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Production of Ethanol from Apple Peels using Acid Hydrolysis and Fermentation

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ABSTRACT

The increased reliance on food-based feedstock for bioethanol production has intensified concerns related to food security and environmental sustainability. Ethanol is produced from sugar and starchy materials like sugarcane, sugar beet, corn, and wheat. A greater dependence on these crops contributes to the global food crisis. Around 6.96 million tons of fresh fruits are produced in Pakistan, including 0.54 million tons of apples annually. As a result, a massive amount of fruit waste is generated, which is often discarded openly, leading to adverse environmental impacts. This work subjected apple peels to acid hydrolysis and fermentation for ethanol production. The parameters of acid hydrolysis such as particle sizes (149, 210, 297, 590, and 2000 µm), solid loadings (3, 6, 9, 12, and 15 grams (gm)), acid concentrations (4, 8, 12, 16 and 20%), and the hydrolysis time (1, 2, 3, 4 and 5 hours) were investigated. The results showed that the maximum sugar of 15.4˚ Brix was obtained at 9 gm per 50 mL of solid loading with a particle size of 297 µm at a 12% acid concentration in 2 hours of incubation time. The fermentation of apple peel hydrolysate yielded 2.0% (v/v) ethanol. Thus, the results suggested that apple fruit waste can be a potential feedstock for ethanol production. Furthermore, it indicated that bioethanol could be produced from a waste resource, which can help to meet the current energy demands and reduce environmental pollution. This approach not only provides a value-added utilization of agro-industrial waste but also contributes to renewable energy generation, reduced environmental pollution, and decreased dependence on fossil fuels.

1. Introduction

The growing population has diverted the world to industrialization, which increased fossil fuel consumption, depleted the fossil fuel reserves, and adversely impacted the environment [1]. The energy consumption and demands are increasing day by day [2]. The world utilized 88.5 million barrels per day of oil in 2020 [3]. According to expectations, utilization will be 115 million barrels in 2040. The transport sector consumes 57% of liquid fuel, which is the major contributor to COx, SOx, and NOx emissions [4].

The bioethanol production was biomass started from Brazil and the United States in the early 1970s. At present, the ethanol production from biomasses is the best-established process for conversion of biomass to energy. Pakistan is a growing economy globally, where 80% of the population experiences an electricity shortfall of 8 to 10 hours per day in the summer season. According to a study [4], only 60% of the total population has access to electricity. Fossil fuel accounted for 80% of the total energy consumption [4]. Usually, people use biomass as a fuel source for (cooking and heating) in the villages [4]. The government strives to decrease oil consumption and increase reliance on coal or alternate resources. This fossil fuel consumption has also rendered adverse environmental impacts like global warming and

climate change [5]. Pakistan needs an indigenously produced liquid fuel to meet energy requirements in this scenario.

Ethanol is a sustainable, non-toxic liquid fuel that burns cleanly and decreases greenhouse gas emissions. It reduces the environmental damage caused by gasoline combustion. It could be a feasible solution to meet Pakistan's energy, economic and ecological challenges. It can withstand as an alternate transportation liquid fuel, potentially decreasing the dependence on fossil fuels and setting up a supportive back to the economy.

In the past, ethanol was produced only from sugar and starchy materials such as sugarcane, sugar beets, and maize [6]. More dependence on these crops resulted in global food shortages affecting the food supply chain. Furthermore, the price of ethanol feedstocks (corn, sugarcane, sugar beets, potato, wheat, etc.) was also increased [7]. Therefore, these crops cannot meet the worldwide ethanol demand due to their primary value in food and feed [6].

Pakistan is an agricultural country where fruit crops are cultivated up to 7466228 hectares [8]. According to a study, the fruit production is 6.96 million tons, including 0.54 million tons of apples [8]. A large quantity of fruit is utilized in food processing industries to produce jam, jellies, pickles, and fruit juices. Thus, a considerable amount of waste is generated, which is dumped in the landfills or rejected by the environment [3]. Inadequate dumping of such waste could also threaten the groundwater where the water table is high. Also, it is an ecological burden to the environment [9].

This study focuses on bioethanol production from apple peels via acid hydrolysis and fermentation. The acid hydrolysis parameters, such as acid concentration, hydrolysis time, particle size, and solid loading, were investigated for maximum saccharification and ethanol production. Being cost intensive in nature, the treatment of the waste adversely affects the cost of production apple peels and hence it is generally dumped as a waste. So, the production of bioethanol is one of the promising methods to overcome fossil fuels.

