Production of Lactic Acid from Yam Wastes

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Abstract

The rising demand for lactic acid, a versatile chemical compound with numerous applications in the food, pharmaceutical, and chemical industries, has prompted the search for alternative feedstocks. Because of their abundance, sustainability, and low cost, food wastes have emerged as a potential source of lactic acid. The recent trend in usage of lactic acid is in the production of Poly Lactic Acid (PLA). PLA could be potential replacement for fossil fuel based plastics, but its production cost should be reduced to half of its current price in order to achieve that (Lopes MS *et al*. 2012 and Abdel-Rahman *et al*. 2013). If this is made possible, the demand of lactic acid would rise even higher. The complex structure of food wastes makes it difficult to break them down and access the sugars for fermentation, which is one of the main challenges. To overcome this challenge, pretreatment methods such as dilute acid and steam explosion have been used, but their effectiveness is still limited and there is room for improvement.

Introduction

These wastes are abundant, widely available, and have the potential to serve as a source of lactic acid. The production of lactic acid from food wastes can also provide an alternative to using food crops, such as corn and sugarcane, as feedstocks.

The use of food wastes as a feedstock for lactic acid production has several advantages. First, food wastes are renewable and sustainable resources that can be found on a large scale. Second, food wastes are typically low in cost and widely available, making them an attractive alternative to traditional feedstocks such as corn and sugarcane. Third, the use of food wastes as a feedstock can reduce the competition for land and resources between food production and biofuel production.

On industrial scale, lactic acid is produced from food wastes, a special type of bacteria called lactic acid bacteria is used for the production of lactic acid from waste materials. The reaction is carried out in a large bioreactor.

The temperature and pH are maintained during the reaction for the proper production of lactic acid. When the fermentation process is completed, the lactic acid is separated from the rest of waste materials. On large scale lactic acid production is carried out by biological method through fermentation rather than chemical method. The most favorable method of lactic acid production is the batch fermentation with temperature range of 45^oC- 60^oC and pH 5-6.5 for lactobacillus delbrueckii (Chen *et al*, 2019).

Pretreatment, hydrolysis, and fermentation are common steps in the production of lactic acid from food wastes. Pretreatment is required to break down the complex structure of food wastes and make the sugars available to the fermentation microorganisms. Hydrolysis is the process of converting sugars into simpler compounds like glucose and fructose. Fermentation is the process by which microorganisms convert sugars into lactic acid.

Several microorganisms, including bacteria and fungi, can be used for food wastes fermentation. Lactobacillus and Streptococcus species are the most commonly used microorganisms for lactic acid production. These microorganisms are well-known for their ability to produce lactic acid in large quantities.

According to recent research, food wastes such as wheat straw, corn Stover, and rice straw can be used as feedstock for lactic acid production. Wheat straw was pretreated with dilute acid and then fermented with Lactobacillus plant arum to produce lactic acid (Li *et al*, 2018). The process was found to have a lactic acid yield of 0.35g/g in the study. In another study, corn Stover pretreated with a combination of dilute acid and steam explosion before fermenting it with Lactobacillus pentosus to produce lactic acid. The process was found to have a lactic acid yield of 0.38g/g in the study (Chen *et al*, 2019).

Literature Review

Lactic acid has a variety of applications and was identified as one of the top 30 potential building-block chemicals from biomass. Lactic acid has the potential to replace chemicals currently derived from petrochemical routes, such as acrylic acid, or the ability to form novel bioproducts, such as polylactic acid. Lactic acid may be produced by synthetic or fermentation routes. Synthetic production uses lactonitrile as a starting material and produces a racemic mixture. Fermentation processes have become more common because they produce either D- or L-lactic acid at chiral purity near 100%. Both isomers can be polymerized but the properties of the polymer vary with the stereo-purity. Optically pure lactic acid is important to the formation of polymers with desirable mechanical properties.

