These findings suggest that fermentation not only enhances the nutritional quality of yam but also significantly reduces microbial spoilage, thereby extending shelf life and minimizing post-harvest losses. Overall, the study highlights the potential of fermentation as an effective post-harvest technology for yam preservation. Further research is recommended to develop suitable starter cultures and to investigate the effects of fermentation on anti-nutritional factors under varying fermentation duration.

**KEYWORDS**
Fermentation; Microbial dynamics; Root-tuber crops;Yam

## 1. Introduction

Globally, root and tuber crops play a significant role in ensuring food security (Sanginga, 2015). Tropical root and tuber crops such as cassava, sweet potatoes, yams, and taro are used as staple or co-staple food for about a fifth of the world population (Ray & Sivakumar, 2009). These food crops are used by humankind as the third major food crop next to cereals and legumes for world populations (Chandra, 2006; Ray & Sivakumar, 2009). In Africa, cassava, sweet potato, yam, taro, and Enset are the most important root and tuber crops used for direct consumption by humans and as fodder for domestic animals (Borrell et al., 2020; Brandt et al., 1997; Sanginga, 2015). These plants grow under different agro-ecological conditions that make them adapt to harsh environments and withstand drought (Brandt et al., 1997; Khan et al., 2016; Saranraj et al., 2019; Shara et al., 2019). The recent global shortage of food grains and the increasing human population allow scientists around the world to give attention to underutilized root and tuber crops. Thus, root and tuber crops will certainly be the answer to the current food crisis due to their high production potential and ability to grow under adverse climatic conditions (Ray & Sivakumar, 2009).

In Ethiopia, diverse and underutilized root and tuber crops have great potential to combat the current food crisis and transform state food security into a stable stage. Among these, cassava, yam, and taro are the well-known root and tuber crops that are predominantly grown in Ethiopia and are used as staple food for the community (Garedew, 2017; Kusse, 2021; Nebiyu & Garedew, 2008a, 2008b; Yebo & Dagne, 2015). Concomitantly, Enset (*Ensete ventricosum*) is the only root tuber crop used as food for more than 20 million people in Ethiopia (Borrell et al., 2019; Olango et al., 2014; Garedew & Ayiza, 2017). Yam plant is grown in tropical and subtropical regions and used as a staple food for humankind (Yebo & Dagne, 2015). The plant is grown in many countries of the world (Sanginga, 2015) and produces underground tubers rich in resistant starch used as staple and co-staple food for people living in tropical and sub-tropical regions (Khan et al., 2016; Seboka et al., 2023; Sanginga, 2015; Yebo & Dagne, 2015).

In Ethiopia, yam-based food products play an indispensable role, particularly in densely populated areas of the southern, southwestern, and western parts of the country (Karya Kate Nanbol & Otsanjugu Aku Timothy Namo, 2019). It can grow on a wide range of soils with an altitude range of 1140 to 2200 m above sea level (Karya & Namo, 2019; Yebo & Dagne, 2015)

The yam-based food product is rich in carbohydrates and nutrients; hence, people in East and West Africa, the Caribbean, South Africa, India, and Southeast Asia are more familiar with this plant (Bekele & Bekele, 2020; Karya & Namo, 2019; Yebo & Dagne, 2015), 2019; Sanginga, 2015). Yams are a rich source of vitamins, fiber, minerals, and proteins (Adane et al., 2013; Bello & Ojokoh, 2013), making the crops suitable for the preparation of fortified food with improved nutritional profiles (Adane et al., 2013; Kasaye et al., 2018; Ojokoh & Adeleke, 2019).

In Southwestern Ethiopia, yam is a crucial crop, particularly considered as a prestigious food preferred by urban populations (Yebo & Dagne, 2015). Traditionally, the communities in southwestern Ethiopia use only the boiling method to produce staple food from yam plant (Karya Kate Nanbol & Otsanjugu Aku Timothy Namo, 2019; Yebo & Dagne, 2015). This resulted in the post-harvest loss of root and tuber crops due to short shelf-life (Adane et al., 2013; Yebo & Dagne, 2015). Unraveling the new technologies for the processing of root and tuber crops (mainly cassava and yam crops) makes the products easier to store than raw products, requires lower storage space, and enhances their shelf life. Thus, advancement in processing technology can prolong shelf life, detoxify anti-nutritional factors, and improve product quality (Adane et al., 2013; Bello & Ojokoh, 2013). Fermentation is a traditional and industrial-level practice by which fermented food mediated by the action of microbes can be produced or obtained (Aruna et al., 2017). Fermentation can produce good quality and palatability, and improve the nutritional profile of root tuber crops by inhibiting anti-nutritional factors through the action of microorganisms (Adane et al., 2013; Holzapfel, 2002; Narayanan et al., 2020).

So far, several studies have reported on the effect of fermentation on the nutritional profile and other anti-nutritional factors of root and tuber crops (Bello & Ojokoh, 2013; Holzapfel, 2002; Igbabul et al., 2014), and there are also studies (Adane et al., 2013; Bello & Ojokoh, 2013) that reported on yam fermentation. However, no studies were conducted on the effect of fermentation on the physicochemical profile and microbial dynamics of the yam during fermentation. Therefore, this study aimed to investigate the effects of fermentation on the physicochemical, proximate profile, and microbial dynamics of yam during fermentation under the conditions of Southwestern Ethiopia.

### 1.1 Statement of the Problem

Yam is one of the most valued staple foods in southwestern Ethiopia and is highly preferred by urban consumers compared with many other traditional foods. Despite its nutritional and economic importance, yam is primarily consumed in boiled form, which remains the dominant and often the only processing method practiced by local communities. This limited utilization contributes to significant post-harvest losses, short shelf life, and the underutilization of yam and its potential value added byproducts. Improving processing and preservation techniques is therefore essential to reduce losses and enhance the value of this important crop.