2. Materials and Methods

2.1 Collection of Raw Material

The experimental procedure of this work is depicted in Fig. 1. The 4 kg peels of Fuji and Gaja, apple fruit, in mixed form, were collected from a juice shop of the local market at Nawabshah, Pakistan. The physicochemical properties of apple peels are mentioned in Table 1. Laboratory scale concentrated HCl and KOH were purchased from Sigma Aldrich, whereas a 10% KOH solution was prepared in the laboratory. Baker's yeast (Saccharomyces cerevisiae) dried powder was purchased from the chemical shop, and the culture was grown in an Erlenmeyer flask and stored at 4oC [3,10].

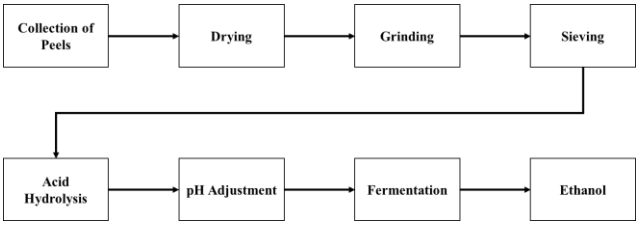

Fig. 1: Process flow chart

2.2 Experimental Procedure

2.2.1 Substrate Preparation

The apple peels were chopped and subjected to grinding in a grinder of model number D-545. Sieve analysis of ground peels was performed to separate in different particle sizes of 2000, 590, 297, 210, and 149 µm of the mesh numbers 10, 30, 50, 70, and 100, respectively, using a sieve shaker Model. No. 881205 (Heiko Seisakusho). Different-sized particles of apple peels were collected and stored for acid hydrolysis.

2.2.2 Acid hydrolysis

Acid hydrolysis of dried ground apple peels was performed at 75oC, with fixed agitation of 120 rpm as suggested by Gebregergs et. al. [11]. Different substrate loadings with five different particle sizes of mesh 10, 30, 50, 70, and 100 were added in 50 mL distilled water at five different acid concentrations to prepare the samples. Each sample was run for 5 hours. Hourly readings were taken to observe the sugar contents. After the hydrolysis, the pH of the solutions was adjusted to 4.9, using a 10% KOH solution. The solution was filtered to remove insoluble particles according to the method reported by Parthiban et. al. [12]. The sugar contents of the solution were checked through the digital Brix meter (model TK-1022).

2.2.3 Yeast Fermentation

The Baker's yeast (Saccharomyces cerevisiae) is a micro-organism that can convert sugar to ethanol and carbon dioxide via the fermentation process [13,14]. Baker's yeast (Saccharomyces cerevisiae) culture was

grown by adding 5 gm of yeast powder in 50 mL distilled water along with 2 mL of H3PO4, 1 mL of H2SO4, and 5 gm of urea in a round bottom flask [15]. Then the solution was kept for agitation at 120 rpm for 36 hours at a temperature of 29oC [1,3]. Later, 10 mL of mature culture was transferred to the maximum saccharified sample for fermentation. The fermentation was carried out at 33oC, 120 rpm, and pH 4.9 [16]. After the fermentation, the ethanol content of the solutions was analyzed using an ebulliometer with its calculating dial [17].

3. Result and Discussion

3.1 Physio-chemical Characteristics of Apple Peels

The composition of apple peels is shown in Table 1, which was taken from the literature [10]. Similar pieces of apple fruit peels were taken for this work. Apple peels contained carbohydrate material that could be solubilized to fermentable sugar. The degree of hydrolysis and its parameters (particle size, acid concentration, solid loading, and hydrolysis time) were investigated in the experimental work.

Parameters	**Range**
Moisture (%)	89.07-90.27
Lipids (%)	0.18-0.35
Proteins (%)	0.30-1.28
Ascorbic acid (%)	0.317-0.322
Fiber (%)	0.87-2.08
Carbohydrates (%)	6.5-9.34
Reducing sugar (%)	0.29-0.97
Total soluble sugar (Brixo)	6.76-6.86
Ash (%)	0.29-0.63
pH	3.53-3.61
All the values are in weight % as per 100 gm of dried sample except soluble sugar and pH.	