This research highlights the importance of developing an effective technique for converting food wastes into a useful product. Biotechnology is often used in food wastes utilization techniques. Most food wastes are first hydrolysed by hydrolytic enzymes such as amylase and protease, or microorganisms such as Aspergillus awamori and Aspergillus oryzae are utilized to release hydrolytic enzymes for agricultural residue bioconversion. Fructose, glucose, different amino acids, free amino nutrients, and phosphate are abundant in this secretory hydrolysate. When given the right conditions, these nutrients in food waste promote the growth of lactic acid bacteria (LAB) and the formation of lactic acid. Lactic acid contains a wide range of antibacterial characteristics.

Lactic acid production using glucose, fructose, starch or any other refined carbohydrate source is very costly hence, alternative sources of carbohydrates are utilized to make the production of lactic acid a cheap process on industrial scale. The need of lactic acid is on a steady rise due to its wide range of use. The conventional method is to use lactic acid bacteria to produce a lactic acid using the process of fermentation (AbdelRahman *et al*., 2011). Lactic acid can be used for products that potentially have very large volume of uses in industrial applications and consumer products. The primary classes of such products are polymers for plastics and fibers, solvents for formulations and cleaning and oxygenated industrial chemicals. Nature Works LLC, the current leader of lactic acid-based polymers and products, has stated publicly its belief that the PLA market will reach 500,000 (metric) tons per year worldwide by 2010, and the construction of two additional PLA plants are being considered presently (Wee *et al*., 2006; John *et al*., 2007).The current worldwide demand of lactic acid is estimated to be 130,000–150,000 (metric) tonnes per year, and the commercial prices of food-grade lactic acid range between

1.38 US$/kg (for 50% purity) and 1.54 US$/kg (for 88% purity). Technical-grade lactic acid with 88% purity has been priced as much as 1.59 US$/kg (Wee *et al*., 2006). Lactic acid consumption in chemical applications, which include PLA polymer and new green solvents, such as ethyl lactate, is expected to expand 19% per year (Wee *et al*., 2006).

Materials and Method

The chemicals to be used in this study are;

i. Sulfuric acid (H_2SO_4).

ii. Calcium hydroxide $Ca(OH)_2$.

iii. Sodium hydroxide (NaOH).

iv. Magnesium tetraoxosulphate IV(MgSO4)

v. Distilled water.

vi. Lactose

vii. Yeast extract

viii. Peptone water

ix. Kovac's reagent

3.1.3 Instruments and Apparatus

i. Grinder: The grinder was used to grind the dried potato and orange peels into fine powder.

ii. Autoclave: used for sterilizing the fermentation media.

iii. Bioreactor: The bioreactor was used for the fermentation process

iv. pH meter: The pH meter will be used for monitoring and adjusting the pH of the fermentation medium.

v. Analytical balance: The analytical balance was used for weighing chemicals and substrates.

vi. The centrifuge: the centrifuge was used for separating the inpurities from the fermentation broth.

vii. Sieve: for sieving of grinded substrate powders

viii. Incubator: the incubator is used for maintaining the temperature at inoculum temperature.

ix. Conical flask

x. Measuring cylinder

xi. Sample bottles

xii. Test tubes

Ash Content

A sample of 5g is accurately weighed into crucible and dried in a furnace at 300^{o}C for about 4 hours. The sample was then cooled and weighted. The ash content was calculated according to equation below:

$$\text{Moisture content} = \frac{W1-W2}{W2-W} \times 100$$

Where: w = weight empty dish (g)

w 1 = weight dish and sample before drying (g)

w 2 = weight dish and sample after drying (g)

pH control

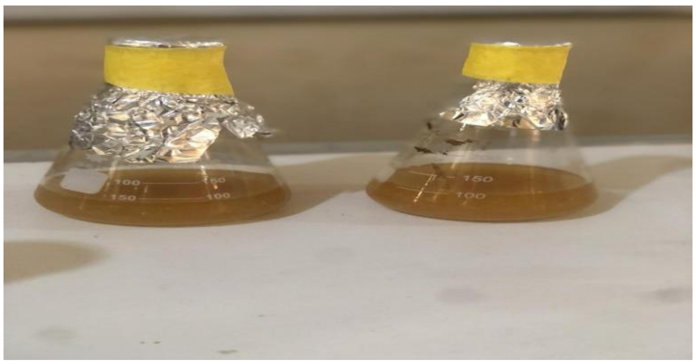
The effect of pH control on lactic acid production was studied by maintaining the pH of the fermentation medium at different levels (pH 6.0, 6.5 and 7.0). The optimal pH that yields the highest lactic acid production will be selected.