Fermentation has long been recognized as an effective traditional and industrial food processing technology that relies on the activity of beneficial microorganisms. It enhances food preservation, improves palatability, extends shelf life, and increases the nutritional quality of food products while reducing post-harvest losses of root and tuber crops. Previous studies have mainly focused on the effects of fermentation on the nutritional composition and reduction of anti nutritional factors in yam. However, there is limited scientific evidence regarding the changes in the physicochemical properties of yam and the microbial dynamics that occur throughout the fermentation process. This knowledge gap limits the development of standardized fermentation technologies for yam processing. Therefore, investigating the

physicochemical changes and microbial succession during yam fermentation is essential for improving product quality, safety, and the development of value added fermented yam products.

### 1.2. Research Objectives

This study seeks to address the following research objectives:

(1) To evaluate the physicochemical changes occurring during yam fermentation;

(2) To investigate the microbial dynamics associated with yam fermentation;

(3) To analyze the proximate composition of both unfermented and fermented yam, and

(4) To develop and validate a potential starter culture (inoculum) for controlled yam fermentation.

## 2. Materials and Methods

### 2.1. Methods

#### Description of the Study Area

The study was conducted at Mizan-Tepi University, Tepi campus, which is situated in Tepi, 611 kms away from the capital of Ethiopia. Tepi campus is in Yeki Woreda at a mean elevation of 1,097 meters above sea level and at a latitude of 7°12′N and longitude of 35°27′E. Tepi is the largest settlement in Yeki Woreda, and higher temperatures, higher moisture content, and lower wind speed characterize its climatic condition. Annual rainfall is 1547 with an average temperature of 22.4 °C, and its altitude is 1400 m above sea level (Getachew et al., 2022). Laboratory experiments were carried out at the Departments of Biology and Chemistry, College of Natural and Computational Science, Mizan-Tepi University, Tepi, Ethiopia.

#### Sample Collection and Preparation

Mature white and brown yam tubers were purchased from the Tepi town local market and taken to the Microbial Laboratory of the Department of Biology, Mizan-Tepi University, Ethiopia. The collected samples were prepared as described by Igbabul et al. (2014). The collected yam tuber samples were washed to remove soil particles and other debris and then peeled using a stainless-steel kitchen knife. The peeled mass of the yam tuber samples was decorticated using a juice blender and then homogenized using disinfected stainless steel for further analysis (Figure 1).

#### Experimental Design and Sampling

The processed yam tuber masses were labeled as Treatment one (1) white yam tuber and Treatment two (2) brown yam tubers. Three micro-silos jars were used for each Yam samples and each micro-silos jar was filled with 2 kg of processed yam mass and allowed to ferment naturally in the laboratory. Each micro-silo was closed to create anaerobic conditions for a period of seven (7) days. The sample was taken at 0, 1, 2, 3, 5, and 7 days of fermentation by using a sampling augur. Physicochemical and microbial dynamics were monitored on each sampling day.