Table 1: Physio-chemical characteristics of apple peels [10]

3.2 Acid hydrolysis of apple peels

Table 2 shows the results of sugar yield after 1 hour of hydrolysis. It can be observed that all particle sizes of apple peels were hydrolyzed slowly for lower acid concentrations, while the degradation was faster at the high acid concentrations. For the particle size of 2000 µm, the sugar contents were 1.7˚, 2.1˚, 2.7˚, 3.2˚, and 3.3˚ Brix at acid concentrations of 4, 8, 12, 16, and 20 % (v/v) respectively, with substrate loading of 3 gm. Thus, the sugar contents increased with the increased acid concentration for all the substrate loadings and particle sizes. The maximum sugar of 7.2˚ Brix was achieved at 20% (v/v) acid concentration with 297 µm particle size and 9 gm substrate loading.

The second-hour results of hydrolysis are shown in Table 3. It can be observed that the peels were hydrolyzed rapidly. For the particle size of 2000 µm, sugar yield was increased to 26, 30, 29, 22, and 28% at 4, 8, 12, 16, and 20% (v/v) acid concentrations, respectively, with substrate loading of 3 gm. For the same particle size, at 4% acid concentration, the sugar yield was increased to 26, 34.5, 58.3, 60.8, and 52% for the substrate loadings of 3, 6, 9, 12, and 15 gm, respectively. Results showed that the high solid loading requires more acid to degrade. Whereas, the maximum sugar content of 15.4˚ Brix was achieved after 2 hours at 12% (v/v) acid concentration, 297 µm (mesh 50) particle size, and 9 gm substrate loading.

The third-hour results are shown in Table 4. It can be observed that maximum hydrolyzation occurred within two hours. For the particle size of 2000 µm, an increase in sugar yield was observed with prolonged hydrolysis time. Specifically, at a solid loading of 3 g, the sugar yield increased from 26% to 32%; at 6 g, from 34.5% to 42.4%; at 9 g, from 58.3% to 60%; at 12 g, from 60.8% to 63.3%; and at 15 g, from 52% to 58.6% However, the hydrolysis in the solutions of 3, 6, and 9 gm of mesh 50, 70, and 100 was stopped in the third hour. Sugar yield achieved 15.7º Brix at 9 gm substrate loading for mesh 50 at 12% acid concentration. Thus, the maximum sugar yield was 2% more than achieved in the second hour. In contrast, further increments in acid concentrations lowered the sugar yield. As in the case of particle sizes 590 µm and 297 µm with 6, 9, and 12 gm solid loading, the sugar yield almost decreased with the increase of acid concentration (Table 4).

Hydrolysis almost stopped during the third hour for most of the conditions. However, during the fourth hour, it proceeded to high substrate concentrations of 12 and 15 gm (Table 5). The sugar yield was slightly increased up to 4%. However, the sugar contents were decreased for the lower solid loadings (3, 6, 9 gm) at smaller particle sizes of mesh 50, 70, and 100. Thus, the hydrolysis process almost stopped after the third hour.

The analysis results of the fifth hour hydrolysis time are shown in Table 6. The sugar contents were reduced for all particle sizes, substrate loadings, and acid concentrations. The organic components of peels deteriorated as they were kept in an acidic environment for a long time. This is also in agreement with Cui et. al. [18].

Since multiple factors affect the rate and extent of hydrolyzation, such as particle size, acid

concentration, substrate concentration, and reaction time. Fig. 2(a) shows the effect of substrate concentration and hydrolysis time. The maxi-mum sugar yielded at an acid concentration of 12% and 149 µm particle size. It shows that sugar production increased over time until the first 2 hours. However, a further increase in the hydrolysis time resulted in