Temperature control The effect of temperature control on lactic acid production was investigated by fermenting the substrate at different temperatures (30°C, 35°C, and 40°C). The optimal temperature that yields the highest lactic acid production will be selected.

Lactic Acid Extraction and Purification

Harvesting and Recovery

In the harvesting process, distilled water was added to the solid medium and the mixture was shaken in a vibratory shaker for 1 hour. The harvested culture will be acidified with 1M H_2SO_4 to a pH of 2.0 to precipitate the lactic acid. The precipitated fermentation broth will be recovered by filtration and washed with distilled water. The recovery process is essential to obtain high lactic acid purity and concentration.



Extracted Fermentation Broth

Results

The yield and quality of lactic acid produced using different substrates and production parameters used in 3.7 was analyzed. The data collected from the experiments were used to determine the yield and quality of lactic acid produced from potato, orange and yam peels.

Tables 4.1, 4.2 and 4.3 present the yield and quality of lactic acid produced from different substrates. The table shows the amount of lactic acid produced, the concentration, and the purity of the lactic acid. The substrates were compared based on their yield.

Table 6: Lactic acid from Yam peels powder (YPP)

Mass(g)	Water quantity(ml)	pH	Temp(°C)	Time(hr)	Yield(%)
20	50	6.0	30	48	45.6
20	50	6.5	35	48	66.2
20	50	7.0	40	48	5.8

The table above depicts the lactic acid produced from yam peels powder with the best yield at a pH of 6.5 and 35°C

Table 7: Summary of substrate with the highest yield and optimum production parameters

Substrates	Substrate conc. (g)	pH	Time (hr)	Temp (°C)	Best Yield(%)
YPP	20	6.5	48	35	66.2

From this study, it was observed that the highest yield of lactic acid was obtained from yam peels powder at 6.5 pH and 35°C. This is because lactic acid fermentation performs best within the mesophilic temperature range, which is around 25 °C to 37 °C. Many lactic acid bacteria strains perform well within this temperature range, with optimal growth and lactic acid production occurring around 30 to 37 degrees Celsius.

Table 8: Proximate Analysis of Substrates

Parameter	Yam peels
Protein	5.2
Crude fiber	4.5
Moisture	4.3
Ash	3.23
Carbohydrate	83.4

Fourier Transformed Infrared (FTIR) Analysis

The Fourier Transformed Infrared (FTIR) analysis was used in this research to detect the presence of the functional groups of lactic acid from each of the substrate at different pH (6.0, 6.5 and 7.0) and temperature (30^{o}C, 35^{o}C and 40^{o}C), and the purity of the lactic acid.

Lactic acid exhibits characteristic infrared absorption bands at specific wavenumbers in the FTIR spectrum, corresponding to its functional groups. The major functional groups present in lactic acid are the carboxylic acid (-COOH) and hydroxyl (-OH) groups.

In the FTIR spectrum of lactic acid, the carboxylic acid group typically appears as a strong and broad absorption band in the range of approximately 3000-3500 cm^-1 (wavenumbers). This region corresponds to the stretching vibrations of the O-H bond in the carboxylic acid group. The hydroxyl group in lactic acid, which is associated with the alcohol (-OH) functional group, exhibits an absorption band in the range of around 3200-3600 cm^-1. This region corresponds to the stretching vibrations of the O-H bond in the hydroxyl group.