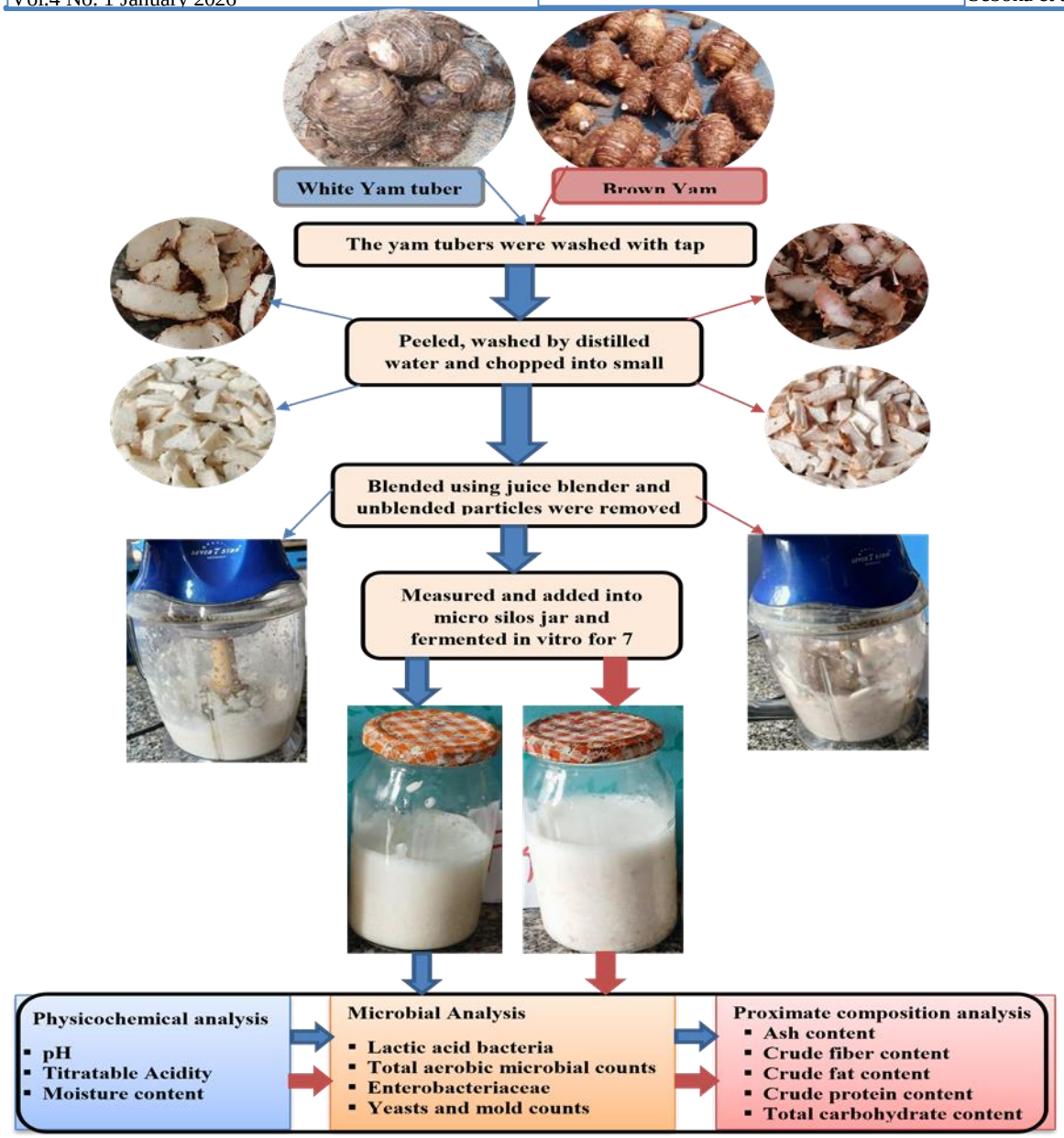


**Fig 1.** A flow chart of Yam processing for fermentation and analysis

## 2.2. Materials

### 2.2.1. Physicochemical Analysis

### pH Value

The pH of the fermenting samples was measured as described by Karssa et al. (2014) and Dibaba et al. (2018). About 10 g of processed and pooled samples were mixed with 90 mL of distilled water and homogenized by vortexing. The pH meter was calibrated using the standard buffer solution of 4, 7 and 11. The pH value of the samples was measured using a digital pH meter (pH 1100H; VWR International, Geldenaaksebaan 464 B-3001, Leuven).

### Titratable Acidity

The titratable acidity of the samples was determined according to Dibaba et al. (2018) by titrating the sample with a standard NaOH using phenolphthalein as the indicator to a pink

color endpoint. Ten milliliters of the filtered homogenized sample was titrated with a 0.1 N standard solution of NaOH after the addition of 3 drops of phenolphthalein indicator. The volume of NaOH consumed to reach the endpoint was determined, and the amount of titratable acidity was calculated.

### Moisture Content

The moisture content of the sample was analyzed following the procedures described in **AOAC (2019)** using an oven drying method. Before the experiment started, the moisture dish was dried in an oven at 105 °C for 24 hours and placed in desiccators to cool. The weight of the moisture dish was determined. The fermenting sample (10 g) was weighed in the moisture dish and the drying process was allowed at 105 °C for 24 hours in a hot air oven. The samples were collected in a desiccator after the weight was determined once the sample reached room temperature (25 °C).

$$\text{Total moisture\%} = \frac{W_3 - W_1}{W_2} \text{x100}$$

$$\text{where } W_1 = \text{weight of a dish } W_2 = \text{weight of the sample, and}$$

$$W_3 = \text{weight of sample and dish after drying}$$

### 2.2.2. Microbial Analysis

Five grams of samples were taken in 45 mL of 0.1% peptone water (distilled water) and allowed for homogenization in a stomacher for 60 seconds as described by Karssa et al. (2014). The sample was further diluted in a series of ten-fold dilutions and aliquots of the appropriate dilutions were spread in duplicate on different media (given information in the following sections). After the appropriate incubation time, the colonies formed were determined by the colony counting machine. All microbial counts were expressed as log cfu/g of the sample by utilizing the following equation.

$$cfu/\text{mL} = \frac{\text{number of colonies counted on plates} * \text{dilution factor}}{\text{volume of culture plate}} \text{X100}$$

### Enumeration of Lactic Acid Bacteria (LAB)

LAB counts were determined as described by Karssa et al. (2014) using De Man, Rogosa and Sharpe Agar (MRS) after incubation at 30 °C for 72 hours.

### Aerobic Microbial Counts

Total aerobic microbial counts were determined as described by Andeta et al. (2018) on Plate Count Agar (PCA) media after incubation at 30 °C for 72 hours.

### Enumeration of Enterobacteriaceae

Enterobacteriaceae was determined as described by Karssa et al. (2014) and Andeta et al. (2018) using Violet Red Bile Glucose Agar (VRBG) after incubation at 37 °C for 24 hours. Formations of pink to red colonies with or without haloes of bile precipitation were enumerated as members of *Enterobacteriaceae*.

### Yeasts and Mold Counts

The yeast and mold were determined as described by Karssa et al. (2014) and Andeta et al. (2018) on oxytetracycline glucose agar (OGA) supplemented with oxytetracycline after incubation at 25 °C for 5 days. The supplement (tetracycline) was added to the OGA medium before dispensing the sample to inhibit the growth of bacteria (Karssa et al., 2014).

### 2.2.3. Proximate Composition Analysis

### Determination of Ash Content

Ash content was determined according to the methods described in AOAC (2019) and Igbabul et al. (2014). Briefly, the crucible was cleaned, dried, and ignited at 550 °C for 1 hour and weighed. About 2 g of sample was taken, then ignited in a muffle furnace at 550 °C. The temperature was maintained for 6 hours or until white ash was obtained. After being ignited, the sample was cooled in a desiccator and the weight was determined. Finally, total ash content was calculated as:

$$Total\ ash\% = \frac{M_3 - M_1}{M_2 - M_1} X\ 100$$

$$where\ M_1 = mass\ of\ empty\ cruciable(g)$$

$$M_2 = mass\ of\ sample\ with\ cruciable(g), and$$

$$M_3 = final\ mass\ of\ ash\ with\ cruciable(g)$$

### Determination of crude fiber content

Crude fiber content of the samples was determined following the procedures described in AOAC (2019) and Igbabul et al. (2014). Briefly, about 2g of sample was weighed as W1 and transferred into a 500 ml beaker containing 200 ml 1.25% sulphuric acid. Then the sample was boiled for 30 minutes while adding water continuously to the boiling sulphuric acid to maintain the initial liquid level. After boiling, the sample was filtered and washed three times with hot water to remove the acid residue completely. Then, 200 ml of 1.25% sodium hydroxide was added to the washed sample and boiled for 30 minutes. After 30 minutes of boiling, the sample was filtered and washed three times using hot water to remove the residue of NaOH completely.