Table 2: First-hour hydrolysis results

Particle size	Mesh 10 (2000µm)					Mesh 30 (590µm)					Mesh 50 (297µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15	3	6	9	12	15
4% HCl	1.7˚	1.9˚	2˚	1.8˚	1.2˚	2.2˚	3.4˚	4.2˚	3.3˚	2.5˚	2.7˚	3.8˚	4.1˚	3.7˚	3.1˚
8% HCl	2.1˚	2.4˚	2.6˚	2.2˚	1.5˚	3.1˚	4.1˚	5.2˚	4.6˚	3.6˚	3.8˚	5˚	5.9˚	5˚	4.1˚
12% HCl	2.7˚	3.1˚	3.2˚	2.9˚	1.6˚	3.6˚	4.5˚	5.4˚	5.2˚	4.1˚	4˚	5.3˚	6.8˚	5.8˚	4.9˚
16% HCl	3.2˚	3.5˚	3.8˚	3.3˚	1.9˚	3.7˚	4.7˚	5.8˚	5.3˚	4.2˚	4.4˚	5.7˚	6.9˚	5.9˚	5.3˚
20% HCl	3.3˚	3.6˚	4˚	3.2˚	2˚	3.9˚	5.1˚	6.2˚	5.6˚	4.4˚	4.6˚	5.8˚	7.2˚	6.2˚	5.6˚
	Mesh 70 (210µm)					Mesh 100 (149µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15
4% HCl	2.5˚	3.1˚	3.9˚	3.4˚	2.9˚	2.3˚	2.7˚	3.6˚	3.2˚	1.8˚
8% HCl	3.4˚	4.3˚	5.3˚	4.5˚	3.6˚	2.9˚	3.9˚	4.9˚	4.2˚	3˚
12% HCl	4˚	4.4˚	6.2˚	5.2˚	4.1˚	3.3˚	4.1˚	5.2˚	4.5˚	3.7˚
16% HCl	4.2˚	4.9˚	6.3˚	5.4˚	4.6˚	3.6˚	4.4˚	5.6˚	4.7˚	4.2˚
20% HCl	4.5˚	5.4˚	6.7˚	5.7˚	4.9˚	3.8˚	4.4˚	5.9˚	5.1˚	4.6˚

Table 3: Second-hour hydrolysis results

Particle size	Mesh 10 (2000µm)					Mesh 30 (590µm)					Mesh 50 (297µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15	3	6	9	12	15
4% HCl	2.3˚	2.9˚	4.8˚	4.6˚	2.5˚	3.1˚	3.7˚	5˚	4˚	3.7˚	3.5˚	4.2˚	5.2˚	4.1˚	3.7˚
8% HCl	3˚	3.5˚	6.3˚	5.7˚	3.3˚	3.9˚	4.9˚	7.4˚	6.6˚	5.6˚	4.3˚	6.5˚	7.9˚	6.4˚	5.5˚
12% HCl	3.8˚	4.4˚	8.1˚	7˚	4.5˚	4.6˚	6.5˚	12˚	8.5˚	7.2˚	5.1˚	7.6˚	15.4˚	9.2˚	7.3˚
16% HCl	4.1˚	5.7˚	8.7˚	7.9˚	5.6˚	4.8˚	6.7˚	11˚	9.4˚	7.6˚	4.7˚	7.2˚	12.3˚	10.4˚	8.7˚
20% HCl	4.6˚	6.4˚	9.4˚	8.2˚	6.2˚	4.7˚	6.5˚	10˚	9.8˚	8˚	4.2˚	6.9˚	11.6˚	11˚	9.2˚
	Mesh 70 (210µm)					Mesh 100 (149µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15
4% HCl	3.2˚	3.5˚	4.8˚	3.5˚	3˚	2.7˚	3.4˚	4.4˚	4.5˚	2.8˚
8% HCl	3.9˚	5.2˚	7˚	5.5˚	4.8˚	3.4˚	4.1˚	6.7˚	6˚	5˚
12% HCl	4.4˚	6.7˚	13.1˚	8˚	6.5˚	3.9˚	6˚	11.7˚	8.3˚	6.9˚
16% HCl	4.1˚	6.5˚	9.7˚	9.9˚	8˚	3.5˚	4.9˚	10.8˚	9.4˚	8.2˚
20% HCl	3.8˚	5.9˚	9.3˚	10.1˚	8.7˚	3.1˚	4.2˚	10.2˚	9.3˚	9˚