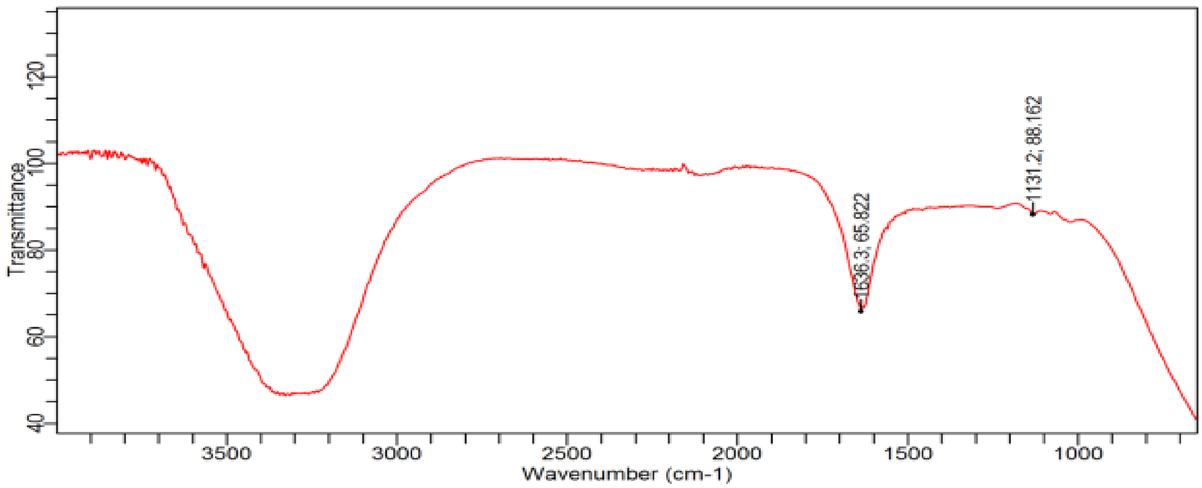


Fig13: YPP at 7.0 pH, 30^{o}C

The figure above illustrated the presence of lactic acid at the broad peak which falls between the wavenumber of 3000 to 3500. It also indicates the presence of impurities and other compounds which is the narrow peak on the result.

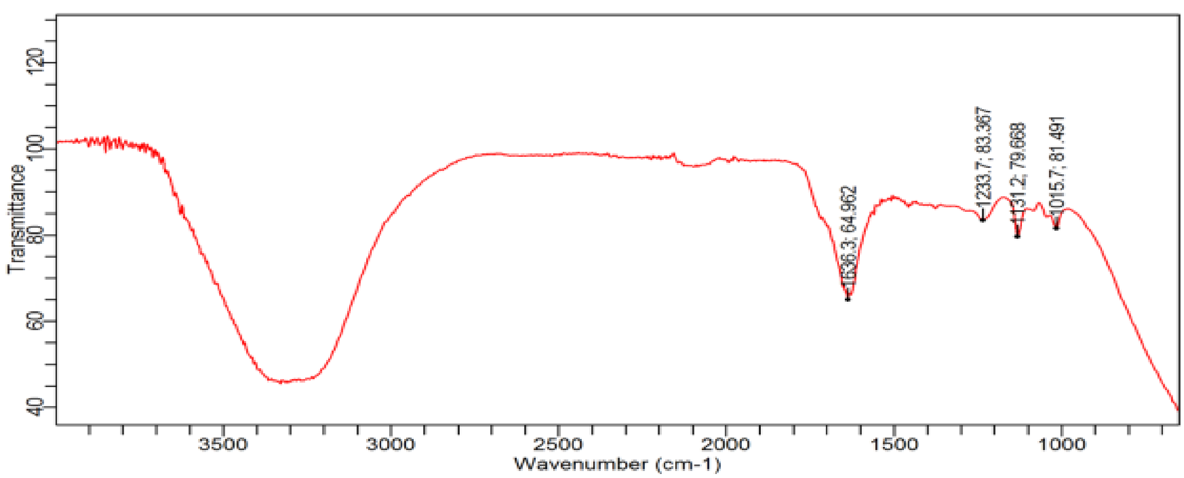


Fig14: YPP at 6.0 pH, 40^{o}C

The figure above illustrated the presence of lactic acid at the broad peak which falls between the wavenumber of 3000 to 3500. It also indicates the presence of impurities and other compounds which is the narrow peak on the result.