The dry weight (W2) was determined after drying the sample in an oven at 130℃ for an hour and cooled in desiccator. Then the sample was transferred to the crucibles to muffle furnace for 6 hours at 550 ° C. Finally, it was cooled again in a desiccator and weighed as W3. The total crude fiber content was determined by using the formula:

$$Crude\ fiber\ \% = \frac{W_2 - W_3}{W_1} X100$$

$$Where, W_1 = weight\ of\ original\ sample$$

$$W_2 = weight\ of\ sample\ after\ oven\ drying$$

$$W_3 = weight\ of\ sample\ after\ ash(g)$$

$$(g), and$$

## Determination of crude fat content

Crude fat of the samples was determined according to the methods described by AOAC (2019) and Igbabul et al. (2014) by using petroleum ether as the extraction solvent. Briefly, the flasks used for extraction were cleaned by placing them in a drying oven at 90 ° C for 1 hour and cooled in a desiccator. The weight of the cooled flask was determined (W2). Two (2) grams of the sample weighed (W1) into the thimble. The thimble with its sample content was placed into the Soxhlet extraction apparatus. The extraction process was done for 6 hours. The flask with its content was removed from the soxhlet and petroleum ether was separated from extracted fat by a rota evaporator. The mass of the flask with its fat contents was measured (W3). The amount of crude fat content was calculated by using the following formula:

$$Crude\ fat\ \% = \frac{W_3 - W_2}{W_1} X\ 100$$

$$Where, W_1 = weight\ of\ sample$$

$$W_2 = weight\ of\ flask(g), and$$

$$W_3 = weight\ of\ flask\ and\ extracted\ fat(g)$$

## Determination of crude protein content

Crude protein was determined according to the procedures described in AOAC (2019) using the Kjeldahl method. Briefly, about 1g of sample was weighed and added to the digestion flask. Then 13 ml of concentrated sulphuric acid and about 2g of catalyst mixture (made of 5g of potassium sulfate and 0.15g of copper sulfate) were added to the digestion flask. The solution was then digested at 370 ° C for three hours in the fume hood. The flask was then removed from the digester and allowed to cool. After it was cooled, the content in the flask was diluted by adding 65 ml of distilled water followed by the addition of 35 ml of 40% NaOH into the digestion flask to neutralize the acid and to make the solution slightly alkaline. The contents were distilled immediately by inserting the digestion tube line into the receiver flask that contains 10 ml of 4% boric acid solution with 3 drops of methyl red, which serves as an indicator.

Finally, the distillate was titrated with a standard acid 0.1N HCl.

$$N\% = \frac{\text{VHCl} - \text{Vblank X 14.007 X NHCl X 100}}{\text{1000 X W}}$$

$where, vHCl =$ volume of HCl consumed at the endpoint of titration,

$Vblank =$ Volume of the standard hydrochloric acid used in the blank titration,

$NHCl = normality\ of\ HCl\ (\ used\ often\ is\ 0.1N)$,

$W = sample\ weight\ on\ dry\ matter\ basis, 14.007 = molecular\ weight\ of\ nitrogen$,

The % of nitrogen was converted to the % of protein using an appropriate conversion factor (protein (%) = 6.25x % N.

$$P = F\ X\ N$$

$$N = nitrogen\ (\%), F = conversion\ factor\ (6.25), P = protein(\%)$$

### Determination of total carbohydrate content

Total carbohydrate was determined by subtracting the sum of other constituents from 100. Carbohydrate content was determined by difference, that is, the addition of the percentages of moisture, protein, fiber, fat and ash and then subtracting it from 100%.

%Carbohydrate = 100 - (%MC + %CP + % CF + % CF + % Ash).

### 2.2.4. Statistical analysis

All statistical analyses were performed using Minitab statistical software (Minitab® 20.3(64 bit, 2021, New York, USA). Variations in physicochemical, dynamics and microbial counts throughout the different sampling days and between treatments were analyzed by one-way ANOVA. For all analyses, multiple comparisons were performed using Turkey's honestly significant difference (HSD), while considering a significance level of 0.05.

## 3. Results and Discussions

### 3.1. Physicochemical Dynamics during Yam Fermentation

### 3.1.1. pH value

At the onset of fermentation (day 0), the pH values of processed and homogenized yam samples ranged between 6.73 and 6.69 for treatment 1 and treatment 2 (Figure 2). Variations in pH values were observed at the beginning of fermentation between treatment 1 and treatment 2 ($p < 0.05$). This could be due to the nature of yam tuber and the soil types from which the samples were collected. Plants and plant-based products composition can be influenced by the acidification of soil (Yadav et al., 2020). Significant reduction of pH value was observed as fermentation duration progressed in each treatment ($p < 0.05$). A decrease in pH was observed due to an increase in acidity inside the fermenting system. This showed that the potential of microbes in the fermentation system aligns with fermentation days and produces organic acid that lead to a decrease in pH value and an increase in titratable acidity of the fermenting yam samples.