Table 4: Third-hour hydrolysis results

Particle size	Mesh 10 (2000µm)					Mesh 30 (590µm)					Mesh 50 (297µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15	3	6	9	12	15
4% HCl	2.5˚	3.3˚	5˚	4.9˚	2.9˚	3.2˚	4.1˚	5.3˚	4.8˚	4.2˚	3.6˚	4.6˚	5.6˚	4.4˚	3.9˚
8% HCl	3.2˚	4.7˚	6.5˚	6.2˚	3.9˚	4.2˚	5.3˚	7.8˚	7.2˚	6.8˚	4.5˚	6.8˚	8.2˚	6.5˚	5.9˚
12% HCl	3.9˚	6˚	9.8˚	8.5˚	5˚	4.9˚	7˚	13˚	9˚	7.6˚	5.2˚	7.9˚	15.7˚	9.7˚	7.9˚
16% HCl	4.3˚	5.9˚	9.1˚	8.7˚	5.8˚	4.7˚	6.9˚	10˚	9.7˚	8.6˚	4.7˚	7.5˚	12.4˚	10.7˚	9.1˚
20% HCl	3.6˚	6.5˚	8.8˚	8.4˚	6.4˚	4.4˚	6.6˚	9.8˚	9.9˚	8.9˚	4˚	7.3˚	10.9˚	10.8˚	9.4˚
	Mesh 70 (210µm)					Mesh 100 (149µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15
4% HCl	3.3˚	3.6˚	5.3˚	3.9˚	3.3˚	2.8˚	3.6˚	4.7˚	4.8˚	3.5˚
8% HCl	4.2˚	5.5˚	7.5˚	5.9˚	4.9˚	3.6˚	4.7˚	7˚	6.4˚	5.7˚
12% HCl	4.6˚	6.9˚	13.2˚	8.6˚	7.1˚	4˚	5.9˚	12.1˚	7.8˚	7.7˚
16% HCl	4.5˚	6.9˚	9.9˚	10.1˚	8.6˚	3.7˚	5.9˚	11˚	8.9˚	8.8˚
20% HCl	4˚	6˚	9.6˚	10.2˚	9.1˚	3.4˚	5.7˚	10.4˚	9.8˚	9.5˚

Table 5: Fourth-hour hydrolysis results

Particle size	Mesh 10 (2000µm)					Mesh 30 (590µm)					Mesh 50 (297µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15	3	6	9	12	15
4% HCl	2.4˚	3.1˚	4.9˚	5.2˚	3.1˚	3.1˚	4.2˚	5.4˚	4.7˚	3.9˚	3.2˚	4.4˚	5.3˚	4.5˚	4.3˚
8% HCl	2.8˚	4.6˚	6.3˚	6.6˚	4.3˚	4˚	5.5˚	7.6˚	7˚	5.9˚	4.1˚	6.6˚	8˚	6.6˚	6.2˚
12% HCl	3.6˚	5.8˚	9.7˚	9˚	5.2˚	4.7˚	6.8˚	12.5˚	9.7˚	7.7˚	4.6˚	7.5˚	15.2˚	9.9˚	8.5
16% HCl	3.6˚	5.7˚	9.1˚	9.2˚	6˚	4.4˚	6.7˚	10.3˚	9.9˚	7.9˚	4.5˚	7.1˚	12˚	10.8˚	9.3˚
20% HCl	3.5˚	5.4˚	8.7˚	8.7˚	6.5˚	4.3˚	6.1˚	9.4˚	9.2˚	8.2˚	3.5˚	7˚	10.4˚	11˚	9.7˚

	Mesh 70 (210µm)					Mesh 100 (149µm)				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15
4% HCl	3.2˚	3.3˚	4.6˚	3.9˚	3.4˚	2.4˚	3.2˚	4.1˚	4.9˚	3.6˚
8% HCl	4˚	5.1˚	7.1˚	6˚	4.9˚	3.3˚	4.4˚	6.6˚	7˚	5.9˚
12% HCl	4.1˚	6.4˚	12.8˚	8.8˚	7.3˚	3.6˚	5.5˚	10.8˚	10.3˚	8˚
16% HCl	4˚	6.5˚	9.3˚	10.7˚	8.9˚	3.3˚	5.2˚	10.1˚	9.6˚	9.5˚
20% HCl	3.3˚	5.4˚	9.2˚	10.5˚	9.5˚	3.1˚	5˚	9.1˚	8.5˚	9.6˚