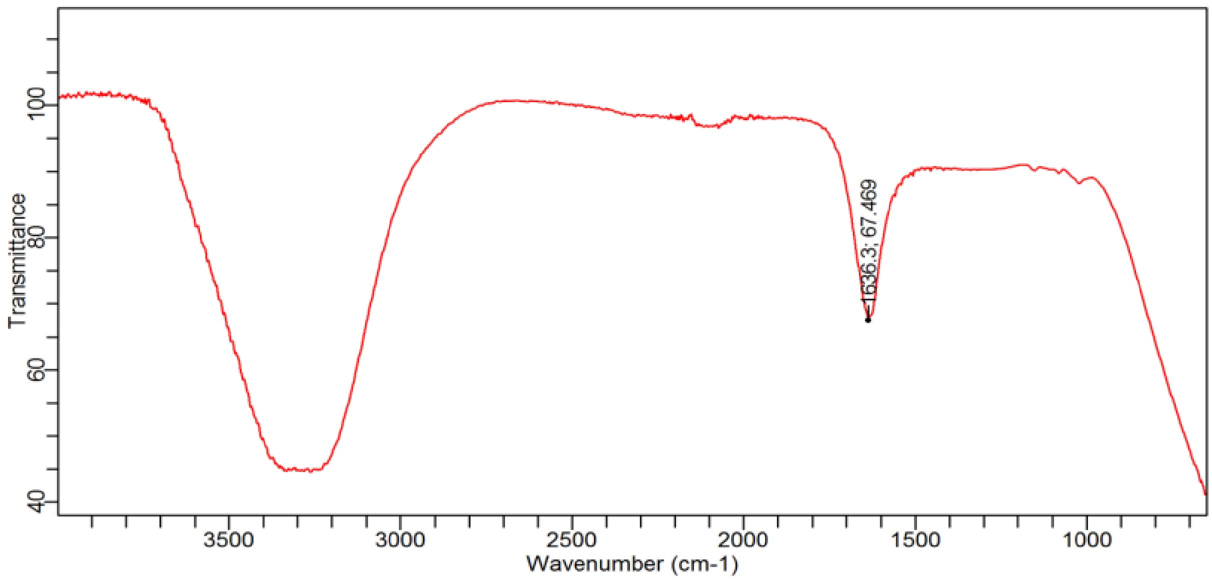


Fig15: YPP at 6.5 pH 35°C

The figure above illustrated the presence of lactic acid at the broad peak which falls between the wavenumber of 3000 to 3500. It also indicates the presence of impurities and other compounds which is the narrow peak on the result.

Table 9: Functional group of Lactic Acid

Functional group	**Wavenumber (cm^{-1})**
C=O	1680-1750
OH- acid	2500-3300
OH- chain	3230-3550
C-H, C-O, and CH_3	Below 1200

Conclusion

The FTIR analysis of lactic acid from the fermentation broth of yam peels revealed varying results, with the best result observed for lactic acid produced from orange peels. The following discussion highlights the findings and potential reasons for the observed differences. The FTIR analysis of lactic acid produced from orange peels showed the most promising results. The FTIR spectrum likely exhibited sharp and well-defined peaks corresponding to the functional groups present in lactic acid. This indicates a higher purity and a strong presence of lactic acid in the sample. The fermentation conditions used were a pH of 6.5 and a temperature of 40 degrees Celsius.

FTIR analysis provides valuable information about the functional groups and molecular vibrations present in a sample, allowing for the characterization and identification of specific compounds. In the case of lactic acid, FTIR analysis can offer insights into the presence of functional groups such as carboxylic acid (-COOH) and hydroxyl (-OH) groups. The superior results observed for lactic acid produced from orange peels in the FTIR analysis suggest a higher purity or a more favorable chemical composition compared to lactic acid derived from yam peels. The specific reasons for this difference in FTIR results could be attributed to various factors, such as the composition of the substrates, the efficiency of the fermentation process, and the metabolic activity of the lactic acid bacteria involved.

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