The decrease in pH values as fermentation progressed resulted from the action of the microorganisms that ferment the samples (Bekele & Bekele, 2020). A reduction in pH value was observed in the fermenting system of root and tuber crops (Borrell et al., 2019; Holzapfel, 2002; Dibaba et al., 2018). The lowest pH value was recorded on day 7 for treatment 1 as 4.03 and for treatment 2 as 3.89. This was statistically significant ($p < 0.05$) compared with the pH value recorded at the beginning of fermentation (Day 0) for both treatments. Acid-producing microorganisms within the fermentation system allow for a reduction of the pH value of fermenting yam (Bekele & Bekele, 2020; Adane et al., 2013; Andeta et al., 2018). A decrease in pH with a corresponding high titratable acidity was observed during the fermentation process. This might result from the metabolic activities of the microorganisms capable of hydrolyzing complex organic compounds and producing organic acids such as citric, lactic acid and butyric acid into the medium that lower the pH (Ojokoh & Adeleke, 2019).

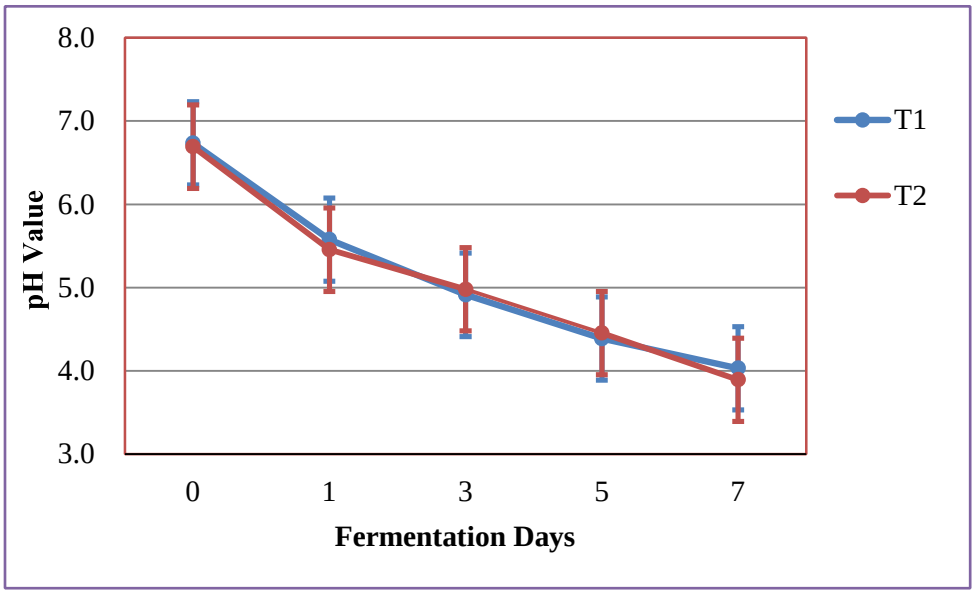


Fig.2. Effect of the fermentation duration on the pH value of fermenting yam (Where T1: white yam tuber; T2: Brown yam tuber)

### 3.1.2. Titratable Acidity

Changes in titratable acidity (TA) of fermented yam were presented in Figure 3. An increase in TA was observed as fermentation duration increased in all yam samples, which was statistically significant ($p < 0.05$). On initiation of the fermentation TA of yam samples was statistically insignificant per treatment ($p > 0.05$). The highest TA was recorded on day 7 for treatment 1 and treatment 2, which were 1.65 and 1.74, respectively. The increase in TA and the decrease in pH value were attributed to the fermenting microorganisms, usually acid-producing microbes (Holzapfel, 2002; Zimbro et al., 2009; Yadav et al., 2020). TA is crucial in inhibiting pathogenic microbes inside the fermentation system and makes the fermented food safe for consumption. An increase in the amount of titratable acidity favors the growth and activities of acid-producing bacteria such as lactic acid bacteria (Borrell et al., 2019; Halake et al., 2019; Yadav et al., 2020).

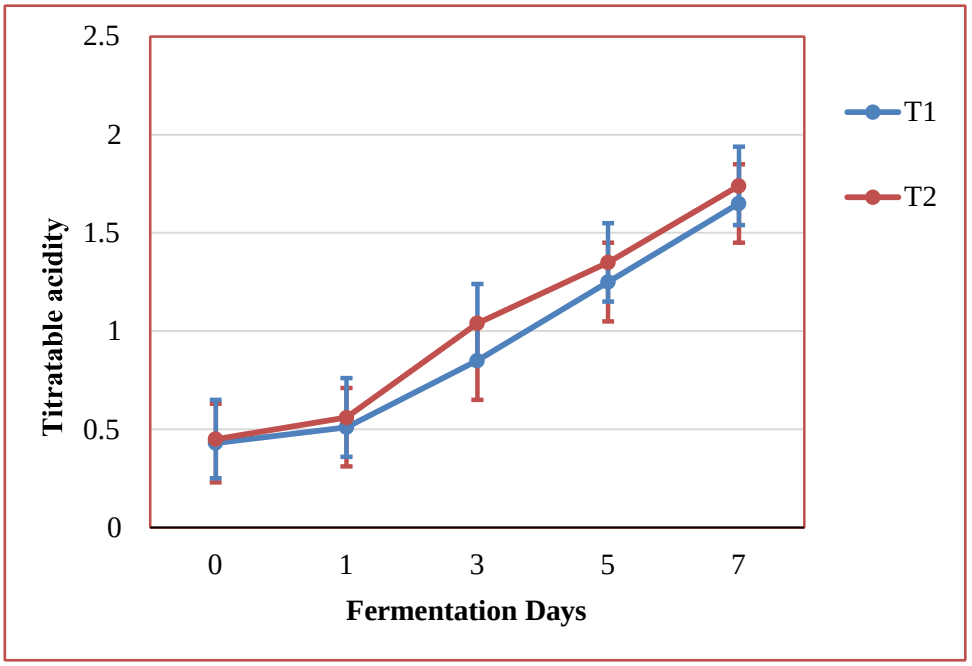


Fig.3. Effect of the fermentation duration and types on the Titratable Acidity of fermented Yam (Where T1: white yam tuber; T2: Brown yam tuber)

### 3.1.3. Moisture Content

The moisture content of the fermenting yam significantly dropped as the fermentation duration increased (Figure 4). In the early days of fermentation, high moisture content was recorded for both treatments. This reflects the availability of water in nature within root and tuber crops. Significant ($p < 0.05$) variation in moisture content was observed at the beginning of fermentation between the two treatments. This may be attributed to differences in the yam varieties (white and brown) considered. Significant variation ($p < 0.05$) in the moisture content was observed between the initial day of fermentation and the final day of fermentation. The lowest moisture content was observed on the final day of fermentation in both treatments. A rapid reduction in moisture content was observed in treatment 2 on day 3 of fermentation, which was statistically significant compared to treatment 1 ($p < 0.05$).