Table 6: Fifth-hour hydrolysis results

Particle size	**Mesh 10 (2000µm)**					**Mesh 30 (590µm)**					**Mesh 50 (297µm)**				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15	3	6	9	12	15
4% HCl	1.8˚	2.0˚	3.8˚	3.3˚	1.3˚	1.4˚	2.7˚	3.6˚	2.3˚	2.7˚	2.1˚	2.7˚	3.0˚	3.1˚	2.1˚
8% HCl	1.9˚	3.3˚	4.4˚	4.6˚	1.9˚	2.4˚	3.6˚	5.1˚	4.6˚	4.1˚	2.6˚	3.9˚	5.3˚	4.7˚	3.8˚
12% HCl	2.7˚	3.8˚	7.3˚	6.7˚	2.1˚	2.8˚	4.9˚	10˚	6.8˚	5.4˚	3.2˚	4.2˚	11.5˚	8.2˚	5.6˚
16% HCl	2.3˚	3.9˚	6.8˚	6.1˚	3.4˚	2.7˚	4.7˚	7.1˚	7.3˚	4.8˚	2.7˚	5.1˚	9.3˚	9.1˚	6.9˚
20% HCl	2.4˚	3.4˚	6.1˚	6.5˚	2.6˚	2.0˚	4.0˚	6.5˚	6.8˚	5.1˚	1.5˚	4.9˚	7.7˚	9.2˚	7.6˚
	Mesh 70 (210µm)					**Mesh 100 (149µm)**				
Solid loading (gm/50mL)	3	6	9	12	15	3	6	9	12	15
4% HCl	1.4˚	1.9˚	2.8˚	2.7˚	1.8˚	1.1˚	2.1˚	2.4˚	3.6˚	2.0˚
8% HCl	1.9˚	3.0˚	4.7˚	3.9˚	2.6˚	1.5˚	1.3˚	3.2˚	4.5˚	3.6˚
12% HCl	1.9˚	3.7˚	8.9˚	5.9˚	5.2˚	1.9˚	2.9˚	6.9˚	7.9˚	5.7˚
16% HCl	2.3˚	3.2˚	6.2˚	7.9˚	6.3˚	1.4˚	2.7˚	5.8˚	7.1˚	6.8˚
20% HCl	1.6˚	2.9˚	5.8˚	8.6˚	6.7˚	1.4˚	2.6˚	5.2˚	7.5˚	6.4˚

reduced sugar contents. This could be attributed due to the catalytic activity of HCl at an optimum concentration which improved the rate of hydrolysis. In contrast, no significant increase in sugar yield was observed beyond 2 hours.

Since multiple factors affect the rate and extent of hydrolyzation, such as particle size, acid concentration, substrate concentration, and reaction time. Fig. 2(a) shows the effect of substrate concentration and hydrolysis time. The maximum sugar yielded at an acid concentration of 12% and 149 µm particle size. It shows that sugar production increased over time until the first 2 hours. However, a further increase in the hydrolysis time resulted in reduced sugar contents. This could be attributed due to the catalytic activity of HCl at an optimum concentration which improved the rate of hydrolysis. In contrast, no significant increase in sugar yield was observed beyond 2 hours.

As shown in Fig. 2(b), particle size also affected the sugar contents. The maximum hydrolyzation was achieved at 297 µm while larger particles declined the sugar yield. At 2000 µm particle size, sugar yield was 3.8˚, 4.7 ˚, 5.1 ˚, 4.5 ˚, and 3.9˚ against the substrate loading 3, 6, 9, 12, and 15 gm, respectively. Maximum production was achieved at 9 gm loading, where the sugar yield was observed at 5.1˚, 7.1˚, 15.5˚, 15.8˚, and 15.3˚ against the particle size 2000, 590, 297, 210, and 149 µm respectively.

Acid concentration also has affected sugar yield during hydrolysis (Fig. 2 (c)). At the optimum solid loading and particle size of the substrate, the maximum sugar yield was achieved at a 12% acid concentration. Therefore, the optimum acid concentration was 12% against 9 gm solid loading with 297 µm particle size.

Thus, 9 gm substrate concentration of 297µm particle size at 12% acid concentration for 2 hours hydrolysis time yielded maximum sugar of 15.4o Brix. The sample above was then subjected to the fermentation process.