As fermentation duration increased, the moisture content of both treatments decreased significantly ($p < 0.001$). The reduction in moisture content creates unfavorable conditions for the growth of pathogenic microbes (Seboka et al., 2023; Andeta et al., 2019). Low moisture content can inhibit microbial activity by lowering intracellular water potential, which reduces hydration and activity of enzymes (Igbabul et al., 2014; Yegrem, 2021). Reduction in moisture content as fermentation duration progressed leads to the characteristics of fermenting microbes (Adane et al., 2013; Holzapfel, 2002; Halake et al., 2019). Reduction in moisture content could be attributed to the fermenting environment and production of organic acids and growth of microbial population inside fermentation systems. The decrease in moisture content as fermentation duration increases may be attributed to the enhanced dry matter content as a result of microbial cell proliferation. Similar trends were reported by various authors, for instance Obadina et al. (2013); Igbabul et al. (2014); this is in line with

the current result that showed an increase in microbial dynamics of fermenting yam.

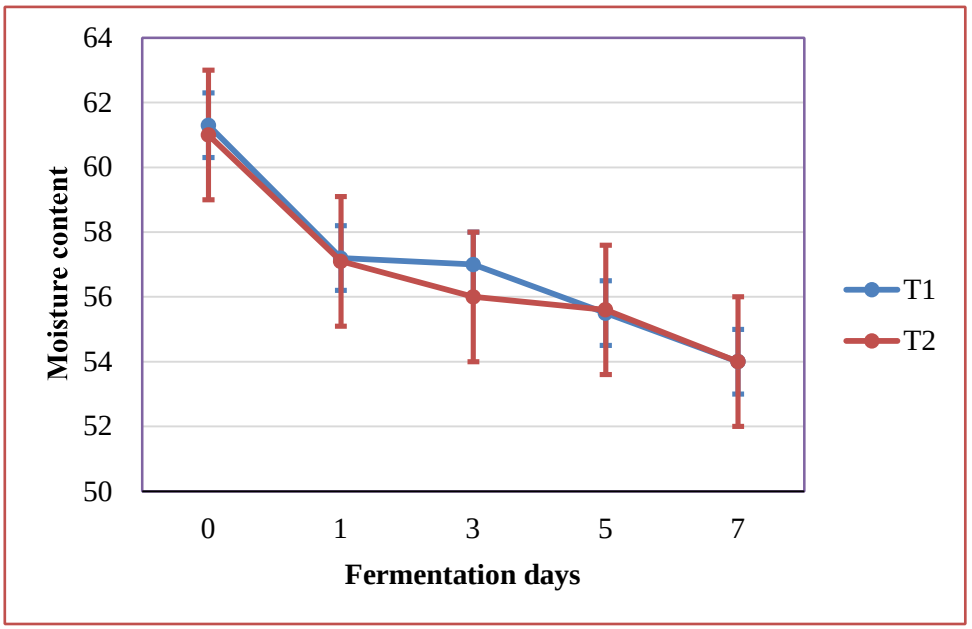


Fig. 4 Effect of the fermentation duration and types on the Moisture content of fermented yam (Where T1: white yam tuber; T2: Brown yam tuber)

### 3.2. Microbial Dynamics during Yam Fermentation

Dynamics of microbial populations during yam fermentation under laboratory conditions were presented in Table 1. Total viable counts, lactic acid bacteria, Enterobacteriaceae, yeast, and mold were investigated during yam fermentation. Lactic acid bacteria (LAB) ranged between 6.30 to 6.03 cfu/g for white yam, and 6.39 to 6.00 cfu/g for brown yam. LAB counts reached the highest on day 3 for treatment 1 (6.93 cfu/g) and for treatment 2 (6.89 cfu/g). An increase in LAB was observed for treatment 1 and treatment between day 0 and day 1 of fermentation ($p < 0.05$). LAB counts increased until day 3 of fermentation and then decreased. The increase in LAB counts in the initial days was attributed to the decrease in the pH, which created favorable conditions for their growth. The breakdown of complex organic compounds of the fermenting substrate by the action of microbes allows the production of ethanol and acids (Bekele & Bekele, 2020; Nzabuheraheza, 2018). After day 5 of fermentation, significant reductions in LAB counts were observed in both treatments. This reflects the inhibition of microbes by the production of organic acids or because of the lower pH value of fermenting samples (Seboka et al., 2023; Weldemichael et al., 2019). A similar decrease in microbial population resulted from the increase in acidity in fermentation mass in previous studies (Bekele & Bekele, 2020).

Total viable counts (TVC) ranged between 7.20 cfu/g and 6.43 cfu/g for treatment 1, and 7.22 cfu/g and 6.38 cfu/g for treatment 2. High TVC count was recorded on day 3 of fermentation in both treatments. This might be attributed to the higher LAB observed on the same sampling day, which contributed to the higher total viable counts. Among the studied microbes, TVC was the greatest in the yam fermentation durations; this is in accordance with the finding of Andeta et al. (2018) in the case of Enset (Ensete ventricosum) fermentation.

The yeast and mold count (YM) ranged between 4.57 cfu/g and 5.27 cfu/g for treatment 1, and 4.60 cfu/g to 5.34 cfu/g for treatment 2. High YM counts were observed on the initial day for both treatment 1 (5.27 cfu/g) and treatment 2 (5.34 cfu/g). YM counts were slightly decreased as fermentation day increased to 7 days. A statistically significant ($p < 0.05$) reduction in YM counts was observed for both the treatments between day 0 and day 7. This might be attributed to the formation of acidic environments by the growth of LAB through the generation of organic acids. The lower pH of the fermenting medium possibly inhibits the growth of yeast and molds (Seboka et al., 2023). In contrast, the finding of Bello and Ojokoh (2013) revealed that the counts of fungi increased as fermentation duration progressed. The rise in any type of microbe in fermenting samples might be due to their ability to utilize the available nutrients in the fermentation medium, favorable environmental conditions, and absence of growth inhibitors (Ojokoh & Adeleke, 2019).

The Enterobacteriaceae bacteria ranged between 6.17 cfu/g and 1.00 cfu/g for treatment 1 and between 6.20 cfu/g and 1.00 cfu/g for treatment 2. High Enterobacteriaceae counts were found at the beginning of treatment 1(6.20 cfu/g), which was statistically significant compared to treatment 2 ($p < 0.05$). At the start of fermentation, high counts of Enterobacteriaceae were observed, which decreased as fermentation duration increased. Similar higher quantities of the Enterobacteriaceae in the yam at the initial days of fermentation are reported by previous studies (Andeta et al., 2018). Enterobacteriaceae counts in fermenting yam were decreased as fermentation duration increased. The number of Enterobacteriaceae bacteria reaches an undetectable level by the 5th day of fermentation in both the treatments. This might be attributed to an increase in organic acid producing bacteria, decrease in pH and increase in the organic acid content. Such conditions inhibit the growth of pathogenic microorganisms. The acidic environment created by the fermentation system creates unfavorable conditions for Enterobacteriaceae counts (Dibaba et al., 2018; Andeta et al., 2018).

**Table 1. Microbial dynamics during yam fermentation in Micro-silos jar under laboratory**

| Treatments | | Microbial counts (log cfu/g) | | | | |
|---|---|---|---|---|---|---|
| | **Microbial group** | **Day 0** | **Day 1** | **Day 3** | **Day 5** | **Day 7** |
| T1 | Total viable counts | $6.71 \pm 0.1^{aA}$ | $7.10 \pm 0.05^{bA}$ | $7.20 \pm 0.02^{cA}$ | $6.63 \pm 0.09^{dA}$ | $6.43 \pm 0.02^{eA}$ |
| | Lactic acid bacteria | $6.30 \pm 0.03^{aA}$ | $6.74 \pm 0.05^{bA}$ | $6.93 \pm 0.04^{cA}$ | $6.19 \pm 0.04^{dA}$ | $6.03 \pm 0.0^{9eA}$ |
| | Enterobacteriaceae | $6.17 \pm 0.04^{aA}$ | $5.94 \pm 0.08^{bA}$ | $4.56 \pm 0.16^{cA}$ | $<1.00 \pm 0.00^{d}$ | $<1.00 \pm 0.00^{d}$ |
| | Yeast and molds | $5.27 \pm 0.02^{aA}$ | $5.17 \pm 0.02^{bA}$ | $4.90 \pm 0.06^{cA}$ | $4.89 \pm 0.01^{cA}$ | $4.57 \pm 0.01^{dA}$ |
| T2 | Total viable counts | $6.89 \pm 0.18^{aA}$ | $7.05 \pm 0.02^{bB}$ | $7.22 \pm 0.03^{cA}$ | $6.46 \pm 0.03^{dB}$ | $6.38 \pm 0.08^{dB}$ |
| | Lactic acid bacteria | $6.39 \pm 0.09^{aB}$ | $6.75 \pm 0.13^{aA}$ | $6.89 \pm 0.09^{bB}$ | $6.14 \pm 0.05^{bcB}$ | $6.00 \pm 0.05^{cA}$ |
| | Enterobacteriaceae | $6.20 \pm 0.02^{aB}$ | $5.99 \pm 0.04^{bB}$ | $4.33 \pm 0.15^{cB}$ | $<1.00 \pm 0.00^{d}$ | $<1.00 \pm 0.00^{d}$ |
| | Yeast and molds | $5.34 \pm 0.07^{aB}$ | $5.09 \pm 0.04^{bB}$ | $4.72 \pm 0.0_{3cB}$ | $4.60 \pm 0.07^{dB}$ | $4.61 \pm 0.01^{dB}$ |

N.B. Data were the mean of triplicate samples, one from each jar per treatment ± standard deviation. $^{A, B}$ Different superscripts per type of microbial count within the same column indicate significant differences ($p < 0.05$). $^{a, b, c, d}$ Different superscripts per fermentation day within the same row indicate significant differences ($p < 0.05$). (Where T1: white yam tuber; T2: Brown