3.3 Fermentation of the Hydrolysate

The hydrolysate mixture of apple peels with the highest sugar was neutralized before being subjected to fer-mentation. Then grown yeast culture was transferred to a hydrolysate mixture. The fermentation was performed for 36 hours in the round bottom flask at 33˚C and 120 rpm. The fermentation process yielded 2% v/v ethanol in the hydrolysate mixture separated by distillation. Different researchers used various fruit peels for ethanol production. Oberoi et. al. [19] used orange peels and produced 0.46 gm/gm ethanol per substrate consumed. Abidin et. al. [20] used cassava peel (Manihot esculenta) and obtained 3.58 % v/v bioethanol. Mushimiyimana and Tallapragada [21] used carrot, onion, potato, and sugar beet peel and achieved ethanol production of 2.2, 14.4, 15.3, and 17.3%, respectively. In addition, Saleem et. al. [22] used Pomegranate waste peels and achieved 0.42 ± 0.08 gm/gm ethanol per substrate consumed. In this study, apple peels yielded 15.7˚ of sugar via acid hydrolysis and 2% v/v ethanol during the fermentation process.

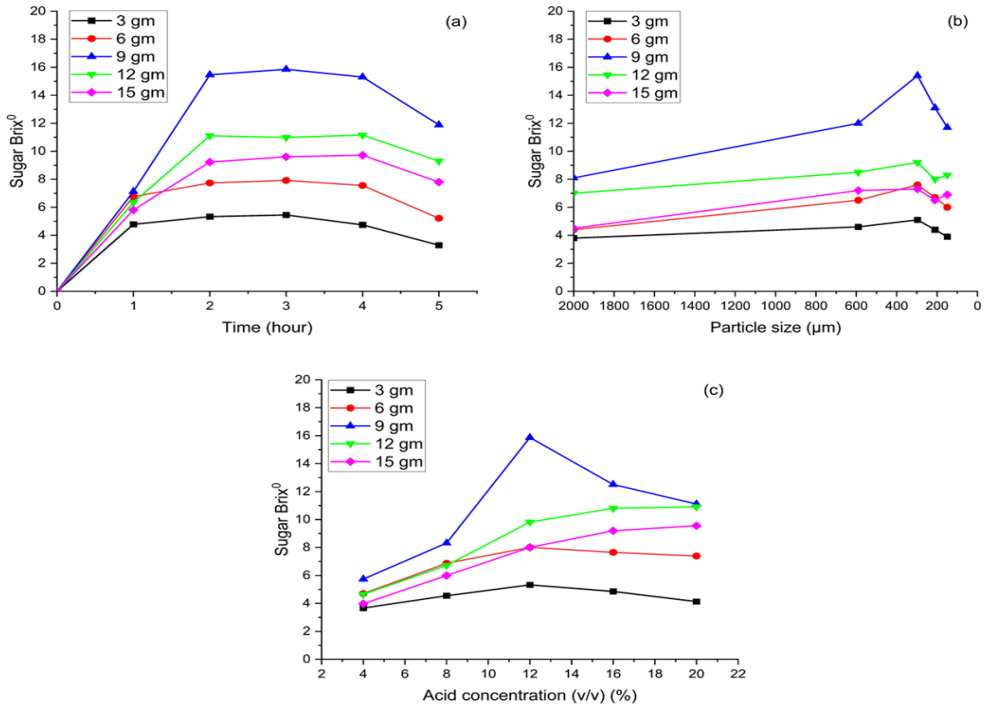

Fig. 2: Effect of (a) hydrolysis time, (b) particle size, and (c) acid concentration on sugar yield during acid hydrolysis of apple peels at different solid loadings.

4. Conclusion

The effect of different parameters such as particle sizes (149, 210, 297, 590, and 2000 µm), solid loadings (3, 6, 9, 12, and 15 gm/50 mL), acid concentrations (4, 8, 12, 16 and 20%), and the incubation time (1,2 3, 4 and 5 hours) was investigated during the acid hydrolysis of apple peels. The apple peel hydrolysate was also subjected to fermentation for bioethanol production. The results showed that the maximum sugar content of 15.4˚ Brix has achieved at 9 gm solid loading per 50 mL, with a particle size of 297 µm at 12% acid concentration in a 2-hour incubation time. The fermentation of apple peels hydrolysate yielded 2.0% v/v ethanol. The study's findings suggest that lower solid loadings can yield high sugar contents with a high rate of hydrolysis. Furthermore, the larger particle size of peels produced less sugar with a long hydrolysis time. In addition, the exposure of peels to the acid for an extended time at high temperatures can deteriorate peels' organic contents, resulting in less sugar content. The study suggests fruit peels from the food industry as the potential feedstock for ethanol production. Furthermore, it provides an insight into bioethanol production from waste resources. This can help meet the current energy demands with less economic burden and minimize environmental pollution.

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Not available

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