**Table 2. Proximate composition of yam fermented under laboratory conditions.**

| Days | Sample | Dry matte r base (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | Code | Moisture | Ash | Crude Protein | Crude Fiber | Crude Fat | Carbohydrate |
| Day 0 | T1 | $61 \pm 0.07^{aA}$ | $1.96 \pm 0.02^{aA}$ | $1.74 \pm 0.03^{aA}$ | $3.4 \pm 0.00^{aA}$ | $0.89 \pm 0.04^{aA}$ | $31.01 \pm 0.11^{aB}$ |
| | T2 | $61.3 \pm 1.81^{aA}$ | $2.05 \pm 0.07^{bA}$ | $1.81 \pm 0.03^{bA}$ | $3.89 \pm 0.04^{bA}$ | $0.83 \pm 0.06^{bA}$ | $30.12 \pm 1.82^{Bb}$ |
| Day 7 | T1 | $54 \pm 0.11^{bB}$ | $0.74 \pm 0.06^{aB}$ | $2.21 \pm 0.06^{aA}$ | $2.65 \pm 0.02^{aA}$ | $0.46 \pm 0.03^{aB}$ | $39.94 \pm 0.24^{aA}$ |
| | T2 | $54.0 \pm 1.12^{bB}$ | $1.08 \pm 0.06^{bB}$ | $2.29 \pm 0.06^{bB}$ | $2.84 \pm 0.03^{bB}$ | $0.43 \pm 0.17^{aA}$ | $39.36 \pm 0.05^{bA}$ |

### 3.3. Proximate composition analyses

In this study, proximate composition evaluated for before fermentation process was initiated (unfermented yam samples) and on day 7 was summarized in Table 2 above. Values were the mean of triplicate samples ± standard deviation; all samples were dried. [a, b] show significant values of treatments within the same column at the same fermentation hour ($p < 0.05$), whereas [A, B,] shows significant values of treatments within the same column at different fermentation hour ($p < 0.05$). (Where T1: white yam tuber; T2: Brown yam tuber).

#### 3.3.1. Ash content

As shown in Table 2, the ash content of fermenting yam samples was ranged on an average between 1.96% and 2.05% at the onset of fermentation. Fermented yam samples for 7 days revealed ash content ranged between 0.74% and 1.08%. This shows the statistically significant ($p < 0.05$) decline in ash content as fermentation duration increased to 7th day. The decrease in ash content may be attributed to the overall activity of microorganisms in the fermenting medium. The enzymatic activity resulted in the breakdown of food components into their absorbable forms (Holzapfel, 2002; Adenike, 2016).

#### 3.3.2. Crude fiber content

Crude fiber contents ranged between 3.4% and 3.89% at the onset of fermentation. As fermentation duration increased to 7th day, a decrease in fiber content was observed, which ranged between 2.65% and 2.84%. A statistically significant difference of crude fiber was found between the initial day and 7th day of fermentation for both yam samples. The findings revealed that crude fiber content declined as fermentation duration increased to 7th day. This might be attributed to the ability of microbial dynamics in fermenting yam mass to degrade fiber as part of microbial metabolism. The decrease in crude fiber content indicates the softening of fibrous tissue (Holzapfel, 2002; Yegrem, 2021). The activities of microbes known for their biological conversion of carbohydrates and lignocelluloses into protein were also a cause for the reduction of fiber content (Holzapfel, 2002).

#### 3.3.3. Crude fat content

Crude fat content of yam samples ranged between 0.83 and 0.86 at the onset of fermentation hours. As indicated in Table 2, crude fat was decreased as fermentation duration increased, ranging between 0.43 and 0.46. This showed a statistically significant ($p < 0.05$) difference in fat content between 0 days and 7th day of fermentation for yam samples. This reflects that the reduction of fat content might be caused by the utilization of fat as an energy source by fermenting microbes (Adenike, 2016). This is also supported by Forsido et al. (Adenike, 2016) and Bosha et al. (Adenike, 2016) in the case of kocho, which has low fat content and declined as fermentation day increased.

#### 3.3.4. Crude protein content

Crude proteins content of yam samples at the onset of fermentation hours was ranged between 1.74 and 1.81. Yam fermented for 7 days showed an increase in protein content, which ranged between 2.21 and 2.29. A statistically significant ($p < 0.05$) increment of protein content was found between 0 day and 7th day of fermentation for all yam samples.

The higher protein content may be reported due to the decreasing ratio of moisture content in the sample and microbes may transforms / biosynthesize the proteins from other macromolecules (Aruna et al., 2017). The increase in crude protein is an indication that yam could be a potential source of protein for people who cannot afford animal protein in their diets (Holzapfel, 2002).

### 3.3.5. Total carbohydrate

At the onset of fermentation hours total carbohydrates ranged between 30.12% and 31.01%. The results of this study revealed that the increase in carbohydrates as the fermentation period proceeded to 7th day for both yam samples, which ranged between 39.36% and 39.94% was statistically significant ($p < 0.001$) in comparison with the first day. This increase in carbohydrates may be attributed to the decrease in moisture content of fermenting yam as fermentation day increased. Moreover, the reduction in other proximate compositions (crude fiber and crude fat) by the degradation of fermenting microbes also results an increasement in carbohydrate content (Adenike, 2016). Igbabul et al. (2014) revealed that the increase in carbohydrate content as fermentation duration increases in cocoyam flour, due to the decline in moisture content.

## 4. Conclusion

In the present study, the effects of fermentation on processed white and brown yam tuber were investigated under laboratory conditions. Moisture content of fermenting yam samples decreased as fermentation duration enhanced, which might be due to the increase in dry matter. The pH value of yam samples decreased as fermentation duration increased due to the enhanced lactic acid bacterial count and titratable acidity in the fermentation system. *Enterobacteriaceae* counts decreased as fermentation duration increased. The acidic environment in the fermentation system allows the reduction of *Enterobacteriaceae* counts. Similarly, a slight reduction of yeast and mold counts was observed as fermentation duration increased. This might be due to the increment of lactic acid bacteria, which have great potential to produce organic acids and bacteriocins that inhibit yeast and mold counts. As fermentation was done for 7 days, ash content, crude fat, and crude fiber were decreased, while crude protein and total carbohydrate were increased for both treatments. From the findings, it is possible to conclude that the fermentation process has a great role in simplifying the processing system of yam tubers for consumption. Moreover, it has significant potential to increase the shelf life of yam-based products and reduce post-harvest loss of the products.

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